Impact of Production Systems Design on Project Performance: An Operations Science Analysis on a Case Study in Construction

By

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I. ABSTRACT

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Current projects from the AEC industry have been using concepts from the administration management sciences, focusing primarily on cost, schedule, quality, and safety (traditional project management metrics – PM metrics) to measure project performance. This practice has led project teams not to consider the existence of variability, which is a problem. To tackle this problem, operations science (OS) can be applied to analyze and develop production systems design (PSD) in construction. However, applying OS is still uncommon. Through an OS analysis, we can find a relationship between PM metrics and OS metrics (i.e., throughput, work in progress, cycle time, % of utilization) to illustrate the relationship between PSD and project performance. Therefore, this master thesis aims to demonstrate the applicability of conducting an OS analysis to find the impact of PSD on project performance in building construction projects.

This master thesis is structured as follows: an introduction to the topic and an explanation of the intended contribution, a description of the research method, and a review of the relevant literature. The thesis continues by explaining the framework used to apply OS in construction, considering the data collection limitations of current construction management practice, followed by the case study that uses this framework on an offsite construction process. Finally, the thesis ends with an explanation of the use of OS in construction projects and a discussion and conclusions sections.

This master thesis uses the framework (OS graphs and equations) proposed by Factory Physics to apply OS in construction. Using this framework is crucial to understanding the relationship between OS metrics and how they influence PM metrics. This research uses an existing analytical model to apply this framework using data collected from a case study. The author addresses the challenge of collecting production-related information from a project site and tackles this challenge by making assumptions during the modeling phase.

The contributions of having achieved this research's objective are: (1) a description of the use of OS to find the relationship of PSD on project performance, (2) the use of OS metrics and PM metrics to illustrate PSD and project performance, respectively, (3) the presentation of demand and batch sizes sensitivity analyses to find the impact of the fluctuation of production parameters on OS and PM metrics, and (4) future research proposals to continue the application of OS in construction.

II. DEDICATION

To my adored Luis Carlos.

To my beloved parents, Luis, and Tatiana, who helped me through all things, great and small. I would not be here without all your support and dedication to allowing me to dream.

También en español, para que lo puedan entender, papás:

A mi adorado Luis Carlos.

A mis amados padres, Luis y Tatiana, quienes me ayudaron en todas las cosas, grandes y pequeñas. No estaría aquí sin todo su apoyo y dedicación para permitirme soñar.

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I am grateful to Strategic Project Solutions (SPS) and Project Production Institute (PPI) for allowing me to use their software. This research would not have been possible without their generous contribution. During the time I developed this thesis, I had the opportunity to be part of the Project Production Systems Laboratory (P2SL) at UC Berkeley, which plunged me into an environment of constant discussion and learning to improve my research. The development of this thesis was financially supported by the Peruvian National Program of Scholarships and Educational Credit (PRONABEC) through the scholarship "Bicentenary Generation 2021," which funded my studies in one of the best universities in the world, and I am infinitely grateful for this opportunity. Any opinions, findings, and conclusions expressed in this material are mine and do not necessarily reflect the views of members of SPS, PPI, P2SL, or PRONABEC.

Finally, I wish to acknowledge Chet Carlson's support during the case study's modeling process, Mary Polizzotti's support during my manuscript's final editing process, and Sergio Rojas' words of encouragement during the last month of my thesis development.

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VII. ACRONYMS

The Project Production Systems Laboratory at the University of California, Berkeley (P2SL) has published a glossary (P2SL, 2022) with relevant information about production systems in projects. Similarly, the Project Production Institute (PPI) has published a glossary with keywords about project production management (PPI, 2022). This thesis uses both sources to define the concepts used here.

AEC	Architecture, Engineering, and Construction
BIM	Building Information Modeling
BIM 4-D	Building Information Modeling of 4 Dimensions
BL	Baseline
BT	Batch Time
Ca	Variation of Interarrival Times
CDC	California Drywall
Ce	Variation of Effective Process Time
CIRP	Collège International pour la Recherche en Productique – French acronym of International Academy for Production Engineering
CLT	Cross-laminated Timber
CONWIP	Constrained Work-in-process
COOPS	Construction Object-Oriented Process Simulation System
CPM	Critical Path Method
CT	Cycle Time
CYCLONE	CYCLic Operation Network
D	Demand
d	Average Demand
DES	Discrete-event Simulation
EIFS	Exterior Insulation and Finish System
ETO	Engineer-to-order
EVA	Earned Value Analysis
EVM	Earned Value Management
FR	Fill Rate
GDP	Gross Domestic Product
HB	Herrero-Boldt
HCAI	Department of Health Care Access and Information
HVAC	Heating, Ventilation, and Air Conditioning
IFOA	Integrated Form of Agreement
IIJA	Infrastructure Investment and Jobs Act
IoR	Inspector of Record
IPD	Integrated Project Delivery
IT	Interarrival Times
JIT	Just-in-time
L	Replenishment Time
l	Average Replenishment Time
LOB	Lines of Balance
LPS ®	Last Planner System

LS	Lot Size
MINWIP	Minimum Work-in-process
MMC	Modern Methods of Construction
MT	Move Time
MTO	Make-to-order
n	Total items to install in a process
OBS	Organizational Breakdown Structure
OM	Operations Management
OR	Operations Research
OS	Operations Science
OSC	Offsite Construction
OSM	Offsite Manufacturing
P2SL	Project Production Systems Laboratory at UC Berkeley
PB	Process Batch
PCI	Precast/Prestressed Concrete Institute
PM	Project Management
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
POM	Production and Operations Management
PPI	Project Production Institute
PR	Process Rate
PSD	Production Systems Design
PT	Process Time
Push WIP	Work-in-process in a push production system
QT	Queue Time
RPT	Raw Process Time
SCI	Steel Construction Institute
SCV	Squared Coefficient of Variation
SPS	Strategic Project Solutions
SSRRH	Sutter Santa Rosa Regional Hospital
ST	Set up or Changeover Time
STROBOSCOPE	State and Resource-Based Simulation of Construction Processes
TB	Transfer Batch
Te	Effective Process Time
TH	Throughput
TLS	Terrestrial Laser Scanning
u	Utilization or Capacity Utilization
UAV	Unmanned Aerial Vehicle
USA	United States of America
VSM	Value Stream Mapping
VUT	Variability, Utilization, and Time
WBS	Work Breakdown Structure
WIP	Work-in-process
WSC	Winter Simulation Conference

CHAPTER 1 INTRODUCTION

1.1 CURRENT PRACTICE IN THE CONSTRUCTION INDUSTRY

The construction industry (also known as the architecture, engineering, and construction industry-AEC) and its broader ecosystem erect buildings, infrastructure, and industrial structures that are the foundation of our economies and are essential to our daily lives. Even though it has successfully delivered challenging projects, from undersea tunnels to skyscrapers, this industry also has performed unsatisfactorily for decades. The construction ecosystem represents 13 % of the global Gross Domestic Product (GDP), but construction has seen a meager productivity growth of 1 % annually for the past two decades (McKinsey & Company, 2020).

Considering the after-covid-19 context in the United States (USA), the AEC industry has a significant role in supporting the nation's growth plan. The Infrastructure Investment and Jobs Act (IIJA), with investments across health care, public safety, and other public infrastructure, is expected to provide jobs for the AEC firms. This industry has increased its investments in digital technologies as it prepares to shift toward connected construction capabilities. These technologies can help AEC firms to support initiatives such as smart cities, urban air mobility, and climate change programs and help enhance internal operational efficiencies, reduce costs, and improve margins (Deloitte, 2021). Since the AEC industry is project-based, understanding the implications of implementing these technologies in the project delivery phase is crucial for improving the industry overall.

Current practice in construction projects (or capital projects, or simply projects) is to use "Conventional project management" (or project management-PM) as a body of management knowledge. However, this body of knowledge lacks two fundamentals concepts in delivering today's complex and dynamic projects. First, the focus on planning and forecasting and the exclusion of the production of projects overlook the need to organize detailed work activities within the project to control overall project performance. Second, there is little to no consideration of the impact of variability and inventory on project performance. Not recognizing variability and inventory does not acknowledge the complex effect that variability and inventory have on each other and on total project performance (Shenoy & Zabelle, 2016).

One way to partially tackle this problem is to apply production system design (PSD) to construction projects. Ballard et al. (2001) stated, "PSD is concerned with the development of operation and process design in alignment with product design, the structure of supply chains, and the allocation of resources." PSD is useful for implementing lean concepts, such as pull production, batch size, takt time, and buffers (Schramm et al. 2006, Lee et al. 2006, Russell et al. 2015, Tommelein 2020). In this regard, applying the Last Planner System (LPS ®) is current practice for quite a few AEC firms involved in designing the production system of their projects. The LPS is also related to lean tools and methods as described in the 2020 Current Process Benchmark for the Last Planner System of Project Planning and Control (Ballard & Tommelein, 2021).

In addition to all the lean tools and methods AEC firms apply, it would be advantageous to focus on project operations management, and not only on the application of these tools and methods. For example, suppose the implications of variability and inventory can be addressed at an operational level through an understandable approach. In that case, the production system for projects can improve performance with fewer amounts of inventory and a more synchronized supply chain. Based on other industries that have developed an analysis of their production systems, part of the AEC industry is applying operations science (OS) to understand project production systems and how to optimize them based on a specific objective. For this purpose, it is necessary to collect production-related data accurately to develop models for the improvement of the performance of project production systems.

The lack of specificity of the data collected by project professionals to conduct OS analysis, the enormous amount of variability, and the poor understanding of the implications of PSD on construction projects' performance negatively affect these projects. Nevertheless, there is a chance to improve project performance by analyzing and understanding the impact of PSD on project performance using OS lenses.

1.2 Problem Statement

OS analysis can be useful in understanding how PSD impacts project performance. However, due to limitations of construction management practices (i.e., data collection methods not related to production-related parameters, a non-steady state system in construction processes, and the need for metrics that materialize production in construction), conducting an OS analysis is challenging. Therefore, the here-described research addresses the lack of methods to collect and analyze projects' data to apply OS to find the impact of PSD on project performance. Consequently, this thesis addresses this by conducting an OS analysis using case-study data based on a framework used in the manufacturing industries.

1.3 Research Scope

This research will focus on understanding the impact of PSD on project performance using an OS analysis, considering the limitations of data collection and data analysis methods used in construction. This research will focus on the offsite building construction sector and be based on a case study that includes a cladding system installation process as the production system to analyze. Due to the novelty of the concept of OS, it is outside of the scope of this thesis to define OS as an industry standard, but I will explain the OS concept I am using and the components that I include as part of the OS analysis.

1.4 Significance

This research is significant for theory and practice. Designing production systems for construction projects is an improvement developed by the Lean Construction movement that started more than thirty years ago. The application of OS in projects is more recent, and its application in more types of projects is a topic to explore. Understanding PSD and its impact on project performance using an OS analysis provide improvements that can be useful to rationalize how production systems behave in construction. A PM approach change is crucial to incorporate OS analysis in the current industry practice effectively. Consequently, more practitioners can add to their current practice a focus on the production of construction projects (and processes) and implement methods and tools to improve the production systems that make up the projects they manage.

OS is related to the concepts of operations management (OM) and operations research (OR). OS studies the transformation of resources to create and distribute goods and services (Factory Physics, 2022). I will provide conceptual differences between these three operations-related concepts. OS focuses on the interaction between demand and supply (aka production) and the variability associated with either or both. OS also describes the buffers required to synchronize demand with production (Project Production Institute-PPI-, 2022). Since the current approach of project management possesses its roots in administration management, incorporating OS to design, control, and predict production systems can provide a solid foundation to manage the production of construction projects. The use of OS may allow for improvements from a production perspective and therefore improve project performance.

This research will present the following:

1. An approach for using data gathering practices in building construction projects to use OS metrics.
2. An approach for developing OS graphs and equations for construction processes.
3. A relationship of the OS metrics to the PM metrics (including sensitivity analysis).

At the end of this thesis, I expect that the research method used can be replicable to other construction processes. Moreover, the work done for this thesis will help AEC practitioners worldwide use OS to enhance their project performance.

1.5 RESEARCH QUESTIONS

These are the research questions:

1. How can we gather production-related data (e.g., production rates, transfer batch, stock points, process batch) from a building construction project to apply OS?
2. To what degree and under what circumstances (assumptions) are the OS analysis, graphs, and equations applicable to find the impact of PSD on the performance of building projects?

1.6 RESEARCH OBJECTIVES

1.6.1 General Objective

Demonstrate the applicability of conducting an OS analysis to find the impact of PSD on project performance in building construction projects.

1.6.2 Specific Objectives

1. Apply a framework for conducting OS analysis to find the impact of PSD on project performance.
2. Analyze the applicability of the current practices of gathering data in building construction projects to conduct an OS analysis to find the impact of PSD on project performance.
3. Present data collection and data analysis processes suitable for using OS analysis to find the impact of PSD on project performance for building construction projects.
4. Conduct a case study (based on an offsite construction example) to apply OS analysis to find the impact of PSD on project performance.
5. Find the relationship between OS metrics (utilization, work-in-process, cycle time, throughput) and PM metrics (time, cost).

1.7 RESEARCH METHODOLOGY

This research relies on methods used in construction management and a case study to develop a framework for understanding the relationship between PSD and project performance using an OS analysis. Figure 1 shows the steps of the research methodology.

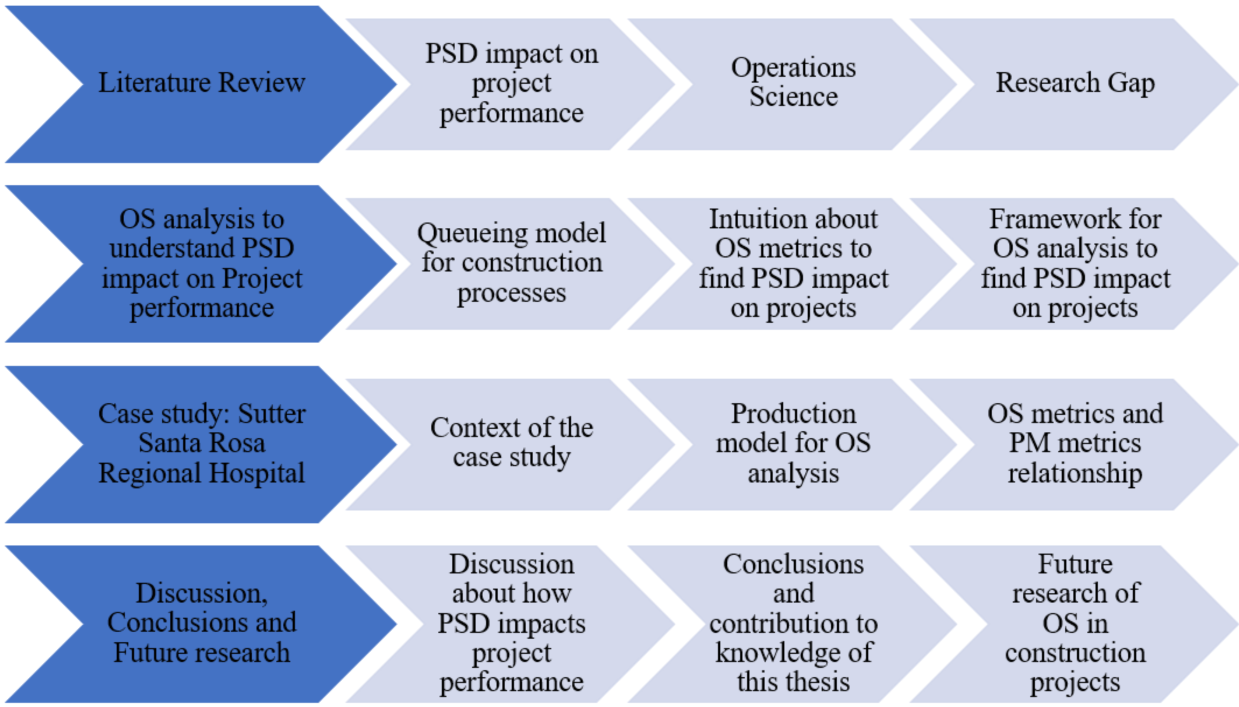


Figure 1: Research Methodology Steps. Developed by Prado.

1.7.1 Literature Review

The research begins by identifying the current practice of PSD and its impact on project performance, primarily based on the literature found in the Lean Construction body of knowledge. Then, I introduce the concept of OS based on its application in not only the AEC industry but more widely understood in the manufacturing industries. Next, I use the explanation of Factory Physics to establish the graphs and equations of OS to build a baseline to conduct the OS analysis. These two main concepts (PSD impact on project performance and OS) allow me to identify the current research gap. The last part of this chapter explains how this research expects to bridge this gap.

1.7.2 OS Analysis to Understand the PSD Impact on Project Performance

I use a queueing theory model to understand the implications of variability in a construction process. First, I address the limitations of the current data collection and data analysis methods used in construction to choose a suitable method to collect production-related data from the project site as needed for an OS analysis. Second, using the OS graphs and equations stated in Factory Physics, I build an intuition of how to use OS to provide a better understanding of the impact of PSD on project performance. Third, considering this intuition, I develop a framework for the application of OS to find the impact of PSD on project performance. Finally, I apply this framework to a case study.

1.7.3 Case Study: Sutter Santa Rosa Regional Hospital Project

The onsite assembly (installation) of the offsite cladding system of the Sutter Santa Rosa Regional Hospital (SSRRH) project is the case study for understanding the relationship between PSD and project performance with an OS analysis. I use the framework I described in OS Analysis to Understand the PSD Impact on Project Performance to demonstrate the applicability of OS to understand this relationship. Also, I explain the implications at the project and supply chain levels.

1.7.4 Discussion, Conclusions and Future Research

The last step is to discuss the results obtained in this research. Then, I present the conclusions and contributions to the knowledge of this research. Finally, I offer future research proposals to keep exploring the application of OS to construction.

1.8 THESIS STRUCTURE

This thesis has the following chapters:

1. Introduction provides the background to this study, as well as presents the context of this study, and introduces the research questions, objectives, and methods to apply.

2. Literature Review discusses the literature on project performance, PSD, OS applications in the AEC industry, and cladding systems in buildings.

3. Framework for Applying OS to Construction uses the current approach of OS in manufacturing industries to intuitively develop a framework to apply OS in the AEC industry.

4. Case Study: Sutter Santa Rosa Regional Hospital applies the framework developed in chapter 3 to find results that illustrate how an OS analysis can provide a better understanding of the PSD impact on project performance.

5. Discussion comments on the two main results of this thesis: a framework to apply OS to construction and the impact of PSD on project performance. This chapter also discusses the limitations of this thesis.

6. Conclusions closes the thesis with answers to the research questions, a summary of the findings, the contributions to knowledge, and a proposal for future research.

7. References provides the thesis' bibliographic references.

8. Appendices contains additional information regarding the case study of this thesis.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

It is a current practice that the construction industry heavily relies on PM techniques to deliver construction projects. This practice has economic implications on how the AEC compares with other sectors in terms of productivity. In parallel, innovations in the AEC industry emerged, including novel approaches to understanding how the production of projects works. Lean Construction surfaced in the 1990s as a new philosophy of production in construction and remained a topic that deserves more exploration (Koskela, 1992). Similarly, academics explored the use of PSD to fill the need for more understanding of production (of both flows and conversion) and its impact on project performance. Most recently, AEC professionals and practitioners developed methods and techniques under the Lean Construction umbrella to apply manufacturing-related concepts to their projects. The concept of OS has its roots and explanation of application for the manufacturing industry in the books Factory Physics (Hopp & Spearman, 2008) and Factory Physics for Managers (Pound et al., 2014).

These two bodies of knowledge (PSD impact on project performance and OS) will provide the theoretical foundation for developing this thesis. Since the case study of this research is related to cladding systems in buildings, I will provide relevant literature about this construction process. After covering these topics, I will develop a synthesis and discussion section to summarize how these topics are related to each other. Finally, I will identify the research gap this thesis is trying to bridge.

2.2 PSD IMPACT ON PROJECT PERFORMANCE

2.2.1 Management of Construction Projects

The Fifth Edition of the Project Management Body of Knowledge (PMBOK) defined a project as "a temporary endeavor undertaken to create a unique product, service, or result" (Project Management Institute-PMI-, 2013). A project should have definite starting and ending points (time), a budget (cost), a clearly defined scope and magnitude of work to complete, as well as specific performance requirements that it must achieve (Heagney, 2015). PM is the application of knowledge, skills, tools, and techniques to activities to meet the project requirements. PM requires the appropriate application and integration of the PM processes identified for the project to achieve its goals. PM also enables organizations to execute projects effectively and efficiently (PMI, 2017).

The PM field is applicable in various industries and types of projects, and the construction industry is not an exception. For construction projects, PM focuses on achieving project requirements defined in terms of document control, safety, quality, cost, and schedule. Consequently, the project manager must balance quality, cost, and schedule within a safe project environment while maintaining control of construction documents (Schaufelberger & Holm, 2017). This describes the "traditional PM" approach, a widespread practice in construction projects.

From the traditional PM approach, the techniques, tools, methods, and methodologies applied to construction are Gantt charts, critical path method, S curves, work breakdown structure (WBS), cash flow analysis, organizational breakdown structure (OBS), earned value management (EVM). These methods, methodologies, techniques, and tools, plus the top-down approach and the fragmented nature of the communication between strategy makers and implementers, are what Levitt (2011) called “PM 1.0”. Levitt (2011) also explains the transition from “PM 1.0” to “PM 2.0,” which is recognized as a more “agile PM process” and includes “lean production” concepts.

It is universally known that the most critical PM metrics are cost, time, and quality based on a specific scope of the project. Based on the framework for project success developed by De Wit (1988), the concept of the “iron triangle” was born in the 1990s, which stated that project success happens by meeting the requirements of cost, time, and quality (Atkinson, 1999). Figure 2 shows the iron triangle, universally recognized as the standard for measuring project success. Even though project success is out of the scope of this thesis, I will use cost and time as metrics to summarize project performance (also called PM metrics) because they illustrate how the project is performing based on its objectives of cost and time.

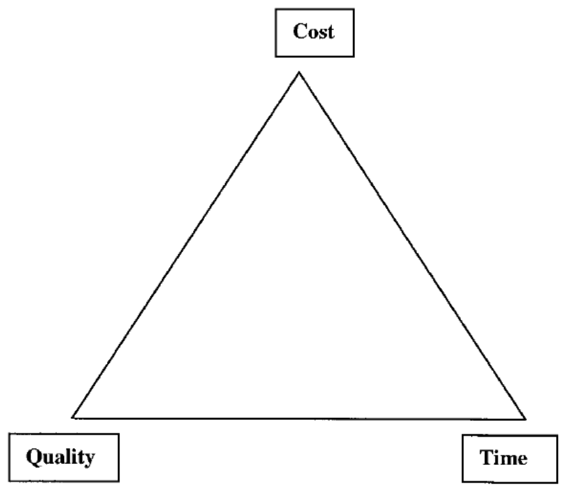


Figure 2: The Iron Triangle. Figure 1 in Atkinson, 1999.

The iron triangle demonstrates that quality, cost, and time are interrelated, which means that no free movements exist between each other. Thus, by changing one of the elements of the triangle, the other two will also change. If we need to keep one of the elements fixed, the other two must move. All these ideas work under the assumptions of a fixed project scope, and the final product’s quality is also related to the expected performance of the project during the delivery phase. Regardless that previous research has shown other factors to measure project performance, such as PM actions, PM procedures, external environment, and human-related factors (Chan et al., 2004), measuring construction projects’ performance in terms of the “iron triangle” components is the standard.

Considering the trend of offsite assembly and offsite construction, it is crucial to address how applicable the PM metrics are to this offsite approach. Various terms and acronyms associated with offsite construction exist, such as offsite manufacturing (OSM), offsite construction (OSC), and modern methods of construction (MMC) (Goodier & Gibb, 2007). OSC refers to a construction method that “brings onsite construction works into a climate-controlled facility where advanced machinery and manufacturing technologies can be utilized to preassemble buildings’ components in a standardized and efficient manner” (Liu et al., 2017).

Previous research in the United Kingdom (UK) has validated the economic implications of moving from a traditional construction sector to an OSC sector that can adopt this method with essential improvements in terms of cost and time (Taylor, 2010). Other studies in the UK also pointed out that adopting OSC does not necessarily mean that there should be more cost at the beginning of the project, but a new cost structure should be applied (Pan & Sidwell, 2011). A study developed in the USA shows positive trends in using OSC in distinct types of projects. In the Razkenari et al. (2020) survey, the respondents were asked to rank project types that currently use OSC. The housing market was selected by more than 60% of the respondents, while educational and healthcare were chosen as potential future markets.

Since OSC projects fall in the intersection between manufacturing (for offsite fabrication and assembling components) and construction (for installing these components on the construction site) industries, it represents a suitable opportunity to apply manufacturing-related concepts. Therefore, manufacturing metrics might be useful to determine the performance of OSC projects, in addition to the traditional PM metrics.

2.2.2 Current Practices of PSD in the AEC Industry

Like other approaches the AEC industry has adopted, PSD applications began in manufacturing industries. Based on Skinner (1985), the PSD objective is to determine a set of policies in the manufacturing setup, and Skinner (1985) divided them into two groups. The first group is related to the resource capacity, facilities and equipment, and technologies to use. The second group is related to infrastructure, workforce management, production planning, and control. Also, Askin & Goldberg (2002) mentioned that PSD is about managing the production resources to meet the customer’s demands.

Based on CIRP (*Collège International pour la Recherche en Productique*, French acronym of International Academy for Production Engineering) (1990), PSD is the conception and planning of the overall set of elements and events constituting a system, along with the rules for their relationships in time and space. Design of production systems involves: (1) defining the problems and objectives, (2) outlining the alternative streams of action, (3) evaluating those alternatives, and (4) developing the detailed design of proposed production systems. The result of the design work is a description (specification) of the production system (Bellgran & Safsten, 2004). In addition, two ways of designing a production system exist: creating a “new” system or “changing the design” of an existing production system (Slack et al., 1998).

Other authors have found that PSD and lean production-related tools and methods can work in a combined fashion. The development period of these tools and methods matches the development of Taiichi Ohno’s Toyota Production System, which marked the beginning of the “lean” production era (Masha, 2002). For example, Yang et al. (2015) presented a method based on Value Stream Mapping (VSM) to improve the production (manufacturing) system of make-to-order (MTO) products (specifically, fishing nets). This method was able to increase the service level of the production system, as well as reduce the work-in-process (WIP). Among other authors, Gomez et al. (2021) proposed an integrated PSD based on an energy approach that considers a multi-view analysis, which considers the cost, time, performance, and safety of manufacturing systems.

The application of PSD in the AEC industry has been a relevant topic since the 1990s. Koskela (1992) stated the need for implementing a new philosophy of production to construction based on the just-in-time (JIT) production system and quality control implemented by Toyota. This new idea of production in construction led researchers to think about ways to apply manufacturing production methods and techniques to projects.

Previous studies analyzed the application of simulation to understand the behavior of production systems in construction. For example, Tommelein (1997) modeled the pipe-spool process through a discrete event simulation (DES) model using the STROBOSCOPE software (Martinez, 1996) to show various forms of uncertainty, waste, flow, conversion, and push vs. pull-driven sequencing. In this paper, the author stated a “matching problem,” which is usually not considered at the project planning level as it is tedious to address. This problem is also explained as matching parts and matching areas, and any of those can stop the work. With no matching parts available, no work can be done. Regarding a solution to this problem, Tommelein (1998) found that “by choosing upstream to process ‘matching parts’ first, the downstream process will proceed more expediently and completed units will be available sooner than would be the case otherwise.” Then, Tommelein (2006) mentioned that the use of standard products in construction could be another way to solve these problems.

Moreover, Ballard & Howell (1998) stated that “construction is essentially the design and assembly of objects in a fixed position, and consequently possesses, more or less, the characteristics of site production, unique product, and temporary teams.” These conditions represent a challenge to applying manufacturing production methods in construction. Tommelein et al. (1998) presented the “Parade of Trades” game to understand the impact of variability on workflow in a single-line production system (which represented a construction process). They found that unreliable workflow results in waste as production stations cannot realize their full production capacity because they starve for resources.

Ballard et al. (2001) presented a guideline for designing production systems in construction projects that contain four levels to accomplish three goals: do the job, maximize value, and minimize waste. In this guide, they acknowledged the need for allowing tradeoffs between goals in a project, as well as the conception of a “project-based production system” as the type of production system in construction. Following these ideas, Koskela & Ballard (2003) developed a three-level requirements hierarchy framework for production systems in construction that recognizes the need for using OM concepts to develop PSD in construction projects and processes.

At the same time, researchers studied other Lean Construction tools and methods to use in parallel with PSD. Schramm et al. (2004) used lines of balance (LOB) to improve PSD, concluding that it was crucial to consider the whole production system rather than individual activities in low-income housing projects. Then, Schramm et al. (2006) applied the same method for managing complex projects, concluding that including suppliers and other stakeholders is crucial in the PSD process to understand the impact of the decision on PSD behavior. Kemmer et al. (2008) used LOB to communicate concepts related to production management, such as cycle time (CT) and WIP metrics. Schramm et al. (2009) showed the role of PSD in supporting the adoption of customization strategy in housing projects, improving transparency, and increasing predictability.

The combination of takt planning alongside PSD presents benefits as well. Fiallo & Howell (2012) used production rates and VSM to find the takt time for a production system, which also serves as a communication tool for translating project goals into daily production goals. Dlouhy et al. (2016) presented a three-level method of takt planning and takt control to design work sequences of production systems and optimize workloads based on the customer’s batch size. Other authors used Building Information Modeling (BIM) with PSD in construction projects and processes. Murguia & Urbina (2018) included using BIM-4D to improve PSD for non-linear and non-repetitive construction processes. These authors also used LOB and simulation tools to understand the implications due to the dependencies between trade contractors. Barth et al. (2020) implemented a PSD in the Chilean house-building sector, including BIM, to improve plans’ accuracy and logistics planning using production-related metrics, such as CT, WIP, and takt time.

All these studies show the current practices of PSD in the construction industry. PSD practice adopts lean tools and methods (with a centered-production approach) and then uses them to improve. Production-related metrics (e.g., CT, WIP) are also part of the studies collected in this literature review as they partially explain the behavior of the production system. These ways to understand and represent how the production system behaves will be substantial for this thesis, which will use OS to understand this behavior more thoroughly and then analyze how it impacts project performance.

2.2.3 Relationship of PSD and Project Performance in the AEC Industry

There are similarities between the concepts of production systems and construction projects. Among others, Carneiro et al. (2009) found interactions between the production system and the performance at a project level. They found that the decisions made at a higher level (project level) will affect the results at an operational level (production system). In contrast, Filho (2013) found that there are implications of the production system and how we design it that will affect the performance at a project level. These implications also affect the decisions made between the parties involved, and the project environment will play a crucial role in the production system's design and implementation.

Shenoy & Zabelle (2016) presented a brief history of the "Eras" of Project Delivery and determined that we are in "Era 3: The emerging construct of Projects as Production Systems", which follows "Era 1 (Scientific Management)" and "Era 2 (Project Management)". Figure 3 shows the relationship between the critical components of Era 1 & 2 and Era 3 of Project Delivery. The difference in each of these Eras helps to see how the approach to the management of projects is changing and starting to consider bodies of knowledge that are more related to a manufacturing set-up, such as inventory and capacity.

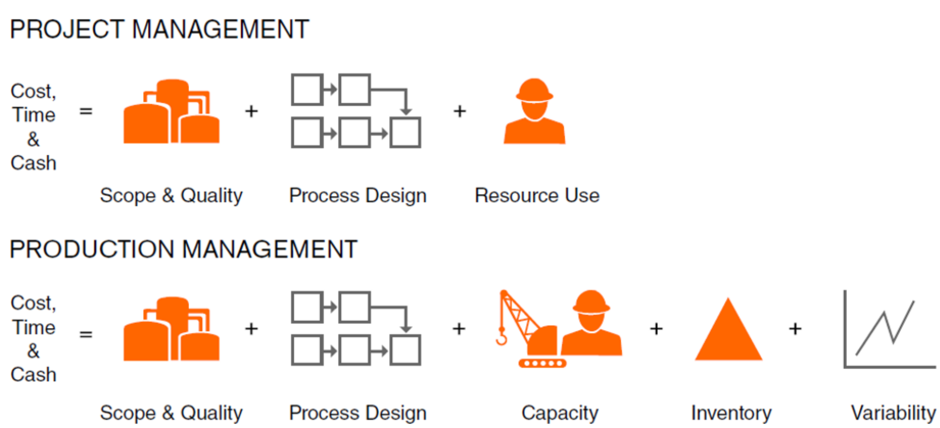


Figure 3: Contrasting Era 1 + Era 2 Conventional Project Management with Era 3 Project as Production System. Figure 4 in Shenoy & Zabelle, 2016.

By recognizing Era 1 + Era 2 as "conventional PM," the lens of Era 3 highlights two gaps in the conventional PM approach: (1) the scope of PM does not include detailed project work execution (no focus on how to manage the operations), and (2) there is no consideration of variability and WIP during project execution. Understanding these gaps explains why typical responses from conventional PM practices related to only cost and time are sometimes ineffective. Era 3 approaches process design very differently from traditional PM because it seeks to design processes that account for the impact of variability by strategically placing buffers within the process. Moreover, the "science of operations management" dictates that buffers can be a combination of inventory, capacity, and time (Shenoy & Zabelle, 2016).

Arbulu et al. (2016) provided an example of the relationship between PM and PSD by using one of the essential project management tools: the schedule, which is related to the PM metric time. Figure 4 shows the relationship between project controls tools (the Master Schedule) and production system control tools (production schedule, production plan, and work executed). As described by Drucker (1974): "The word 'controls' is not the plural of the word 'control' … the two words have different meanings altogether. The synonyms for controls are 'measurements and information.' The synonym for control is direction … Controls deal with facts, which is with events of the past. Control deals with expectations, that is, with the future."

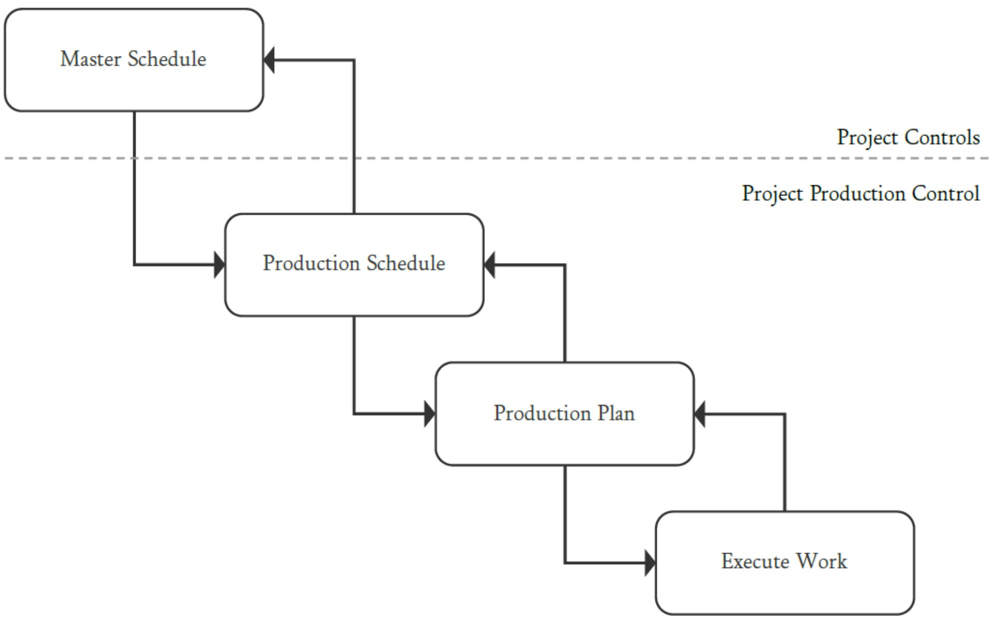


Figure 4: Project Controls and Project Production Control Schematic. Figure 3 in Arbulu et al., 2016.

After understanding the relationship between the metric "time" in PM and PSD, it is evident that this relationship also applies to the metric "cost." The examples and applications described in 2.2.2 mentioned that controlling the production system of their respective construction projects and processes improved time, cost, and quality. Based on the Product-Process Matrix (Schmenner, 1993), Spearman & Choo (2018) argued that projects should be viewed as a network of connected production systems, each tailored for the production activity required for project execution. This idea makes the relationship between PM and PSD more evident and how PSD has the power to impact project performance. The concept of projects as the summation of production systems highlights the relationship between these two concepts. It suggests the need to keep studying them and find ways to control the "behavior" of production systems to obtain better project performance.

There are relationships between PM and PSD, demonstrating the need for controlling production systems to positively impact project performance at a higher level. Nonetheless, the AEC industry is reluctant to acknowledge the importance of this relationship. This status might be due to the lack of metrics to account for quantitative measures to illustrate this relationship. Therefore, this thesis will present a framework based on OS to illustrate the impact of PSD on project performance.

2.3 OS

2.3.1 OS Definition and Applications

The applications of PSD in the AEC industry provide a better understanding of how production systems can impact project performance. Nonetheless, a lack of knowledge of the "relationship" or "direct connection" between the impact of production systems on project performance still exists. To solve this lack of relationship, the concept of OS provides a common foundation for applying manufacturing concepts related to PSD in the AEC industry. Based on ideas presented in the book Factory Physics (Hopp & Spearman, 2008) and Factory Physics for Managers (Pound et al., 2014), the concept of OS emerged to explain Era 3 of Project Delivery (Shenoy & Zabelle, 2016). Due to the novelty of OS, I will use the concepts related to OM and OR to define OS and how I will use it within the limitations of this thesis.

OM has its core in managing processes and operations that produce goods and services (Krajewski & Ritzman, 2001). The concepts of operations and production are used interchangeably by authors in this field of study, even using the term Production and Operations Management (POM) as a synonym for OM. Adam (1983) developed a typology to organize the points of view in the OM field, finding that depending on the point of view (e.g., management science, the systems view, lifecycle approach, the managerial process approach), practitioners apply OM differently. This study also concludes the need for a "managerial" approach that encompasses these various points of view instead of a "problem and solution" procedure. Swamidass (1991) recognized the need for developing a broader strategy that considers all the topics related to OM and found that building an empirical theory for OM will provide substantial benefits.

OR is a systematic approach to solving problems and uses one or more analytical tools in the process of analysis (Zandin, 2001). Based on Ackoff (1956) OR is applicable to different problems from various disciplines and can be implemented by practitioners. Nonetheless, he suggested that OR possesses the following steps: (1) formulating the problem, (2) constructing a mathematical model, (3) deriving a solution from the model, (4) assessing the model and solution, (5) establishing controls over the solution, and (6) implementing the solution. Heiman (1960) explored the use of OR in the AEC industry, concluding that OR may examine problems to seek causes rather than treat effects.

Despite the similarity in their uses and methods, OM and OR are not the same. Fuller (2005) explains the differences between OM and OR: "At the conceptual or philosophical level, OM and OR differ substantially. OM is concerned with managing production resources critical to a company or organization's strategic growth and competitiveness. It entails designing, operating, controlling, and updating systems responsible for the productive use of human resources, equipment, and facilities in developing a product or service (Chase et al., 2001). Philosophically, therefore, OM is managerially and activity oriented. At the same time, OR is technique and mathematically oriented, involving modeling a situation or a problem and finding an optimal solution for it (Anderson et al., 2002)."

There are inevitable overlaps between OM and OR. The technically focused approach of OR provides the tools for developing models that provide meaningful and optimal solutions to problems. These solutions are the basis for understanding the implications of their implementation at an organizational level by using OM. These interactions between OM and OR share common ground; however, they also lack a component that integrates OM and OR. Since these two concepts were born within manufacturing and considering the need for finding an empirical theory to OM

(Swamidass, 1991) and the development of OR as a science (Ackoff, 1956), Hopp & Spearman (2008) provided the foundation of a "science of the operations."

OS is the study of the transformation of resources to create and distribute goods and services. (Factory Physics, 2022). OS focuses on the interaction between demand and production and the variability associated with either or both. OS also describes the set of buffers required to synchronize demand with production (PPI, 2022). Based on Spearman & Spearman (2020), OS is the science that describes the behavior of operations. They defined operations as the transformation of entities through the utilization of resources to create and distribute goods and services that satisfy a given demand. Considering these definitions of OS, for this thesis, the meaning of OS I will use is: "OS is the study of operations that aims to produce goods and services by aligning the production system and resource capacities to the external demand while considering the effects of variability on this system."

Inevitably, OS uses the methods and tools of OR and explains the logic that OM uses to translate the solutions that OR provides to specific problems. The difference between these three concepts is flexible, and instead of dealing with a thorough differentiation of them, this thesis will use the OS concept, as I stated. The applications of OS started in the manufacturing industry to explain how these production systems behave. Pound et al. (2014), in their book Factory Physics for Managers, go into the details of OS from empirical examples of manufacturing production systems and argue that three equations and four graphs can explain the behavior of production systems. Spearman & Pound (2016) stated that the concepts described in Factory Physics for Managers apply to projects, proposing the term "project physics," which is the application of OS in a project.

Shenoy (2017) compared the three concepts (OM, OR, and OS) and argued that OR describes the mathematical and analytical techniques used to make better decisions in OM. Furthermore, OS uses principles and equations to unify the concepts of OM and OR from a manufacturing approach to any production system (including projects). Prado (2022) also explained these three concepts and argued their applicability to OSC projects to accomplish a JIT delivery and production control. Considering all the benefits of OS-related concepts described in Factory Physics and Factory Physics for Managers, it is essential to acknowledge that even though "projects are different," the manufacturing industry provides the elements to construct buildings, bridges, highways, and factories (Ballard & Arbulu, 2004). Therefore, the application of OS applied directly to the project or the manufacturer's part of its supply chain will enhance the production systems of the project. Due to the foundation of OS in a manufacturing environment, I will use metrics explained in more detail in Pound et al. (2014) and Hopp & Spearman (2008) to illustrate how production systems in a project behave. OS metrics will be instrumental for this thesis:

1. Cycle time (CT): CT is the time it takes a product, piece of information, or chunk of work (e.g., a room or building) to go from beginning to end of a production process; that is, the time it is WIP. It is the time for a product to transit the system, thus defined by how one defines the boundaries for that system. The production system design parameters can influence CT, as equation 1 shows, where BT = batch time, MT = move time, ST = set up or changeover time, RPT = raw process time (or processing time), and QT = queue time (or waiting time) (Project Production Systems Laboratory-P2SL, 2022):

$$CT = BT + MT + ST + RPT + QT \quad \text{(Equation 1)}$$

2. Work-in-process (WIP): Work-in-process consists of inventory between the start and end points of a routing.
3. Throughput (TH): Throughput is measured as the average output of a production process (machine, station, line, plant) per unit of time.
4. Interarrival times (IT): Interarrival times are the average time between job arrivals at a workstation.
5. Effective process time (Te): Effective process time is the time a product spends in the station working with that product.
6. Utilization (u): utilization is the fraction of time a station is not idle for lack of parts.
7. Replenishment time (L): Replenishment time, also known as lead time, is the time it takes a product to go from being ordered to being delivered as input to a production process (P2SL, 2022).
8. Demand (D): Demand refers to how much of that product, item, commodity, or service is required to be produced and then delivered to the next step, station, or next production system.
9. Lot size (LS): Lot size refers to the quantity of an item ordered for delivery on a specific date or manufactured in a single production run.
10. Fill rate (FR): Fill rate is the probability that a part is not back-ordered. In other words, it is the probability that a part is on hand in inventory when demand for it occurs.

Considering these metrics, I will mention the three equations and four performance graphs stated by Pound et al. (2014) because I will use the framework presented in Factory Physics for Managers to explain how the production system of the case study behaves.

2.3.2 Three OS Equations

1. <u>The VUT equation:</u> The Variability, Utilization, and Time (VUT) equation (also known as the Kingman equation) is an approximation for the mean waiting time in a queue in a system with a single server where arrival times have a general (meaning arbitrary) distribution and service times have a (different) general distribution (PPI, 2022). Equation 2 shows the industrial engineering version of the Kingman equation, where Ca^2 = squared coefficient of variation of interarrival times, an indicator of demand or flow variability, Ce^2 = squared coefficient of variation of effective process times, an indicator of process variability. Te is the mean process time. (u) has a significant impact on QT, as explained by Roser (2017); the higher u, the more prolonged QT, which will approach infinite as u comes to 100%.

$$QT = \left(\frac{Ca^2 + Ce^2}{2}\right) \times \left(\frac{u}{1-u}\right) \times Te \quad \text{(Equation 2)}$$

2. <u>Little's law equation</u>: This is the formula that describes the fundamental relationship between WIP, CT, and TH for production flows. This relationship is typically written as expressed in equation 3. CT is a function of WIP and TH, and from a practical standpoint, this means that WIP is a leading indicator of CT. Gharaie et al. (2012) applied Little's law to the house-building industry by modifying the formula to obtain means of the values of CT, WIP, and TH that represent the nature of the construction industry. He predicted the

average house completion using this law, having a 5% error compared with the actual data collected onsite.

$$CT = WIP \;/\; TH \text{ (Equation 3)}$$

3. The Variance of Replenishment Time Demand equation: This equation describes the behavior of replenishment time (of the production system) and external demand (the customer) and provides information to guide practitioners' intuition on how to manage stocks and inventory. This equation is a function of the replenishment time and demand variability. Equation 4 shows the function, where l = average replenishment time, σ_l^2 = variance of replenishment time, d = average demand, and σ_d^2 = variance of demand. If the variability of replenishment time and demand increases, management of the inventory will be inadequate, which means that the production system capacity will not match the demand, creating either too much wait time (because of the lack of products or services), or doing overproduction (because of the excess of products or services).

$$Variance\ of\ replenishment\ time\ demand = l\sigma_d^2 + d^2\sigma_l^2 \quad \text{(Equation 4)}$$

These equations are the basics for developing the OS graphs presented in the following section.

2.3.3 Four OS Graphs

1. Cycle Time versus Utilization graph: This graph visually represents the VUT equation. It shows that when u increases toward 100 %, queue time (or CT) goes infinite. As shown in Figure 5, with more variability (comparing curve V=0.25 and curve V=1, where V represents the amount of variability in each curve), the CT tends to go to infinite at a higher u. This graph represents the combined effect of u and variability to CT, showing that it is necessary to control both (u and variability) to obtain an appropriate CT in the production system.

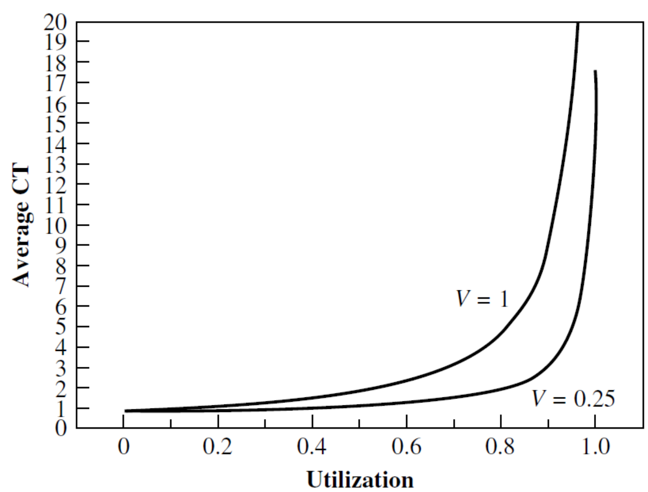


Figure 5: Cycle Time versus Utilization Graph. Figure 9.2 in Hopp & Spearman, 2008.

2. Production Flow graph: Figure 6 shows the Production Flow graph, which is a combination of two graphs: TH versus WIP and CT versus WIP. The effect of variability in the

production system causes less TH (Actual throughout curve) compared with an ideal scenario of zero variability (Best case throughput curve). Variability has a similar effect in the CT (Actual cycle time curve vs. Best case cycle time curve). Given a production system's capacity and variability level, CT and TH vary directly with the amount of WIP in a system. Therefore, WIP is a control parameter for determining the amount of TH and CT a system will produce. As Hopp & Spearman (2008) explained, the "magic" of pull systems is that they control WIP. Therefore, the level of WIP is a design parameter for determining the performance of a production system.

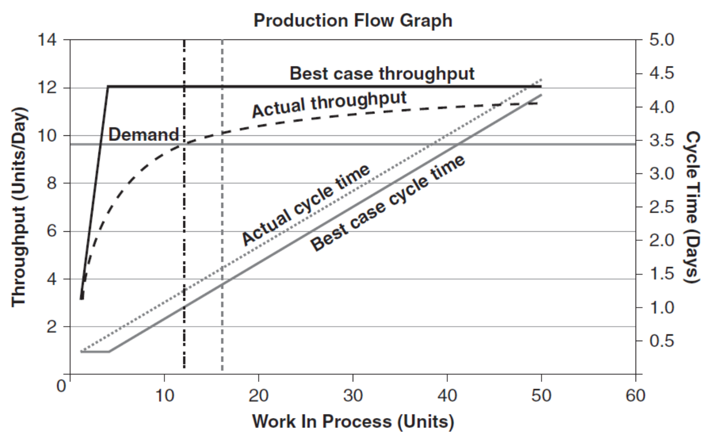


Figure 6: Production Flow Graph. Figure 3-19 in Pound et al., 2014.

3. Average Inventory Investment versus Fill Rate graph: Also known as Tradeoff Plot, it is a graphical representation of the Variance of Replenishment Time Demand equation (equation 4). The tradeoff is between inventory investment and fill rate. It graphically illustrates the effect of variability on inventory, and as Figure 7 shows, at fill rates close to 100 %, inventory requirements increase nonlinearly to infinity. Figure 7 also shows that doubling order frequency from 80 to 160 orders per period significantly reduces inventory at a given fill rate. The three curves are efficient frontiers representing different capacity profiles for replenishing parts. A detailed explanation of the efficient frontiers can be found in Pound et al. (2014).

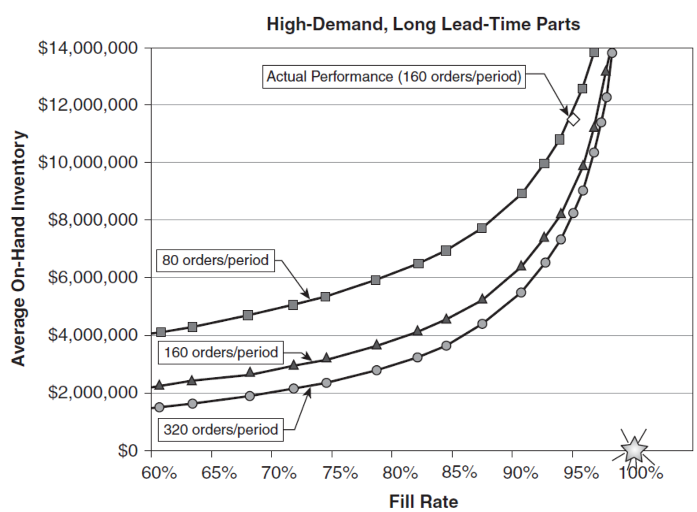


Figure 7: Inventory versus Fill Rate Graph. Figure 10-3 in Pound et al., 2014.

4. <u>Cycle Time versus Lot Size graph:</u> This graph is known as the lot size graph. The Lot Size graph results from a combined optimization of stocks and flows. As Figure 8 shows, there is an optimal minimum for LS, corresponding to the curve's lowest CT point. CT to the right of the optimal LS increases because parts wait in larger lots for all the parts in front of them at process centers. CT to the left of the optimal LS increases even faster because the LS is smaller, creating a higher frequency of set-up times and increasing CT exponentially. Potoradi et al. (1999) provided an empirical demonstration of how to construct this graph based on a semiconductor back-end factory, showing the detrimental effects of non-optimal calculations of the LS in terms of an increased CT for that production system.

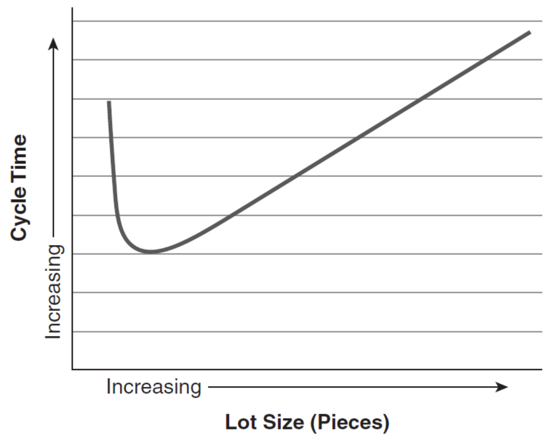


Figure 8: Cycle Time versus Lot Size Graph. Figure 3-31 in Pound et al., 2014.

2.4 CLADDING SYSTEMS IN BUILDINGS

2.4.1 Cladding Systems Definition and Applications

Considering the scope of the case study to explain in Chapter 4 of this thesis, it is essential to comment on a building's cladding systems (or façade), how this concept is relevant for the construction of the building, and what trends in construction apply to these systems. Based on Herzog et al. (2004), the façade is the separating and filtering layer between the outside and inside the building, between nature and interior spaces occupied by people. In addition, diverse other requirements have been added to these protective functions: light in the interior, an adequate air change rate, a visual relationship with the surroundings, and, simultaneously, a boundary between the private sphere and public areas. Consequently, these uses lead to control and regulatory functions added to the protective functions of façades. Based on the Steel Construction Institute (SCI) (2006), the primary function of the cladding system is to provide a weathertight building envelope, suitable for the intended use of the building.

As the building envelope cannot usually be produced in one piece, it is necessary to break it down into individual parts. Building the façade on site is linked with the chronological progression of erection and assembly. Depending on the situation, external conditions can influence the progress of the building work. As an example, climatic conditions have a direct influence on the progress of the building work. A change in the weather can lead to delays in construction processes related to the cladding systems that influence all subsequent work and generate delays in other construction activities. The erection of a façade as protection against the weather enables the fitting-out of the building to take place independent of the weather conditions (Herzog et al., 2004).

Based on Alumtech (2020), we can use different criteria to divide façade types. Material is the most common criterion used to divide façade types, and the level of offsite assembly principles applied to the system (or degree of preassembling) is another criterion. Regarding the materials, there are facades made of stone, clay, concrete, timber, metal, glass, and plastics (Herzog et al., 2004). SCI (2006) identified three types of metal cladding using a "double skin" system comprising two metal sheets with a layer of insulation in between. These categories are built-up systems, insulated panels, and standing seam systems.

Regarding the supply chain involved in the development of façade systems in buildings, Azcarate-Aguerre et al. (2021) mentioned that stakeholders get involved in the façade systems design, installation, operations & use alongside the lifecycle of the building itself. Figure 9 shows stakeholders interact when the façade systems are delivered for a particular project. Therefore, a supply chain approach helps make decisions collaboratively among the stakeholders involved in delivering this system. Like the different supply chain configurations of pipe supports explained by Arbulu & Tommelein (2002), the owner and the designer sides can select the proper configuration to achieve project goals.

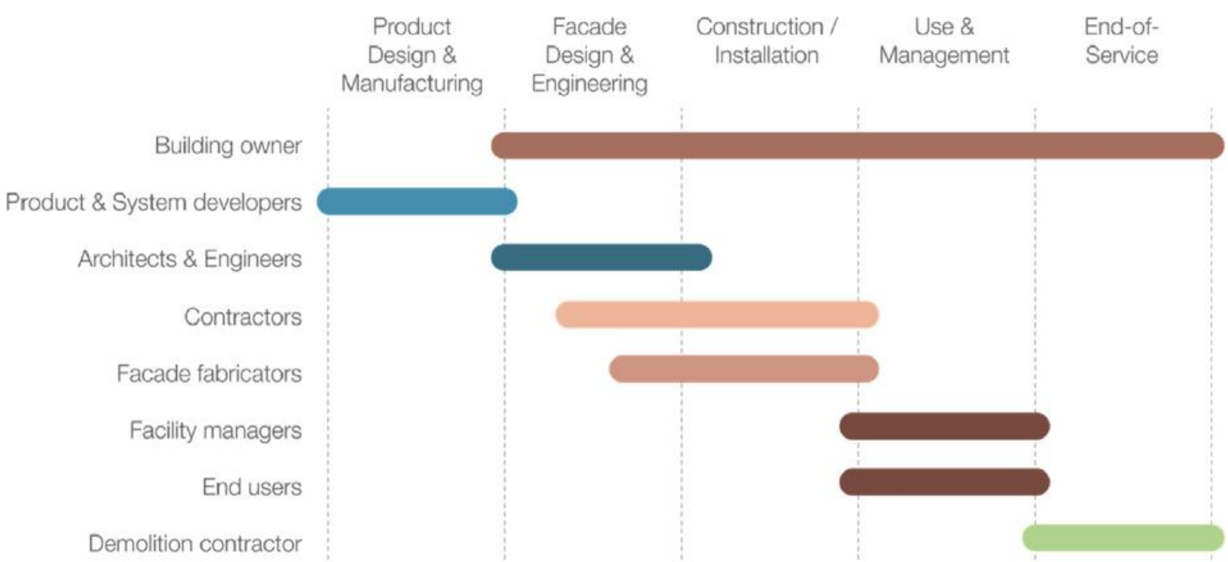


Figure 9: Stakeholder Involvement over the Life Cycle of a Linear Façade. Figure 22.4 in Azcarate-Aguerre et al., 2021.

Current trends such as offsite construction and lean-related concepts have been considered to apply to the development of cladding systems. For example, Friblick et al. (2009) proposed an integrated glass façade system for high-rise buildings using lean principles. In addition, they proposed de-coupling of the cladding installation from other trades, which, based on that study, reduces dependencies between trades and reduces uncertainty and variability in the construction process. Guerra et al. (2017) developed a BIM-based methodology for incorporating an early energy efficiency analysis in all the stages of the design-construct-install-operate process of preassembled façade panels. By including relevant information about the panels in the study using BIM models, project teams can analyze various retrofit alternatives for buildings.

Gasparri et al. (2015) developed a study of the influence of the degree of preassembling of façade in tall cross-laminated timber (CLT) buildings in terms of cost and time savings, as well as onsite work quality and safety issues. The detailed construction site scheduling results outlined how offsite assembling allowed time savings, which is even more relevant when dealing with the timber-based structure, as minimizing exposure to weather agents is the primary concern. Pascha et al. (2016) analyzed the application of a wood-glass preassembled load-bearing façade, finding that this system provides benefits in time reductions and is compatible with the "real world" market products. Based on an MMC approach using point clouds, Torres et al. (2021) introduced a "plug and play" method for installing façade in the renovation of buildings, which showed benefits by reducing uncertainty as a considerable proportion of the work was developed in a controlled environment.

2.4.2 Tolerances in Cladding Systems

Tolerance problems of preassembled components for buildings are also an issue in cladding systems, which has been an area of interest among researchers and practitioners of the AEC industry. Considering the preassembled components of cladding systems, tolerances of the order of centimeters are reasonable in reinforced concrete and timber and of the order of millimeters in steel and aluminum (Knaack et al., 2007). Therefore, engineers should control these tolerances during the construction of the building. For example, Funtik et al. (2015) developed a method based on BIM and terrestrial laser scanning to control the tolerances of the façade, which provided real-time data to take action if the tolerances were not appropriate.

Da Rocha et al. (2018) argued that the elements of modularized systems in buildings present a tolerance problem: the interfaces among these elements are combined, so tolerance accumulation exists between these elements. As a method to tackle those problems, that study proposed using visual management to visualize the issues by comparing the data collected onsite with BIM models and communicating potential solutions. Considering the nature of preassembled components in buildings and how to manage their tolerances, the concern about structural connections is essential. Therefore, it should be regarded as part of the construction method selection for that specific system.

Regarding the interaction between the cladding systems with the structures of the building, it should be noted that there is a significant structural implication in the design of the façade system to be compliant with the structural system of the building. Based on Herzog et al. (2004), facades are primarily vertical and planar (two-dimensional) structures positioned between the external and internal environments. Regardless of what materials are employed, various applicable features and engineering design principles are valid for façades, such as air permeability, light permeability, geometric variability (the surface of the facade can react to changing external conditions by modifying the position or the properties of components), and degree of preassembling.

Joints in external facade surfaces are exposed to the full force of the weather. The wind load increases with the height of the building. The position of joints concerning the direction of precipitation and run-off water, determined by gravity and wind, is a crucial factor in collaborative design. Changes in the length or volume of adjoining components due to loading, temperature fluctuations, and water absorption/release place extra stresses on any joint (Herzog et al., 2004). Considering the supply chain of cladding systems, structural connections are usually developed and provided by the subcontractor in charge of the façade of the building. Therefore, selecting these members of the supply chain and structural connections is crucial for optimal facade performance.

Alongside selecting the proper connections provided by the supplier, considering the appropriate tolerances during design is crucial. As stated by Kazmiercsak (2008), designers need to fully understand the movements and tolerances during the construction of extensive commercial and public facilities, which usually contain large spans. In addition, understanding the nature of materials, their production limitations, and the specifications of the project are critical for the delivery of construction documents. For example, Figure 10 shows a live-load deflection of dead-load support points of a curtain wall, which indicates the forces that the cladding system should be designed to resist.

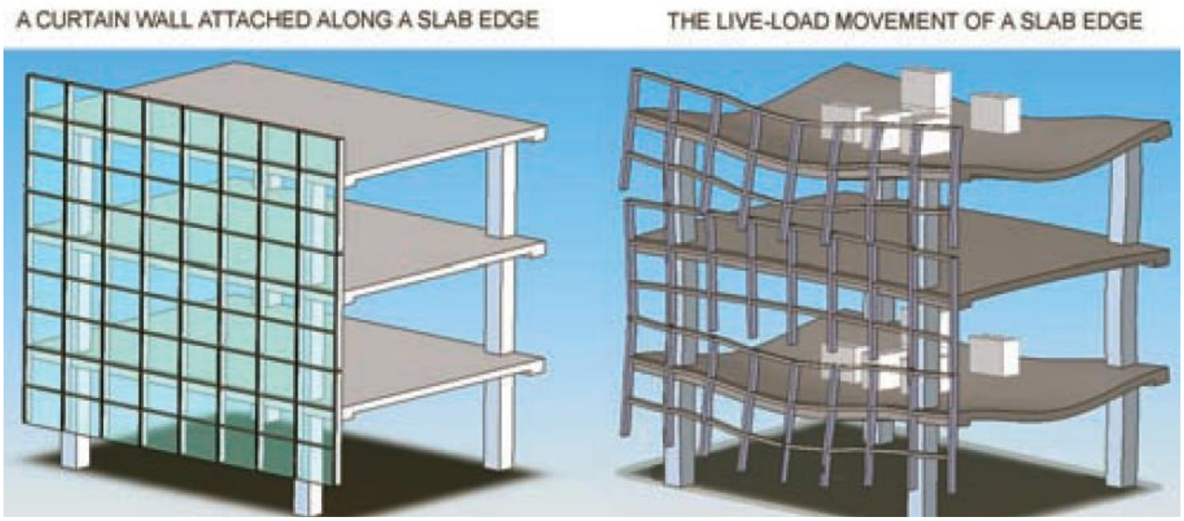


Figure 10: Live-load Deflection of a Dead-load Support Points of a Curtain Wall. Figure 7 in Kazmiercsak, 2008.

The designer's notebook of the Precast/Prestressed Concrete Institute (PCI) (2012) explained the erection tolerances in the context of precast facades and the position of the individual precast concrete members as they are located and placed in the assembled structure. They usually involve the general contractor and various subcontractors, such as the precast concrete erector. Erection tolerances help to achieve uniform joint widths, level floor elevations, and planar wall conditions. Erection tolerances should be determined based on individual unit design, shape, thickness, materials composition, and overall unit scale in relation to the building. The specified erection tolerances may affect the work of different building trades and must be consistent with the tolerances specified for those trades.

2.5 SYNTHESIS, DISCUSSION AND GAP IDENTIFICATION

2.5.1 Synthesis

The iron triangle provides the most critical metrics in PM to summarize project performance, showing that the quality, cost, and time of a project are interrelated, which means that there are no free movements between each other. In addition, OSC is a trend allowing to adopt most manufacturing-style processes in construction projects, changing the way supply chains in the construction industry work. PSD has been part of the Lean Construction field of study for over two decades, and it provides a way to design the operations involved in the processes of construction projects. Currently, researchers and practitioners are conceiving construction projects as a network of production systems, showing that the behavior of the production systems of a project impacts project performance using the PM metrics.

OS, a term deeply related to OM and OR, is a novel concept used for explaining the science behind how production systems behave, regardless of the industry. Although Shenoy (2017) and Prado (2022) compared these three concepts, this thesis uses the following definition of OS. “OS is the study of operations between resources aiming to produce goods and services by aligning the production system capacity to the external demand considering the effects of variability on this system.” OS provides metrics that explain the behavior of production systems, the most crucial OS metrics are CT, WIP, TH, and u. These metrics are instrumental components of the three equations and four graphs that explain how production systems behave. For example, cladding systems are crucial for buildings, and the tolerances considered for the façade are relevant to the development of the façade as a production system during its installation and its performance during operation.

2.5.2 Discussion

Two bodies of knowledge explained in the literature review (PSD impact on project performance and OS) have a common ground since PSD impacts project performance, and OS can explain the last relationship. OS provides a novel analysis that allows finding a relationship between the OS metrics and PM metrics for a production system. To understand this relationship, building construction processes can provide a scenario to study it. As a result, this thesis is using a case study based on an offsite cladding system in a healthcare building, which will provide the space to understand the interactions between PSD and project performance. Since the case study of this thesis will use a cladding system to analyze the applicability of OS in this production system, the consideration of tolerances on this system is essential to acknowledge as it can influence the installation process and, therefore, the production system itself.

2.5.3 Gap Identification

Due to the novelty of the concept of OS, a piece of literature has yet to present a relationship between PSD and project performance using an OS analysis. One crucial consideration is that manufacturing production systems are conceived as steady-state production systems, which significantly differ from construction processes, which are temporary production systems. This is a challenging part of building construction, and it is essential to understand the applicability of an OS analysis within this restriction. Therefore, the research gap this thesis is trying to bridge is to what degree the OS analysis is applicable to building construction to understand the impact of PSD on project performance and what are the assumptions to develop this analysis.

CHAPTER 3 FRAMEWORK FOR APPLYING OS TO CONSTRUCTION

3.1 INTRODUCTION

In this chapter, due to the relationship between OS and OR, I will use components of OR (queueing theory and simulation) to explain how variability affects production systems and how the durations of activities in construction can be set up as stochastic models. Moreover, I will explain the utilization of analytical models to study the production systems of construction projects. Subsequently, I will develop an "intuition" about the relationship between PSD and project performance using OS. Then, I will explain the challenges of gathering data from a construction project, which is a crucial part of the OS analysis. Since each project is different (by definition), the quality of data and the consideration of the variability in the data gathered onsite affect the outcomes obtained from the OS analysis. As I will show, current data gathering methods used in construction constrain how we analyze production-related data and the types of results obtained from these methods. Last, I will present a proposed framework considering these challenges and the use of OS to find the relationship between PSD and project performance.

3.2 OS AND QUEUEING THEORY

3.2.1 Application of Queueing Theory in Construction

The concept of OS is related to concepts already applied in the manufacturing industry. I will use queueing theory, a concept part of OR, to understand how variability affects PSD. Heiman (1960) stated that OR might perform for construction management the service it has already performed in other fields, and it can examine problems to seek causes rather than treat effects. For over 50 years, pieces of literature have shown the application of queueing theory to construction and construction processes aiming to model them and understand their performance under different circumstances. Here, I will provide examples of these applications.

Carmichael (1968) compared queueing theory models to find the one that best described the characterization of shovel trucks in earthmoving activities. He suggested that there is no "perfect model" and that several models can provide remarkable results in understanding the system's behavior. Figure 11 shows the schematic representation of the shovel-truck operation analyzed in Carmichael (1968). In the literature review conducted by Abourizk et al. (1992), they suggested that the use of queueing theory models was related to repetitive construction processes (i.e., tunneling, road construction, and glass installation on buildings).

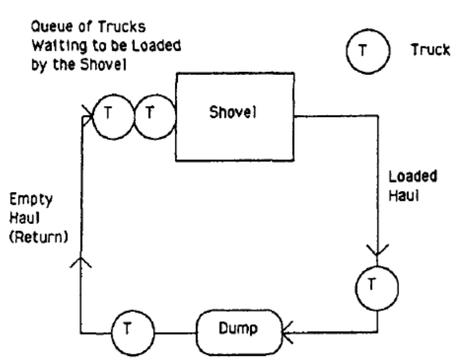


Figure 11: Schematic Representation of Shovel-truck Operation. Figure 1 in Carmichael, 1968.

As part of the application of queueing theory in construction, academics in the 1960s started to explore the use of simulation in various applications. For example, Touran (1992) conducted a literature review of simulation in construction, finding that it was helpful in representing the effect of weather on construction processes (Benjamin & Greenwald, 1973), planning on building construction (Ashley, 1980), probabilistic scheduling (Moder et al., 1983), and tunneling operations (Touran & Asai, 1987). These cited references are only a sample of the simulation applications and are intended to show a variety of uses in construction.

The development of software platforms was also instrumental in developing simulation applications in construction. To name a few: (1) CYCLONE (CYCLic Operation Network), a software that simplified the simulation modeling process and made it accessible to construction practitioners (Halpin, 1973); (2) COOPS (Construction Object-Oriented Process Simulation System), a DES system with an object-oriented design (Liu & Ioannou, 1992); and (3) CIPROS, an object-oriented interactive system for constructing DES networks and simulating construction plans (Odeh et al., 1992).

Abourisk et al. (1992) presented other simulation applications in construction, such as claims analysis, dispute resolution, and project planning and control (combining the Critical Path Method-CPM- with simulation models). Another source of research related to queueing theory and simulation in construction is the Winter Simulation Conference (WSC). Since 1992, this conference has included a track related to simulation applications in construction project management (https://informs-sim.org/wsc92papers/prog92sim.html). In the mid-1990s, Martinez (1996) developed STROBOSCOPE (acronym of State and Resource Based Simulation of Construction Processes), a general-purpose simulation programming language designed to model construction operations. Using STROBOSCOPE as the baseline, Martinez (2001) also developed EZStrobe, an easy-to-use but powerful version of STROBOSCOPE.

Since the creation of STROBOSCOPE, authors have used this simulation tool to extend and explore the use of DES in construction. For example, Tommelein (1997) modeled a pipe-spool installation process and a concrete placement process to show Lean Construction concepts such as uncertainty, waste, flow, conversion, and push- and pull-driven processes. Gil et al. (2001) presented a simulation of the design process under an unpredictable environment, which showed that different postponement strategies affect the overall performance during design. Arbulu (2002) simulated the performance of five supply chain alternatives of pipe supports to evaluate the interactions between stakeholders. Alves & Tommelein (2004) analyzed Lean Construction concepts such as buffering and batch sizes in the supply chain of heating, ventilation, and air conditioning (HVAC) systems. Wong et al. (2007) used EZStrobe to simulate a set-based design method for rebar design.

Queueing theory and simulation have been applied in construction for over half a century, and its usage is diverse. The use of DES models has been enhanced due to the development of software platforms, which considered the complexity of construction operations and processes in their interface. However, DES models are not the only type of model. Analytical models have also been developed to improve construction. Moreover, I will use one analytical software in the case study. I will explain this type of model and the main differences with DES models.

3.2.2 Application of Analytical Models in Construction

In parallel to the extensive wide use of simulation in construction, researchers also explored analytical solutions and optimization in construction through mathematical models. Analytical models are collections of mathematical equations that, when solved, predict the system's expected behavior. These models can be solved with a pencil and paper if the model is simple, or it might require using vast computational resources if it is overly complex (Law & Kelton, 1991). One application is related to project planning optimization. For example, Karshenas & Haber (1990) combined CPM with analytical models to optimize project duration and resource allocation for simple projects. However, they also argued that computers are required for more complex projects.

Another application of analytical models is related to model construction processes. Among others, Beliveau & Dal (1994) presented an analytical model of the handling materials construction process considering using a crane moving throughout the project area to transport the handled materials. Their results helped to visualize several scenarios of this process to select the most appropriate one based on an optimization objective. Another application is related to the supply chain of projects. For example, O'Brien et al. (2002) used analytical models to optimize the suppliers' performance and provide more accurate policies for controlling inventory.

Another application is to compute a decision-making tool to analyze various scenarios of construction engineering and management issues for the training purposes of practitioners (Rojas & Mukherjee, 2003). In addition, another use of analytical models is to address claims and dispute resolutions in projects as it provides a tool to understand the implications of the decisions made under certain circumstances within the claims process (Ho & Liu, 2004). Later, using analytical models in construction was combined with other methods and techniques to solve complex problems. For example, Talmon & Bezuijen (2011) used an analytical model on a bored tunneling project to find the construction process that will optimize the beam action during construction. Furthermore, Hazir (2015) combined earned value analysis (EVA) with analytical models to predict project performance aiming to optimize the metrics considered in the EVA.

Analytical models and optimization have been relevant topics in construction for more than thirty years. Their usage is related to various decision-making problems at project and supply chain levels. These models provide "only one" solution based on the model's purpose and the optimization's objective. Despite the power of these models, some problems in construction are too complex to address with analytical models, and DES models can be helpful in addressing those problems. Both models have advantages and disadvantages, which should be acknowledged to develop a realistic model to solve the problem.

3.2.3 Tradeoffs Between Analytical and DES Models in Construction

Since the purpose of using these models is to represent construction production systems, I will use literature related to ways to study systems to address the differences between these models. Based on Law & Kelton (1991), there are ways to study a "system." They argued that initially, a system could be studied through experiments on the actual system or through experiments with a model of the system. Then, the system can be analyzed through physical or mathematical models within this second type of study. Lastly, the mathematical models can be either analytical or simulation; this last type of mathematical model is where the DES belongs. The substantial difference is that the analytical model can provide an exact solution after solving the equations as part of the model. In contrast, DES changes a countable number of points in time in the inputs of the model to see how they affect its outputs (Law & Kelton, 1991).

They also argued that if an analytical solution to a mathematical model is available and is computationally efficient, it is usually desirable to study the model in this way rather than via a simulation. However, many systems are extraordinarily complex, so simulation is the only alternative to studying the system. Oloufa (1993) agreed with this idea as he argued that applying analytical models is preferable to simulation, but most practical systems are too complex to model by mathematical techniques. This is especially true when random activities are inherent in the system. This is another significant difference between these two models: the analytical would require a manageable set of equations to solve, and the DES can solve any equations regardless of their complexity.

Regardless of the differences between these two types of models, having the two of them allows us to validate the results from one to another and to have tradeoffs between these results. For example, the analytical model will provide outcomes under certain assumptions (to solve the equations of the system mathematically), which can reduce the model's accuracy. Still, this drawback can be tackled using DES models to analyze a more complex version of the same system. Also, the DES model would require several iterations and runs to provide statistically sound results for the system. For more detailed differences between these two models, Hewwit (2002) found other tradeoffs between analytical and DES models in manufacturing production systems. These tradeoffs can apply to construction production systems.

Considering these characteristics of the models for studying production systems in construction, in this thesis, I will use Strategic Project Solutions (SPS)' Production Optimizer ® as an analytical model software. This software aims to provide an analytical solution for a production system in terms of OS metrics under specific production parameters. Because this software possesses SPS' proprietary information, I am not authorized to provide details about how this software works. However, this is a brief explanation of the modeling process in this software: first, it is required to create a process map considering operations, stock points, and queues; second, production-related parameters (i.e., demand, production rates) are added to the process map components; third, Production Optimizer runs its engine to determine the "only solution"; fourth, the software solution provides the OS metrics (CT, WIP, TH, u) of the production systems.

Although providing a detailed description of the algorithms of Production Optimizer is out of the scope of this thesis, the brief explanation of this software helps to understand the logic behind this software and the purpose of its application in this thesis. In fact, after obtaining the results of the production system model (OS metrics), I will use them to find PM metrics and analyze the relationship between these metrics as well as the capacity of the production system to respond to certain changes in the production parameters. Finally, in CHAPTER 4, I will explain the model's inputs and the changes the software allows to do to the production system model, such as considering a constrained work-in-process (CONWIP) signal to control the production system.

3.2.4 Stochastic Models for Task's durations in Construction Processes

One crucial aspect of the application of queueing theory in construction is that the times used for the steps in the construction processes are not deterministic but stochastic. Therefore, stochastic processes can consider variability in calculating these times, a topic related to OS. Queueing theory provides a foundation for understanding the inclusion of variability in construction processes through stochastic models. In this section, I will present a stochastic model based on queueing theory concepts, which I will use to construct the "intuition" about OS in construction.

I assume that the construction crew is a discrete-time queueing system with an arrival rate (characterized by a mean and a standard deviation) and process time (represented by a mean and a standard deviation). This is a simplification for this queueing system. For this explanation, I assume that the construction process is the installation of panels in the façade of a building. I also assume that the number of panels the construction crew can install each day is a random variable. This means that each day the number of panels installed is independent of the previous days (characteristic of a Markov Chain).

These are the parameters of the queueing system:

- Construction crew for façade panel installation (the crew): discrete-time queueing system.
- The façade's panels arrive onsite at a certain frequency: arrival rates of "inputs" for the system.
- The times that the construction crew takes to install the façade's panels: process rates of the "inputs" the system can produce, which is a random variable.

Considering these parameters and a Markov Chain to model this process, I make the following assumptions: (1) façade panels arrive every day, which the crew must install; (2) on average, the process rate is larger than the arrival rate, but since there is variability in the system, there will be some days in which the panels required to install are more than the panels that were installed, creating a backlog for the next day. X_n represents the number of panels installed each "n" day. If there is a backlog from the day "n," this will affect the number of panels that must be installed on the day "n+1". Therefore, the number of panels installed will be the minimum value between: (1) the number of panels required to be installed that day considering the backlog of the day before, and (2) the number of panels that the crew can complete that day considering the variability of the system (stochastic process). Equation 5 shows the formula for calculating X_n.

$$X_n = Min(B_{n-1} + O_n, P_n) \quad \text{(Equation 5)}$$

The parameters of Equation 5 are:

- B_{n-1} is the backlog of the day "n-1".
- O_n is the number of panels required to install in day "n" based on a random variable. In other words, it is the number of panels that the crew should install based on what the schedule says. This variable represents the variability in the arrival times.
- P_n is the number of panels the crew will install based on a random variable using a Markov Chain model. This variable represents the variability in the process times.
- X_n is the number of panels the crew will install in the day "n." This value can be: (1) The summation of the backlog of the day "n-1" (B_{n-1}) and the required number of panels to install in the day "n" as a random variable (O_n); or (2) The number of panels that can be installed based on another random variable (P_n). Either way, the minimum of the two values described is the one that X_n will take.

Equation 5 makes sense in terms of finding the impact of variability in the completion of panel installation for the project. These are the two potential outcomes of equation 5:

- If $B_{n-1} + O_n < P_n$, the crew has more capacity and it would be able to install P_n panels, but it is only required to do $X_{n-1} + O_n$; so there will be some capacity that it is not used.
- If $B_{n-1} + O_n > P_n$, the crew will be saturated and it will not be able to install all the panels, but only P_n, and the difference between ($B_{n-1} + O_n$) and (P_n) will produce a backlog of panels that were not installed on that day.

In either case, there are options to have a backlog for each day which will be equal to or greater than zero. Equation 6 shows the formula to calculate the backlog of the day "n."

$$B_n = B_{n-1} + O_n - X_n \text{ (Equation 6)}$$

It makes sense to avoid having a backlog in this process, which has the resources (if available) to produce that specific operation. Therefore, I will use the backlog as "performance metrics." The objective is to optimize (minimize, in this case) them by trying to keep them as close as possible to zero. In this regard, I will use two performance metrics:

- The backlog of façade panels on the last day the crew receives panels, which means that the team is not finishing the façade panels installation on the day it is scheduled to finish them. A zero in this metric will mean that the crew finished the process on time, and something larger than zero will mean that it will be necessary to extend the process's time.
- The summation of the backlogs of all the days the crew develops the operation (21 days).

After providing the logic of the stochastic process, I will provide the data I will use for the variables defined in equations 5 and 6. Table 1 shows the data and distribution 1 of the variable O_n.

Table 1: Number of Panels Ordered for a Specific Day (Distribution 1). Developed by Prado.

Day	Number of panels ordered for the day
0	
1	7
2	8
3	10
4	10
5	12
6	13
7	14
8	14
9	13
10	11
11	13
12	13
13	11
14	10
15	12
16	12
17	13
18	13
19	13
20	10
21	10

The variable O_n describes the number of panels ordered per day, and I assume that we want to install all of them the day after they arrive on site. Therefore, the crew must install 242 façade panels in 24 days (the scheduled demand) and the "distribution" as shown in table 1. I should mention that this distribution is an assumption I made for this queueing system model. Considering this distribution, the mean of O_n is 11.52 and the standard variation is 1.91, which represents the variability of O_n.

The variability of P_n is more challenging to represent. Table 2 shows the probability of completing a certain number of panels (based on assumptions aligned with the experience of construction professionals involved in the case study) and the cumulative distribution of those probabilities.

Table 2: Probabilities of Panels Installation for One Construction Crew. Developed by Prado.

Probability of completing that number if I have an infinite number of panels	**Panels installed**	**Cumulative distribution**
		0.00
0.01	8.00	0.01
0.08	9.00	0.09
0.16	10.00	0.25
0.09	11.00	0.34
0.14	12.00	0.48
0.16	13.00	0.64
0.17	14.00	0.81
0.03	15.00	0.84
0.15	16.00	0.99
0.01	17.00	1.00

Based on the data in Table 2, the number of panels varies from 8 to 17, which were the limits of the panels installed on a "bad" day, and on a "good" day, respectively. The probability of completing a fixed number of panels falls under the assumption that if the construction crew has the capacity to finalize all the panels, they can finish them. No "decimal panels" will be part of the process. The cumulative distribution sums the probability of the previous values.

Considering the data provided in tables 1 and 2 and the objective of this stochastic model (to optimize the performance metrics previously defined – the backlogs), I will compute a simple simulation model to represent the impact of variability in the system. Because the values of the panels installed in this production system can be a fixed number between only two options ($B_{n-1} + O_n, P_n$), the changes of these variables will directly affect the performance metrics. Therefore, it will show the effect of variability on the system's performance.

Using a spreadsheet (MS Excel) and a random number as part of this spreadsheet, I built an engine that provides a specific number of panels installed (from the column Panels installed of table 2), which is the final P_n value for each day. Considering the values already described for P_n, and O_n, I built the backlog (B_n) and the actual number of panels installed (X_n) metrics for each day shown in table 1. Table 3 shows one run (in each run, the random numbers of P_n will change based on the new random number as part of the engine I developed) of running equations 5 and 6 based on the stochastic model. Table 3 also shows the "Total grand" cell that represents the performance metric summation of backlogs, which shows how the system behaves, focusing on optimizing this metric (as close to zero as possible).

Table 3: Results of the Stochastic Model for Determining the Backlog of Panels Installation. Developed by Prado.

Day	Backlog of the day before (Bn-1)	Number of panels ordered for the day (On)	Total of panels required to install (Bn-1 + On)	Potential number of panels completed during the day (Pn)	Actual number of panels completed (Xn)	Number of panels as backlog (Bn)
0	0					
1	0	7	7	16	7	0
2	0	8	8	11	8	0
3	0	10	10	10	10	0
4	0	10	10	16	10	0
5	0	12	12	13	12	0
6	0	13	13	12	12	1
7	1	14	15	11	11	4
8	4	14	18	13	13	5
9	5	13	18	9	9	9
10	9	11	20	14	14	6
11	6	13	19	15	15	4
12	4	13	17	12	12	5
13	5	11	16	16	16	0
14	0	10	10	10	10	0
15	0	12	12	12	12	0
16	0	12	12	16	12	0
17	0	13	13	13	13	0
18	0	13	13	9	9	4
19	4	13	17	13	13	4
20	4	10	14	13	13	1
21	1	10	11	13	11	0
					Total grand:	43

The last part of this stochastic model was to run this simulation one hundred times, which will provide a more statistically sound output in terms of the variability we can see by changing the variable P_n and its distribution. After running the simulation one hundred times, we obtained the following values for the performance metrics we defined:

- The backlog of façade panels on the last day: B_{21} mean 2.35 panels, and B_{21} Standard deviation 3.36 panels.
- The summation of the backlogs of the 21 days: B_n mean 62.68 panels, and B_n Standard deviation 45.23 panels.

With these performance metrics, we can see that the two σ are as big as their respective μ, which indicates that: the crew will need to spend one more day to finish installing the backlogged façade panels, and there is high variability in that system. The distribution selected for the variable P_n and O_n the main contributors to this increased variability. This shows how difficult it is to manage the construction process and how difficult it is to predict what might happen in these situations. To tackle the large amount of variability in the system understood after simulating this process, I will assume another distribution for O_n (distribution 2) and conduct the same analysis and provide the new performance metrics to see how the queueing system behaves. Table 4 represents the new distribution of O_n. Considering this further distribution, the mean of O_n is 11.52, and the standard variation is 0.61, one-third of the standard deviation of distribution 1.

Table 4: Distribution 2 of Number of Panels Ordered for a Specific Day. Developed by Prado.

Day	Number of ordered EIFS panels for the day
0	
1	11
2	12
3	11
4	11
5	12
6	12
7	12
8	12
9	11
10	12
11	12
12	11
13	12
14	12
15	12
16	12
17	12
18	11
19	11
20	11
21	10

Considering this new distribution and maintaining the same distribution of P_n and all the values of the other parameters of the queueing system, these are the results of the performance metrics after running the new model one hundred times:

- The backlog of façade panels on the last day: B_{21} mean 0.85 panels, and B_{21} Standard deviation 2.35 panels.
- The summation of the backlogs of the 21 days: B_n mean 32.36 panels, and B_n Standard deviation 24.85 panels.

The performance metrics show better results than the first distribution of O_n used. Table 4 shows more balanced values than Table 1. This means less variability in the system, therefore providing improved results, as shown in the performance metrics.

3.3 INTUITION ABOUT THE IMPACT OF PSD ON PROJECT PERFORMANCE

3.3.1 Relationship between OS Metrics and PM Metrics

PM metrics are related to the indicators traditionally considered to assess the performance of projects, whereas OS metrics are associated with the performance of the production systems that govern projects. Following the idea stated by Spearman & Choo (2018), projects are the summation of connected production systems (or a network of production systems), which will create a relationship between any construction process, now viewed as a production system, and its impact in project performance by finding the impact of OS metrics to PM metrics. Based on the OS metrics in 2.3.1, I will focus on CT, TH, WIP, and utilization. In addition, I will focus on time and cost based on the PM metrics provided in 2.2.1. Finally, considering the definition of each metric, I will provide an intuition of how the OS metrics can affect PM metrics.

Since Little's Law is the relationship between CT, WIP, and TH, these OS metrics are interrelated, and changing one of them generates changes in the others. For example, having a larger CT will increase the time of the project, and this larger time of the project will incur in using resources more time, assuming that there is a constant level of resources needed. Similarly, due to the direct relationship between WIP and CT, we can infer that increasing WIP will generate a larger CT, causing the mentioned effects in time and cost. Regarding the TH of a production system, we can argue that this metric has a limit, as explained in 2.3.3. This means that TH will remain constant after a certain amount of WIP in the system. Considering this limitation, I can argue that increasing the TH can provide benefits by using the production system capacity with a specific demand. However, after this limit, any attempt to increase TH by adding more WIP will create adverse effects, as the only parameter that increases will be the CT.

As opposed to practitioners' beliefs in construction projects, the larger the % of utilization in a project, is more sensible the impact of variability. As explained in 2.3.3, the closest the u metric approaches 100%, the CT tends to go to infinity, and when the CT grows, PM metrics get worse (more time and cost).

The VUT equation explains the relationship between CT and u, which due to this effect, has terrible implications in cost and time as U grows in a production system. This intuition about the two types of metrics makes us realize the factors to consider while designing a production system. Similarly, having a better understanding of these factors' implications in CT can allow construction professionals to directly impact PM metrics by avoiding unnecessarily larger CTs. One way to provide this control of CT is to use CONWIP techniques that control the number of items in the system at specific stock points.

3.3.2 Complexity of OS Metrics in Projects

The construction industry applies innovations or improvements slower than other industries do, and the use of production systems is no exception. As a result, I need to address challenges aiming to explain the context in which construction teams develop construction projects and why applying OM, OR widely, and other OS-related concepts in a project setup are challenging. These are the challenges found in a project:

1. No infinite production system: Since the analytical tools used in OS analysis are based on a steady-steady system assumption, applying them directly to a construction project's production system can present challenges just by acknowledging that a construction project's

production systems are temporal. However, the OS graphs and equations remain applicable. Still, we should develop this analysis with different assumptions and consider more variability due to the lack of an infinite steady-state production system. In an infinite steady-state system, the law of large numbers provides better support for using means when representing a sample of values. In this case (no infinite steady-state system), the mean and the squared coefficient of variation (SCV) of the parameters can represent the variability as part of the OS analysis.

2. Lack of efficient control of detrimental variability in the system: The amount of variability in construction is enormous and difficult to control. OS graphs and equations provide a way to understand the representation of variability in construction production systems. In addition, unlike other industries, construction possesses the challenge of being a project-based industry, which creates a "negative uniqueness" as any project creates a set of unique production systems.
3. Work plans are constantly changing: Due to the elevated levels of variability in construction projects, the work plans for these projects are constantly changing. Under these circumstances, redesigning production systems can be a solution (although very laborious), but developing PSD in construction is not yet a common practice.
4. AEC practitioners' misconception of OS metrics: Construction production systems are still a novel topic, and OS metrics are a novelty for construction practitioners. Some practitioners believe that a project schedule represents the project production system. This represents the misconception of OS-related concepts in the AEC industry. Another misconception is the aiming of having a u of 100% without understanding its detrimental implications on CT.

These challenges add complexity to any study exploring the use of OS in construction. Nonetheless, OSC can provide a smooth transition to apply these concepts in construction. The most crucial improvement when comparing OSC with the onsite approach using the OS lens is the reduction in variability, which affects the challenges already described. Since this approach requires transferring the work to a controlled environment, it is possible to reach a shorter CT without compromising the quality of the final deliverable and doing it within the budget for that specific OSC process. In addition, considering that most of the construction process is developed in a manufacturer shop, it might be possible to have something close to a steady-state production system. Although, the challenging part remains in the operations that are happening onsite, i.e., installation and onsite assembly.

There are implications of OSC on project and supply chain levels. These new conditions can create a suitable environment for collaboration between the parties, promote knowledge transfer between them, and create an incentive for innovation. An offsite setup also reduces the variability of the OS metrics collected from the steps of the production system because of the control techniques in the manufacturer's shop (i.e., a more rigorous quality control process, *andon* systems implemented in the shop). However, the variability on site will remain, but this will be less variability compared with the highly variable environment of a traditional construction project.

3.4 Data Collection and Data Analysis For Applying OS in Construction

3.4.1 Current Practices for Gathering Data in Construction Projects

Oglesby et al. (1989) collected methods to gather data on a project site to plan and execute construction operations for the first time. Construction practitioners adopted these methods from the social science field and are related to qualitative and quantitative methods. These are the methods used:

1. Questionnaires and interviews (semi-structured and structured) are methods used in construction management to understand the behavior of people involved in the construction crew and onsite staff members. Questionnaires or interviews are employed because experience has shown that workers or supervisors often perceive situations onsite better than higher-level management. An issue to consider while gathering data is whether the source of information is unbiased, which can lead to making uneducated decisions for operations improvement in the field.
2. Activity sampling. This method is divided into three categories: (1) field ratings, where the observations are simply working or not working; (2) productivity ratings, where activities are recorded in more detail and then reported as effective, contributory, and not-useful work; and (3) 5-minute ratings, where the activities of a crew are recorded for short intervals. To ensure an adequate representation of the universe, the observations of the sample should be collected at random times and in different sequences.
3. Photographs, video recordings, and other media are useful for collecting data. In this regard, Carter & Fortune (2004) analyzed the implications of conducting paper-based data collection methods compared to web-based collection methods, finding a tradeoff between these two mechanisms to gather data onsite. More recently, AEC's practitioners implemented other techniques to collect digitalized data. Among other authors, Perez et al. (2022) used unmanned aerial vehicle (UAV) and terrestrial laser scanning (TLS), among other technologies, to capture digitalized data from the field, creating point clouds of university campuses. Also, there are suppliers of the AEC industry that provide the service to capture data from various devices to track construction processes in the field. This is undoubtedly a trend in our industry.
4. Using construction processes' documents and files that explain the technical aspects of construction operations, such as construction process specifications and plans, as well as work plans for each construction activity. Additionally, the parties involved in the construction process can provide more detailed information such as work sequences, deliverables schedules, production plans, BIM models, and other technologies that can communicate the work. Historical data is also relevant in this section, as it helps to compare construction processes' performance at various times.

Despite all these efforts, it is still uncommon to see that any of these documents or files collect information and insights about the "production system" of construction processes. OS metrics are not part of these documents, and the production system behaves with no control in the construction project. The challenges stated previously about how difficult it is to conduct this type of analysis in construction is a big reason there is no focus on tracking or finding these metrics in projects. Nonetheless, there are trends (technologies to capture digitalized data) that allow us to gather data more rapidly and precisely, and we can make assumptions at the time to collect relevant data for the OS analysis of the production system of the project.

3.4.2 Proposed Data Collection and Analysis Processes to Apply OS

I will use interviews and other methods described in 3.4.1 to collect data from the project staff. The project managers from the parties involved in the construction process to analyze will be the people selected to have an interview. I will also develop workshops to understand how the parties interact with each other. One of the outcomes of the analysis will be the process maps of the construction process, which will provide the context in which the production system works and how the parties interact. I will also collect data relevant to define the "parameters" of the production system, which are process batch (PB, also called current reorder quantity), transfer batch (TB), and demand (D) of each of the steps considered in the construction process to analyze. The strategy will be to collect data from the project team and then infer the production system parameters (PB, TB, D) by the information that describes how the production system performs.

Other information, such as the number of completed activities in a day, is essential because it provides a rate at which the construction crews perform the work. This rate provides an idea of the process rate (PR) or process time (PT) by dividing the number of completed activities or units in a full day (or on an hourly basis). The same logic can be used to find PB and TB in the production system by asking the engineers and craftsmen involved in the process about how they perform the work, if there is any moment in which the resources used need to be changed or if there is any turnover to keep developing the activities of that specific operation. This information is specific to the onsite operations, which requires a detailed understanding of these activities to provide an accurate estimate of these data sets.

Another crucial piece of information is the number of resources used in each construction process's activities. The resources can be a combination of people, materials, pieces of equipment, subcontractors, and services required to complete the construction process to analyze. The information about the resources will help quantify their % of u based on the time available for the specific construction process. Another piece of information to collect is the arrival time in which the work goes from one step to another. This last piece of information resembles the arrival rate used in the queueing model in 3.2.4. Considering the time to gather for each step, I would be able to provide a production metric that explains the behavior of the production system.

Since this study considers a stochastic approach, I will use the mean and SCV of the data collected to represent variability in this construction process. All these considerations for the data collection and analysis processes are part of the framework I will use to conduct an OS analysis in building construction, which I will evaluate with the case study.

3.5 Synthesis, Discussion And Presentation of this Framework

3.5.1 Synthesis

Based on the foundation of queueing theory and Markov chains, I used a stochastic model to understand the impact of variability in the construction process of façade panels installation. This model demonstrated the detrimental effect of variability in the performance of the production system, how performance metrics can measure this impact, and provides an understanding of how this "variability" can be identified to reduce it. The stochastic model based on queueing theory is the baseline for understanding the impact of PSD on project performance intuitively and relating OS metrics to PM metrics. CT is the OS metric that most impact might have in the production system, which can impact the project overall, measured by the PM metrics. OSC is an approach that helps close the gap between these manufacturing and construction production systems and allows a more suitable application of OS concepts in construction.

The current data gathering and data analysis processes face challenges even in OSC projects. These practices for collecting data in construction projects (especially during the onsite execution) focus on crucial aspects of the process. However, a focus on collecting detailed production-related data can improve these practices. I proposed data collection and analysis processes in an effort to ameliorate the current process for the data gathered from the project site. These processes are the baseline to conduct OS analysis in the production system selected.

3.5.2 Discussion

The application of OS in construction offers a better understanding of the relationship between PSD and project performance. OSC can facilitate this relationship because it provides a more steady-state system than an onsite approach. I presented a proposal for data collection and data analysis processes to be able to run an OS analysis in building construction. The data collection proposal enables finding the production system parameters relevant to understanding OS metrics. The data analysis process uses the SCV of the times and sizes used in the production system to consider the variability in the system. To better understand this data gathering proposal and how it will provide the input for conducting an OS analysis, I will develop a case study based on an analytical model. To conduct this case study, I will present a framework starting in the data gathering process until the relationship between OS metrics and PM metrics is found.

3.5.3 Presentation of this Framework

The framework for applying an OS analysis to understand the impact of PSD on project performance of a construction process consists of the following steps:

1. Collect data regarding the context of the construction process, including relevant milestones.
2. Collect data about the rationale of the “production system” from the project team’s perspective.
3. Collect data onsite related to the operations of the construction process.
4. Collect data related to the times of each operation and the resources used in each step.
5. Analyze the data collected and make reasonable assumptions to explain how the production system works.
6. Translate (decode) the data collected regarding production parameters.
7. Develop process maps that explain the construction process and the production system.
8. Use simulation tools to find the OS metrics of the production system.
9. Apply the OS equations and graphs to understand the logic of the OS metrics.
10. Assess how the OS metrics impact the PM metrics with the intuition developed.
11. Develop a sensitivity analysis with the production parameters and the OS metrics to understand how their impacts on PM metrics might change.

This framework is the baseline for developing a case study.

CHAPTER 4 CASE STUDY: SUTTER SANTA ROSA REGIONAL HOSPITAL

4.1 INTRODUCTION

This chapter presents a case study of the framework for applying OS to understand the impact of PSD on project performance. I selected the construction of a healthcare building in Santa Rosa, California, USA, as the case study. The Sutter Santa Rosa Regional Hospital (SSRRH) project consists of a new three-story expansion wing on the east side of the hospital, tied to the existing structure on the 1st and 2nd floors. The expansion adds 58,000 square feet of space and includes forty patient beds in all-private rooms, one endoscopy and gastroenterology room, twenty intensive care unit beds, and eleven post-anesthesia care unit bays (The Boldt Company, 2022). This is a total of $158 million investment to expand the hospital and increase its capacity (Sutter Health, 2022). The project's owner was Sutter Health, the architect on the project was Stantec, and the construction manager and general contractor was the Herrero-Boldt joint venture. The project applied an Integrated Project Delivery (IPD) arrangement that included an Integrated Form of Agreement (IFOA) (Herrero, 2022).

The project team researched options for creating an innovative exterior skin to get the building weather-tight ahead of the rainy season. This expansion is the first HCAI (Department of Health Care Access and Information) project to use an offsite, panelized exterior skin (cladding system) of this kind (HCAI healthcare building type 1). As a result, the project team saved almost $800,000 and four months on an already tight schedule, as well as reducing safety risks. This is an example of an innovation to replicate in both the outcome and the innovation process itself. This experience shows the detailed coordination between the members and the emphasis on technical aspects of construction processes to obtain an efficient production system. I selected the cladding system construction process to apply OS to understand the impact of PSD on project performance. This process finished about one year before this thesis was written. This study is limited to the cladding system's installation (onsite assembly) process with its engineer-to-order (ETO) components. This chapter covers the data collection methods, the data analysis process, the results of the analysis using OS, and the discussion and conclusion of the case study.

4.2 DATA COLLECTION

4.2.1 Offsite Cladding System in the SSRRH project

The SSRRH project team developed innovation in this healthcare building (i.e., the change from an onsite approach to an offsite approach for the cladding system) to gain productivity and be more profitable. I describe the decision-making process to victoriously implement this innovation, which considers construction tolerances, among other things, to facilitate the installation of the façade. Also, despite focusing on the cladding system's installation process, I describe the work that the project team developed during the design phase to implement this innovation successfully. Similarly, I describe the coordination process to ship the components of the façade in a JIT manner. The main actors of this innovation are Herrero-Boldt (HB), California Drywall (CDC), and Baystone. The latter is a company that the SSRRH project team (HB and CDC) found to fabricate the Exterior Insulation and Finish System (EIFS) panels, which are the main components of the offsite cladding system.

4.2.2 Methods and Tools to Collect Data

The data collection process for this case study started with a kickoff meeting between representatives of the project team, Iris Tommelein, and me. Then, meetings and interviews were developed to collect specific data (i.e., the design and coordination processes of the offsite cladding system and the innovation process of the offsite cladding system). Table 5 shows the dates of the interviews, meetings, and the type of data collected.

Table 5: Data Collected from Meetings with the Project Team. Developed by Prado.

Type of meeting	Date	Companies involved	Type of data collected
Kickoff virtual meeting	2022-05-11	- HB - CDC	Project overall information
Site visit 1	2022-05-19	- HB - CDC	General production rates and resources
Site visit 2	2022-05-26	- CDC	Innovation and coordination processes data
Virtual interview 1	2022-05-27	- CDC	Production process steps and rates
Virtual interview 2	2022-06-19	- HB - CDC	Specific data about the constraints in the cladding system process
Virtual interview 3	2022-07-13	- HB	Specific times of the steps of the process
Site visit 3	2022-08-30	- HB	Production process review and construction tolerances

The project team shared the files they used to develop and control the construction of the cladding system. I used these files to understand how the project team developed this process. These were the handouts:

1. A3 of the evaluation developed to compare a traditional cladding system (based on the first version of the project's design) vs. an offsite cladding system.
2. Sequence matrix of the EIFS panels (ETO) to install on the building elevation.
3. Daily deliverables with trucks based on the sequence matrix of the EIFS panels.

These handouts are part of Appendix A of this thesis.

4.3 Data Analysis

4.3.1 Overall Project Analysis

Based on the information collected, I constructed two swim lane process maps that explain the innovation conducted in this case study. These process maps are:

1. Innovation process: from onsite to offsite cladding system
2. Design and coordination processes: from onsite to offsite cladding system

These two process maps are related since the first explains the decision-making process of the innovation (changing from a stick-and-built approach to an offsite approach for the cladding system), and the second describes its design and coordination processes.

<u>Innovation process: from onsite to offsite cladding system</u>

This process map shows the steps for implementing an offsite cladding system using assembled EIFS panels. It explains the main steps and decisions the project team followed to propose (to use EIFS preassembled panels against the traditional stick-and-built EIFS panels). It also shows how they obtained approval to execute this innovative solution for cladding systems in this building. Finally, I use this process map to give an overall idea of how the project team implemented this innovation and how relevant stakeholders accepted it. I used MS Visio to develop this process map, shown in Figure 12. A bigger version of it is shown in Appendix B.

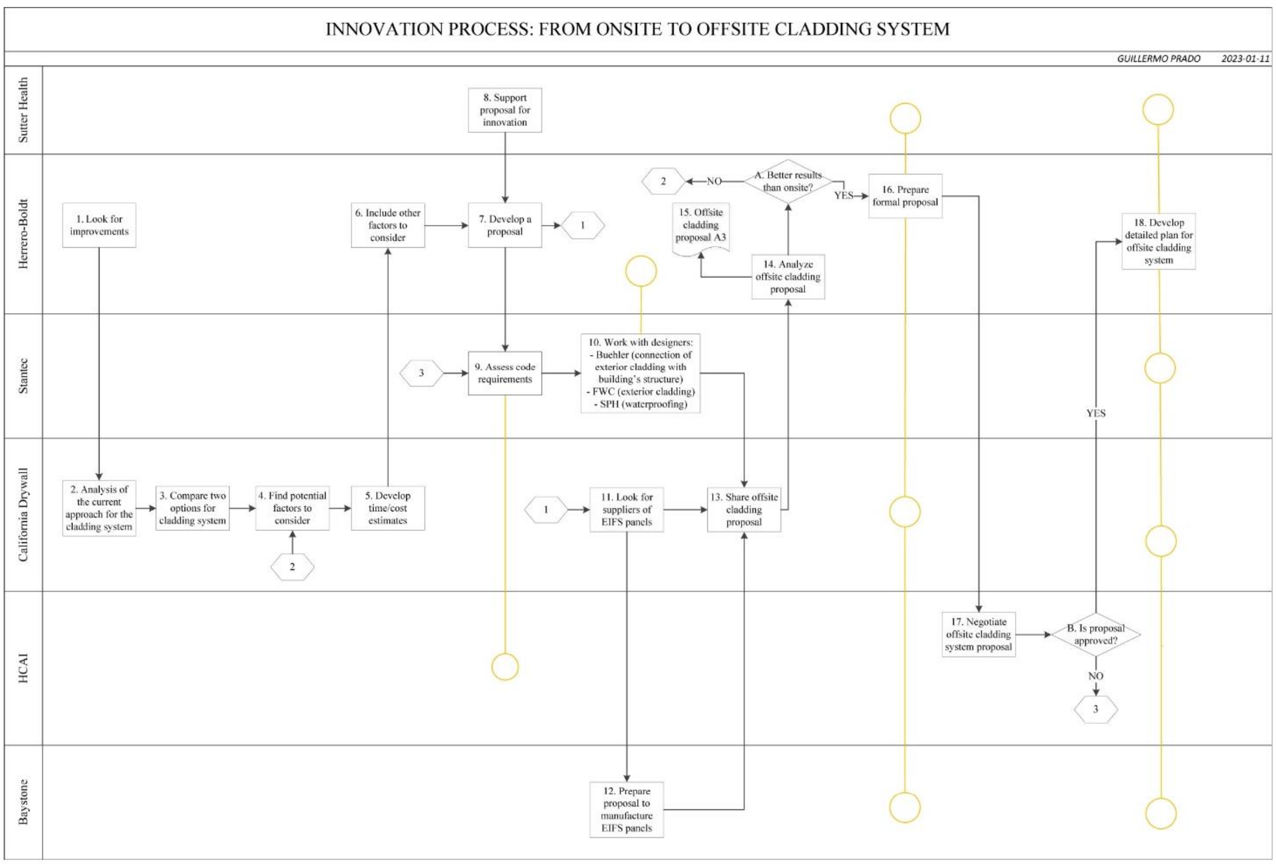
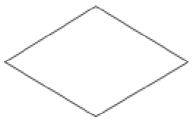
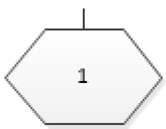
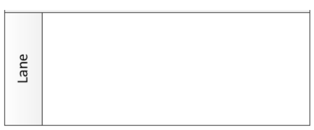


Figure 12: Innovation Process Map. Developed by Prado.

The symbols used are part of the standard for developing process maps. First, however, I explain the name and meaning of each symbol in Table 6. Then, considering Figure 12 and Table 6, I explain each step of this map.

Table 6: Symbols Used for Innovation, and Design and Coordination Processes Maps. Developed by Prado.

Symbol	Name and meaning
	Process or step: Represents an activity or work to be done. In a swim lane process map, the actors involved in the lane are those performing the process or step shown in that lane.
	Decision node: represents a decision-making event, which can result in one out of two (yes arrow [Result] or no arrow [another result]) alternative paths being followed.
	Relationship with other stakeholders: related to other stakeholders' participation in processes.
	Map connector: this symbol is not part of the process map per se but can be used to relate a part of the map to one another to avoid crossing arrows on a single page in a complex map.
	Resources (documents, information) provided or produced related to a process.
	Lane: Represents an actor, stakeholder, or party involved in the process. They perform the processes and decisions located inside this lane.
	Connector: an arrow that represents a precedence relationship

This is the explanation of the steps considered:

1. Look for improvements: HB looks for opportunities for improvement in the construction processes of the project.
2. Analysis of the current approach for the cladding system: CDC analyzes the possibility of improving the current onsite approach of the cladding system as it was proposed in the original design.
3. Compare two options for the cladding system: CDC considers an offsite approach for the cladding system to compare it against the onsite approach for this construction process.
4. Find potential factors to consider: CDC looks for factors to consider while evaluating the two approaches stated in step 3 about the cladding system.
5. Develop time/cost estimates: CDC develops time and cost estimates of the two approaches stated in step 3 as part of the evaluation.
6. Include other factors to consider: HB adds more factors to include in the analysis, including the scope of work of CDC and the project overall.
7. Develop a proposal: HB develops a proposal with the factors considered in steps 4, 5, and 6.

8. Support proposal for innovation: Sutter Health supports the innovation regarding the offsite cladding system.
9. Assess code requirements: Stantec assesses HCAI code requirements to develop a fully panelized cladding system.
10. Work with designers: Stantec works with its specialty designers to analyze the design stated in step 9. The scope of work of the designers is as follows:

- Buehler Engineering Inc. (engineering of the connection of exterior cladding to the building structure)
- FWC Structural Engineers (engineering of exterior cladding)
- SGH (waterproofing)

11. Look for suppliers of EIFS panels: CDC looks for suppliers close to the project site that can develop the EIFS components of the fully panelized cladding system.
12. Prepare a proposal to manufacture EIFS panels: Baystone develops a proposal to manufacture the fully panelized EIFS components.
13. Share offsite cladding proposal: CDC merges Baystone proposal and Stantec code analysis to provide and share a proposal for the offsite cladding system.
14. Analyze offsite cladding proposal: HB analyses the CDC proposal developed in step 13 and includes more input.
15. Offsite cladding proposal A3: HB develops the cladding system proposal in an A3 format considering the analysis provided in step 14.
A. Better results than onsite? HB assesses if the offsite cladding system provides better results than the current onsite cladding system.
16. Prepare formal proposal: HB develops a formal proposal considering the input of Sutter Health, CDC, and Baystone to implement the offsite cladding system.
17. Negotiate offsite cladding system proposal: HCAI negotiates the conditions with HB to implement the offsite cladding system.
B. Is the proposal approved? HCAI assesses if the offsite cladding system formal proposal is compliant with HCAI regulations.
18. Develop a detailed plan for the offsite cladding system: HB develops the plan for the design and execution of the offsite cladding system considering the input of Sutter Health, Stantec, CDC, and Baystone.

<u>Design and coordination processes: from onsite to offsite cladding system</u>

This process map shows the steps followed to design and coordinate the EIFS delivery onsite from Baystone's shop in Reno, NV, to the project site in Santa Rosa, CA. This swim lane process map explains how the stakeholders interact, their responsibilities in the design and coordination processes, and how the project team made decisions toward a JIT delivery of EIFS panels. I am using one process map to show design and coordination processes because the project team's approach was to consider these two processes concurrently. Therefore, I include the construction tolerances review process with the design team and concurrent inspection to accomplish the innovation. I used MS Visio to develop this map, as shown in Figure 13. A bigger version of it can be found in Appendix C. Table 6 explains the symbols considered. Considering Figure 13 and Table 6, I explain each step of this map.

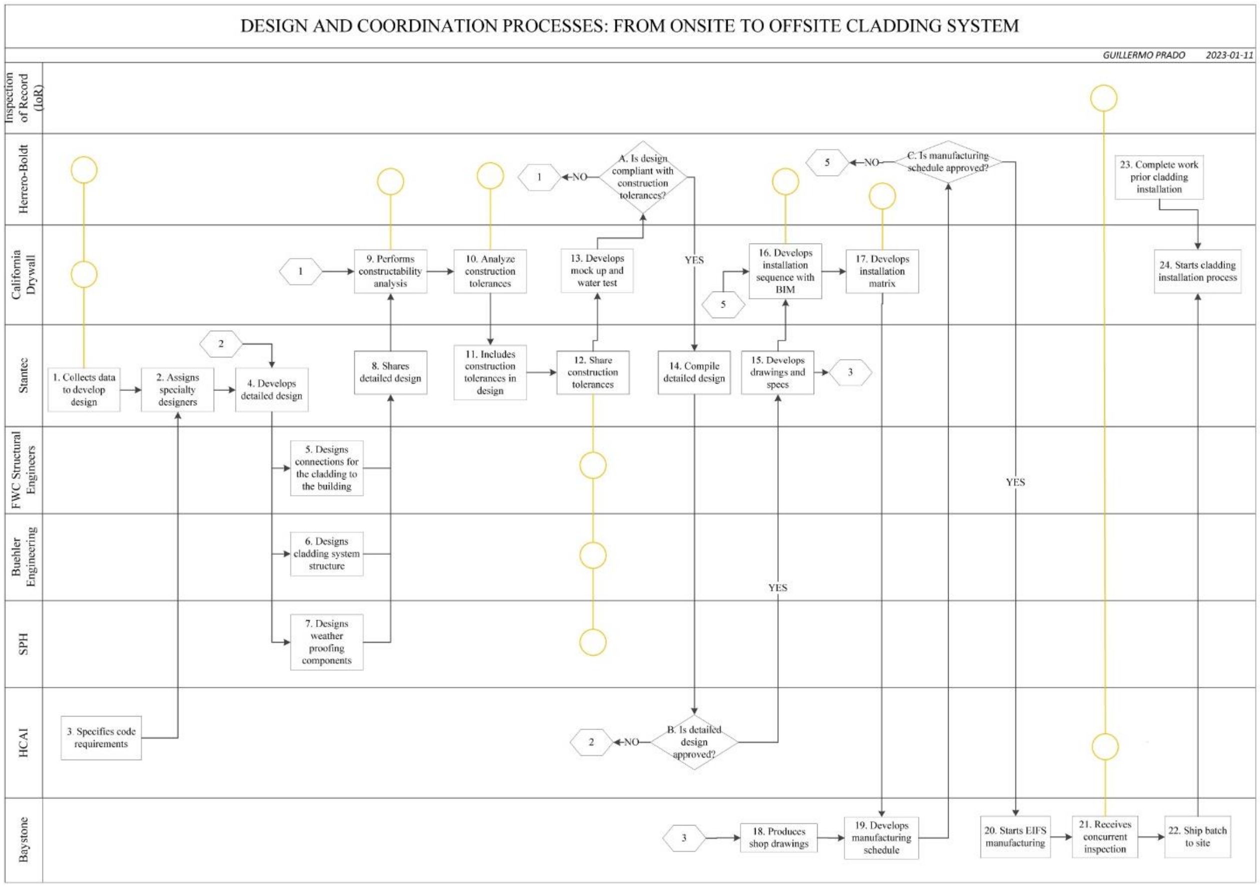


Figure 13: Design and Coordination Process Map. Developed by Prado.

This is the explanation of the steps considered:

1. Collects data to develop design: Stantec collects data from CDC and HB to develop the detailed design after the approval of the preliminary design for the offsite cladding system.
2. Assigns specialty designers: Stantec looks for specialty designers to assign individual pieces of work to complete the new design.
3. Specifies code requirements: HCAI provides the specific code requirements that Stantec's new design must comply with.
4. Develops detailed design: Stantec develops the detailed design with all the systems that are changing because of the offsite cladding system.
5. Designs connections for the cladding to the building: FWC Structural Engineers design the structural connections between the cladding system and the structure of the building.
6. Designs cladding system structure: Buehler Engineering designs the structure of the cladding system (the framing).
7. Designs weatherproofing components: SPH designs the weatherproofing components of the offsite cladding system.
8. Shares detailed design: Stantec receives the designs of 5, 6, and 7 to merge them with the piece of design in charge of Stantec to share it with CDC.
9. Performs constructability analysis: CDC evaluates the constructability of the design provided in 8.
10. Analyze construction tolerances: CDC evaluates if the construction tolerances are included in the design provided in 8.

11. Includes construction tolerances in design: Stantec includes in the detailed design the construction tolerances provided in 10.
12. Share construction tolerances: Stantec shares the construction tolerances included in 11 with the other designers (FWC Structural Engineers, Buehler Engineering, and SPH).
13. Develops mock up and water test: CDC develops the mock up of the cladding system to analyze the final product and the installation process, as well as the waterproofing test.
A. Is the design compliant with construction tolerances? HB assesses if the detailed design provided in 11 and 12 includes the tolerances guidelines for construction purposes.
14. Compile detailed design: Stantec compiles the design, including the construction tolerances elements and their impact on other systems.
B. Is the detailed design approved? HCAI evaluates if the design provided in 13 is compliant with the respective regulation.
15. Develops drawings and specs: Stantec develops drawings and specifications after HCAI approves the detailed design.
16. Develops installation sequence with BIM: CDC uses BIM models to indicate the order of the EIFS panels to install, which are unique panels for each location.
17. Develops installation matrix: CDC develops the installation matrix using the input of 16 to indicate the batches of EIFS panels erection considering the restrictions of the project site.
18. Produces shop drawings: Baystone uses the input of 15 to develop show drawings for the EIFS panels.
19. Develops manufacturing schedule: Using the input of 17, Baystone develops a manufacturing schedule to comply with the order established in 18.
C. Is the manufacturing schedule approved? HB assesses if the input of 19 follows the same order as the project's schedule.
20. Starts EIFS manufacturing: Baystone starts EIFS manufacturing using the input of 19.
21. Receives concurrent inspection: Baystone receives concurrent feedback and inspection from the inspector of record (IoR) and HCAI during the manufacturing and offsite assembling processes of the EIFS panels.
22. Ship batch to site: Baystone ships the EIFS panels in the batches produced in 21.
23. Complete work prior to cladding installation: HB completes the work in the other systems of the project to perform the cladding system installation.
24. Starts cladding installation process: CDC starts the cladding system installation after 23 finishes.

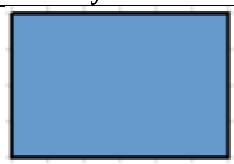
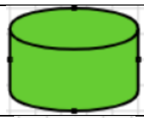
These two swim lane process maps explain the general context of the innovation. Then, I use them to develop a process map and an analytical model of the production system of the installation of the façade. Finally, with this model, I analyze the impact of PSD on project performance using an OS lens to apply the framework explained in CHAPTER 3.

4.3.2 OS Data of the Production System

I develop the production process map of the installation of the cladding system. This process map is the baseline for developing a production model that will show this process's production metrics (WIP, CT, TH, u). To create this process map, I used PPI Process Mapper provided by SPS/PPI (Georgy, 2019). Figure 14 shows this process map, and a big version of it is shown in Appendix D. Table 7 explains the symbols used in this map.

Figure 14: Production Process Map. Developed by Prado.

Table 7: Symbols Used in the Production Process Map. Developed by Prado.

Symbol	Name and meaning
	Production process (or steps or operations): This represents the production process, which will transform the “inputs” into “outputs” based on the data considered for each process. Blue boxes represent production processes, and orange boxes represent inspection production processes.
	Stock: Represents any resources ready to be used, such as raw materials, space, or outputs from previous production processes.
	Queues: Represents the inventories between each of the processes and stocks.
	Connector: The arrow represents a precedence relationship.

In this process map, I am assuming that:

- There are no decisions made during the production process.
- There are “inspections” that are part of the production process.

This is the explanation of the steps considered (I am not including either the stocks or the queues):
1. Prepare space: The crew in the project site prepares the space in the building and the storage area of the site to receive the truck with the EIFS panels.
2. Transport EIFS: Baystone ships the batch of EIFS panels to the project site.
3. Store EIFS: The crew receives and stores the EIFS panels of 2.
4. Inspect 1 EIFS: The IoR inspects the EIFS panels received in 3.
5. Truck Changeover: The truck moves from one location to another to give more space for the next truck arriving with more materials.
6. Hoist EIFS: The EIFS installation crew uses a crane to hoist the EIFS panels to start the installation process.
7. Place EIFS: The EIFS installation crew places the EIFS hoisted in 6 to the final location using the installation matrix that CDC developed.
8. Attach EIFS: EIFS installation crew attaches the EIFS panels’ framework to the building structure using hooks.
9. Inspect 2 EIFS: The IoR inspects the EIFS panel installed in its specific location.
10. Approve EIFS: After inspecting the EIFS panels installed, the IoR approves them.
11. Transport windows: The window supplier ships the batch of windows to the project site.
12. Store windows: The crew receives and stores the windows of 11.
13. Inspect 1 windows: The IoR inspects the windows received in 12.
14. Align windows: The windows installation crew uses the openings between the EIFS panels installed to place and align the windows.

15. Attach windows: The windows installation crew attaches the window to the EIFS panels installed using hooks in the borders of the windows.
16. Inspect 2 windows: The IoR inspects the windows installed in their specific locations.
17. Approve windows: After inspecting the windows installed, the IoR approves them.
18. Ship on site caulking 1: A crew member ships caulking materials from the site warehouse to the building elevation.
19. Prepare area for caulking: The caulking crew cleans and prepares the area to do the caulking between the cladding system's elements.
20. Caulk EIFS and windows: The caulking crew to the caulking between the EIFS panels and the windows.
21. Inspect caulking 1: The IoR inspects the caulking developed between the EIFS panels and windows.
22. Approve caulking 1: After inspecting the caulking between the EIFS panels and windows, the IoR approves it.

Considering this process map and the data gathered from the project team, I developed an analytical model that allows using the OS metrics, graphs, and equations to understand how the production system behaves. As I explained in section 3.2.3, I used Production Optimizer ®, an analytical model simulation software provided by SPS/PPI. Furthermore, I had training sessions with SPS engineers to learn how to use this software during the case study development. Based on the training sessions and the methods used by SPS engineers, I am making the following assumptions to model this production system:

1. I use SCV as a measure of the variability in the system: Based on SPS' Production Optimizer, the SCV values considered can be: SCV=0.5 for a low variability environment, SCV=1.0 for a medium variability environment, and SCV=1.5 for a high variability environment. These values are part of the practice of SPS engineers.
2. The PR/PT parameters have a normal distribution: This allows me to consider the SCV a relatively accurate variability metric.
3. This is a steady state system with no "warm-up" phase: The purpose of the analytical model is to provide results under this assumption.
4. The matching problem has been addressed through detailed coordination between the project team parties: As explained in section 4.3.1, the project team acted before the beginning of the installation of the cladding system. These actions allowed them to have "zero" matching problems. Therefore, the analytical model does not consider matching problems. Appendix A shows the sequencing matrixes developed between the project team members to control this potential issue.
5. There is no rework between the operations: Thanks to the coordination described in point 4 and the dry runs the project team did, there was no rework in the construction process, and I did not consider rework on the model.
6. The resources work on the operations serially. The resources are working in each step at a time, which are organized serially.

Figure 15 shows the process of developing the analytical model, considering the assumptions made. The model's outcome is the results sheet with OS metrics and graphs.

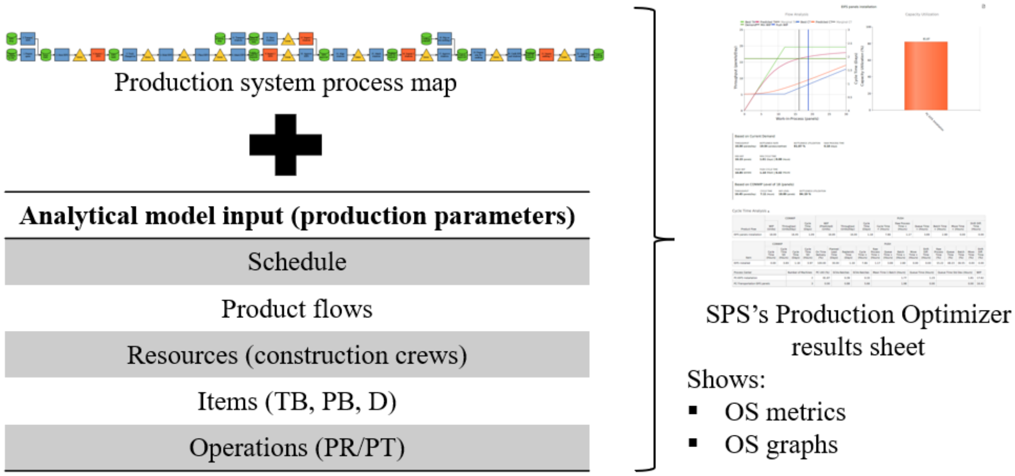


Figure 15: Process to Develop the Analytical Model. Developed by Prado.

To construct this production model, I included this input:

- Schedule: the hours of work per week.
- Product flow: the units in which the production system analyzes the OS metrics. Each production system can have more than one product flow.
- Resources: people and equipment of each construction crew involved in the production system. These are the executors of the operations. If the construction crew involves only people, then the executor is a "work group," and if the crew also uses equipment, then it is a "process center."
- Item: the products that are transformed throughout the production system. Each stock is the end of the current item and the beginning of the new one downstream.
- Routing: the production streams between two stocks. Each one is associated with one item.
- Operation: Table 7 provides its definition. Also, each operation has a PR or PT, depending on the time it takes for the construction crew's resources to complete the operation. Here I use the SCV to input variability in the system.

Figure 16 shows the allocation of production flows and resources in the production system process map. Each product flow is assigned a resource (work group or a process center). The results sheet of Production Optimizer provides OS metrics and graphs for each pair of product flow and resource.

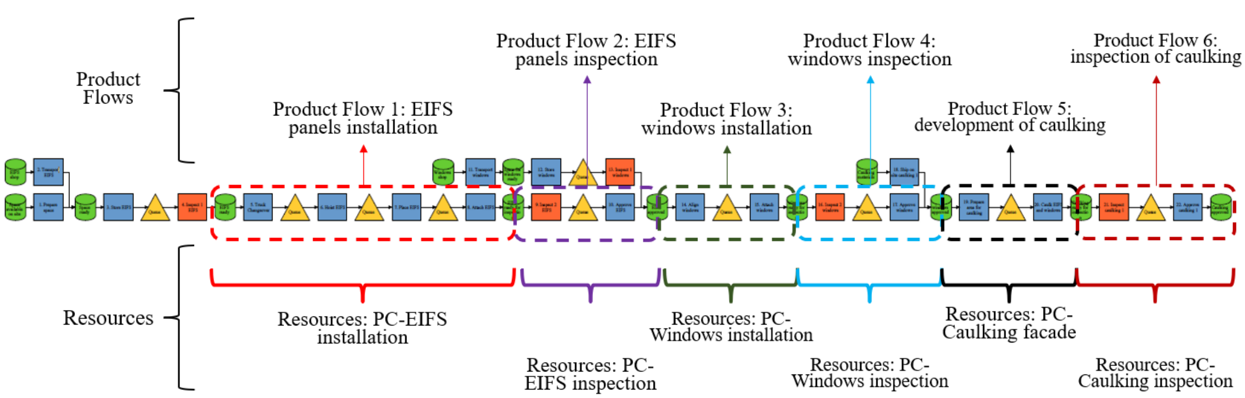


Figure 16: Product Flows and Resources of the Analytical Model. Developed by Prado.

I included the production-related parameters related to operations (PR or PT) and items (PB, TB, D). To input these parameters, I analyzed, processed, and translated the data collected to assume reasonable values of these production parameters. These are the parameters considered:

- TB: I assumed the number of items to finish and then transferred them to the next step of operation in the production system.
- PB: considering that the construction crew can produce a fixed number of EIFS installations per day, I used that value to determine the PB of the items.
- D: the schedule of the process provided the "demand" of EIFS installed per day, which is the value of D. I followed a similar process with the other items.
- PR or PT: these are the times that the construction crews take to produce the operations of the process. This can be a rate per unit (PR) or a time for the complete batch (PT). I collected these onsite data considering the SCV, which I assumed to be SCV=1.5 for almost all the operations.

Table 8 shows the parameters considered for the operations of the production system.

Table 8: Production System's Operations Parameters. Developed by Prado.

#	Steps (operations)	Units processed	PR [units/hour]	PT [hour]
1	Prepare space	Space for an EIFS panel	20.00	
2	Transport EIFS	Truck		6.00
3	Store EIFS	Truck		0.17
4	Inspect 1 EIFS	EIFS panel		1.00
5	Truck changeover	Truck		0.50
6	Hoist EIFS	EIFS panel	7.00	
7	Place EIFS	EIFS panel	7.00	
8	Attach EIFS	EIFS panel	3.50	
9	Inspect 2 EIFS	EIFS panel		4.00
10	Approve EIFS	EIFS panel		1.00
11	Transport windows	Truck		8.00
12	Store windows	Window		0.17
13	Inspect 1 windows	Window		1.00
14	Align windows	Window	1.00	
15	Attach windows	Window	3.00	
16	Inspect 2 windows	Window		4.00
17	Approve windows	Window		1.00
18	Ship on site caulking 1	Caulking material		0.17
19	Prepare area for caulking	Caulking material	6.00	
20	Caulk EIFS and windows	Window	3.00	
21	Inspect caulking 1	Window		4.00
22	Approve caulking 1	Window		1.00

Table 9 shows the parameters considered for the items of the production system. Item 4 was the most important one since its demand determined the demand for the other items.

Table 9: Production System's Items Parameters. Developed by Prado.

#	Items	Units	TB [units]	PB [units]	D [units/week]
1	Space available for panels	Panels	8	40	80
2	EIFS panels	Panels	12	12	80
3	EIFS stored on site	Panels	12	12	80
4	EIFS installed	Panels	1	8	80
5	EIFS inspected	Panels	61	61	200
6	Windows	Window	10	10	30
7	Windows stored on site	Window	10	10	30
8	Windows installed	Window	1	5	20
9	Windows inspected	Window	12	12	30
10	Caulking 1 materials	Package	1	1	30
11	EIFS and windows caulked 1	Window	1	5	30
12	EIFS, windows and caulking 1 inspected	Window	13	13	60

Since the product flows are the units of analysis, Table 10 shows the product flows created for this production system.

Table 10: Production System's Product Flows. Developed by Prado.

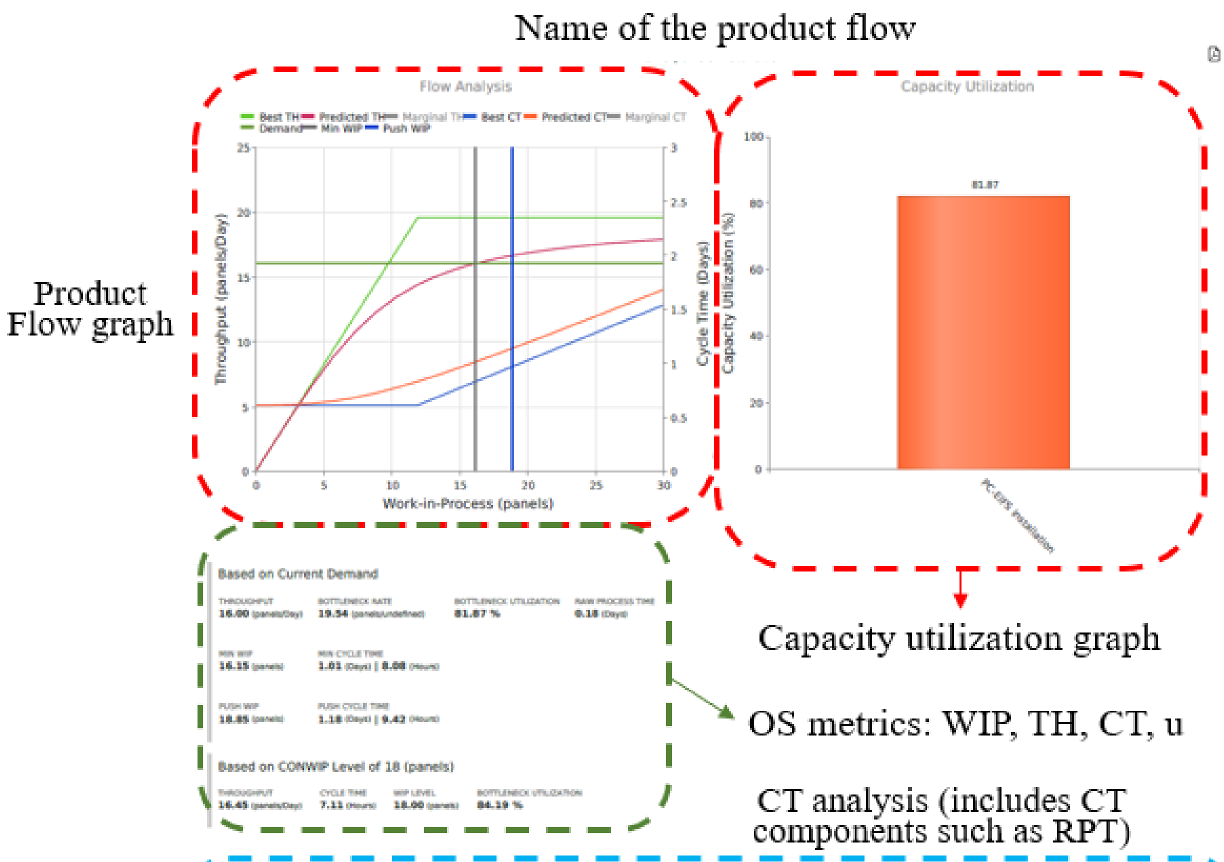
#	Name	Units of measure
1	EIFS panels installation	panels
2	EIFS panels inspection	panels
3	Windows installation	windows
4	Windows inspection	windows
5	Development of caulking	windows
6	Inspection of caulking	windows

I provide the details of all components of the input of the analytical model in Appendix E.

4.4 RESULTS

4.4.1 OS Equations and Graphs

From the three equations and four graphs shown in 2.3, the scope of this case study included using Little's law and the capacity utilization graph to describe the behavior of CT, TH, WIP, and u (of the resources). SPS' Production Optimizer provided the results sheet for each product flow analyzed. Figure 17 shows the data I extracted from the results sheets to apply the OS analysis. I used the product flow and capacity utilization graphs only to see the behavior of the OS metrics involved. Moreover, the data I used for the OS analysis are in the OS metrics and CT components sections shown in Figure 17. Appendix F shows the complete results sheet of all the product flows considered for this first run of the model.



	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	16.45	1.09	18.85	16.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	3.69	1.18	3.97	100.00	30.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00	15.22	48.23	36.55	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	81.87	0.39	0.33	1.77	1.23	1.81	17.62
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	16.41

Figure 17: Result Sheet of the EIFS Panels Installation Product Flow. Developed by Prado.

The product flow graph section of Figure 17 shows the TH of the production system, which can produce more than 16 EIFS panels/day (D). The intersection between the "Demand" and the "Predicted TH" (which considers the effect on variability in the TH) lines provides the "MINWIP" vertical line. MINWIP shows the minimum amount of WIP required to satisfy D. Similarly; the software algorithms calculate the vertical line "Push WIP," which shows the amount of WIP that works under a push production system. The OS metrics section of Figure 17 also shows the results (TH, WIP, CT, u) with a CONWIP, if established for that specific product flow. Ideally, the CONWIP established to control the production system should be between these MINWIP and Push WIP vertical lines.

In the case of the EIFS panels installation, the CONWIP can be between 17 to 19 EIFS panels to control WIP in the system and still satisfy the demand. Regarding the CT, Figure 17 shows that increasing the WIP of the system also increases the CT ("Predicted CT" line) to produce that specific TB. This is the tradeoff between deciding to have a more significant CONWIP signal and a larger CT or a shorter CONWIP signal that comes with a faster CT. The CT analysis section of Figure 17 compares the OS metrics under two scenarios, the CONWIP of 18 EIFS panels and the Push system. This section shows the components of CT in terms of RPT, queue time, batch time, move time, and shift time, all of them expressed in hours. I am only considering values in RPT and queue time for this case study.

Considering the u of the resources (work groups and process enters) is also part of the OS analysis. Figure 18 shows the capacity utilization of all the process centers (resources) used in the production system model. The process center of the EIFS installation (which is the one that corresponds to the EIFS panels installation product flow) shows a u of 81.87%. Since this u is not too close to 100%, it allows the production system to control production and avoids a peak in CT. This OS metric (u), alongside TH, CT, and WIP, helps to understand if the production system can afford more WIP, which will affect the u and CT. Based on the VUT equation, if there is a higher u in the system, CT can go to infinite. Figure 18 also provides an idea of the "bottleneck" of the production system. The bottleneck is the resource with the highest u, which is the PC-Windows Installation resource for this production system, related to Windows Installation Product Flow. The potential improvement points are the resources with lower u, as they can share their capacity with other activities.

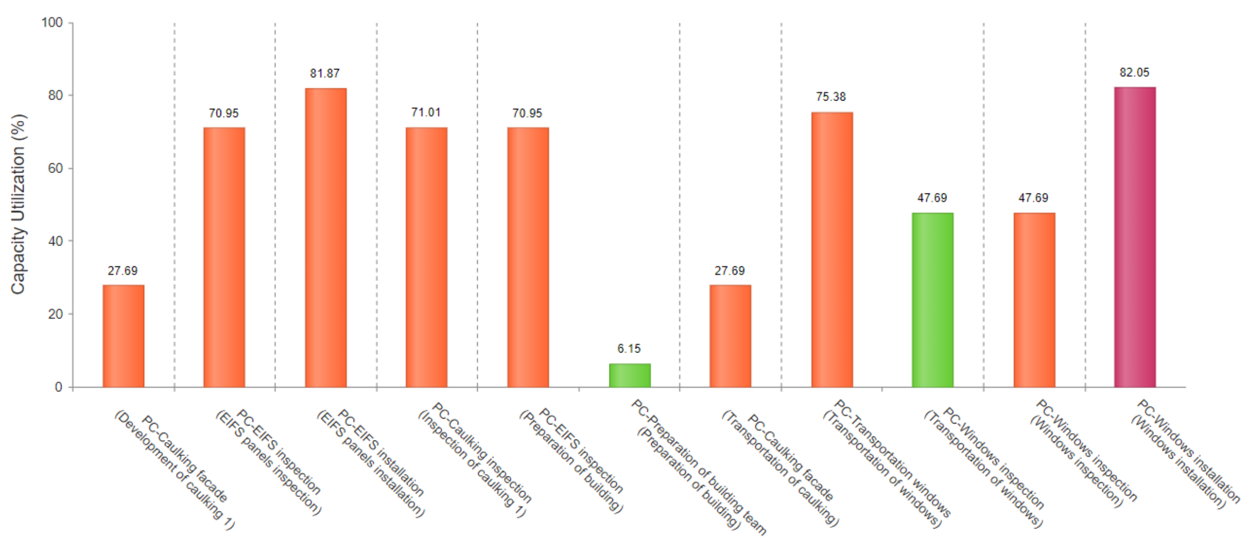


Figure 18: Capacity Utilization of the Resources of the Production System. Developed by Prado.

4.4.2 OS Metrics and PM Metrics

The intuition developed in 3.3 helps to understand how OS metrics impact PM metrics. Therefore, I can calculate PM metrics for the construction process by having a set of OS metrics for a product flow. Considering this case study, I use CT to determine the duration of the construction process that encompasses the production flow I am analyzing. In other words, CT (a result of WIP, TH, and u) can impact the calculation of the PM metric time. Equation 7 shows this relationship using CT component raw process time, TH, and the total EIFS panels to install (n). Based on PPI (2022), RPT is the summation of the average time required to process the first transfer batch, including all detractors, such as downtime and setup time. It does not include queue time or the time blocked when a downstream station has no queue space.

$$Time\ (duration) = RPT + (n - TB)/TH \text{ (Equation 7)}$$

Using the results of Figure 16 and equation 7, I determine the duration of the construction process under the PUSH system scenario. These are the numbers considered:

- RPT: 0.18 days
- n: 243 EIFS panels
- TB: 1 EIFS panels
- TH 16 EIFS panels/day

Using these values, I obtain the following calculation:

$$Duration\ of\ EIFS\ panels\ installation = 0.18\ (days) + \frac{243 - 1}{16}(days) = \ 15.31\ days$$

This result shows the impact of PSD on project performance considering the PM metric time. Considering this impact, I can extend it to how this time change can impact cost, another PM metric. Due to the time change, I can require days of resources and the construction crew to work this additional or less time. Therefore, there is a “chain effect” that makes any set of OS metrics affect time, and time will affect the cost of the construction process due to more resources required. Equation 8 shows the cost change only for the construction process change of time. I used the duration of the first run as a baseline to calculate the impact on cost due to a new process duration.

$$Cost\ change\ (\%) = \frac{New\ process\ duration}{Baseline\ process\ duration}\ X\ 100\% \text{ (Equation 8)}$$

I will use the results shown in Figure 16 to provide an example of how to apply equation 8. In Figure 16, I considered a CONWIP of 18 EIFS panels for the EIFS installation product flow. The results under the CONWIP (18) scenario are in the OS metrics section. These are the numbers considered:

- RPT: 0.18 days
- n: 243 EIFS panels
- TB: 1 EIFS panels
- TH 16.45 EIFS panels/day

Using these values, and equation 7 I obtain the following calculation for the CONWIP scenario:

$$Duration\ of\ EIFS\ panels\ installation = 0.18\ (days) + \frac{243-1}{16.45}(days) = \ 14.89\ days$$

Considering this new process duration, I apply equation 8 to calculate the change in cost. These are the numbers considered:

- New process duration: 15.27 days
- Baseline process duration: 14.85 days

Using these values, I obtain the following calculation:

$$Cost\ change\ (\%) = \frac{14.85\ days}{15.27\ days}\ X\ 100\% = 97\%$$

This result shows the impact of PSD on project performance considering the metric cost. The two results showed how OS metrics provide a better understanding of the relationship between PSD and project performance. Using OS metrics to calculate the process's duration shows the impact of designing the production system to match the demand established in the project schedule. These results also show the positive implications of using CONWIP systems as it takes shorter durations (0.41 days less) to complete the process, and this potentially causes less cost (3% reduction). To rationalize the impact of CONWIP, I will run the model with five scenarios:

- CONWIP scenarios: {CW16, CW17, CW18, CW19, CW20}, which are related to CONWIP systems of {16, 17, 18, 19, 20} EIFS panels, respectively.

Table 11 shows the OS and PM metrics using the PUSH system as a baseline to compare the results of the 5 CONWIP systems. I used equations 7 and 8 to calculate these results. The results sheets of these runs are in Appendix G.

Table 11: OS Metrics and PM Metrics of the EIFS Panels Installation Product Flow. Developed by Prado.

	OS metrics					PM metrics	
Type of system	**WIP [panels]**	**CT [days]**	**RPT [days]**	**TH [panels/day]**	**u [%]**	**Duration [days]**	**Cost [%]**
PUSH	18.85	1.18	0.18	16.00	81.87	15.31	100%
CONWIP 16	16.00	1.00	0.18	15.96	81.68	15.34	100%
CONWIP 17	17.00	1.05	0.18	16.22	83.01	15.10	99%
CONWIP 18	18.00	1.09	0.18	16.45	84.19	14.89	97%
CONWIP 19	19.00	1.14	0.18	16.65	85.21	14.71	96%
CONWIP 20	20.00	1.19	0.18	16.83	86.13	14.56	95%

The results of Table 11 show the benefits of using CONWIP systems as a mechanism to control as part of PSD. These benefits are shown on the PM metrics cost (variation of cost) and time (duration). I followed a similar process to find the PM metrics of the other five product flows considered in this model. Using equation 7, I calculated the durations of each product flow. Table 12 shows these calculations, and I included a column called "real duration." This column indicates the durations stated by the project team members, which I used to verify that the models' results resembled what happened in the project. I included the results sheets of these product flows in Appendix F. In Table 12, I am not considering the PM metric cost because for the other product flows there is no CONWIP signal established.

Table 12: OS Metrics and PM Metrics of the Production System's Product Flows. Developed by Prado.

	OS metrics					PM metrics
Product Flow	**WIP [units]**	**TH [units/day]**	**u [%]**	**CT [days]**	**RPT [days]**	**Duration [days]**
EIFS panels installation	18.85	16.00	81.87	1.18	0.15	15.27
EIFS panels inspection	116.88	40.00	70.95	2.92	0.63	5.20
Windows installation	8.22	4.00	82.05	2.06	0.17	12.42
Windows inspection	10.46	6.00	47.69	1.74	0.63	6.96
Development of caulking 1	1.52	6.00	27.69	0.25	0.06	8.23
Inspection of caulking 1	41.75	12.00	71.01	3.48	0.63	3.79

Considering the results in Table 12, the input was crucial for obtaining accurate values representing what happened in the construction process. Table 8 and Table 9 provide information on the production model, and if change one or more values of these tables or any of the inputs provided in Appendix E, the production model results will vary. I identified three potential components of the input that might change the results of the production model:

- The parameters of how the items are produced: PB, TB.
- The parameter of what the project schedule is requesting: D.
- The parameters of the capacity of the construction crews: PR or PT.

These three types of parameters can influence the results of the production system, generating changes in the OS and PM metrics.

4.4.3 Sensitivity Analysis

<u>Demand sensitivity analysis</u>

The parameters related to how the items are produced (PB, TB) are associated with the number of units the construction crew can produce daily. The project team did not record this information directly from the surveys onsite, so I had to interpret the information available to obtain the values of PB and TB. The parameter related to the project schedule (D) is easy to change since this is a decision the project team can take regarding the project objectives. This change affects the construction processes upstream and downstream of the cladding system installation process. The parameters related to the capacity of the construction crews can change freely, which are influenced by weather, labor strikes, and other onsite conditions. Considering the nature of these parameters, I will use D as the parameter to "change" in a structured way, so I can provide a better understanding of how the production system changes under a different D, how the OS metrics change, and how this change impacts the PM metrics.

Based on the conversations with the project team, the objective of the offsite cladding system was to install 8 EIFS panels a day (40 per week). And, after completing the mockup, they realized that the construction crew could install 16 EIFS a day on average (the actual input of the production model). Considering this change in the demand, I will use the integer values between 8 and 16 EIFS panels as the parameter D to develop the sensitivity analysis. Therefore, the values of D in units installed per day will be D [units/day]: {8, 9, 10, 11, 12, 13, 14, 15, 16, 17 18, 19, 20}. I will multiply these values by five to obtain the respective demand per week D [units/week]: {40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100}. These last sets of values are the demands I will use for each of the "runs" of the sensitivity analysis. These are the values of D of EIFS panels installation:

- Demand sensitivity runs: {A2, A3, A4, A5, A6, A7, A8, A9, BL, B2, B3, B4, B5}, which are related to these demands: {8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20} of EIFS panels installation respectively.

The change in parameter D will be consistent throughout all the items of the production system. I am assuming all the changes in the demand are based on the first run I did, which I called run baseline (BL) for this analysis. The parameters TB, PB, PR, or PT will remain the same, as I assume each of the production system's parameters is independent of the others. Table 13 shows the input for each of the production system's items for the nine sensitivity analysis runs.

Table 13: Demands of the Items of the Nine Runs of the Sensitivity Analysis. Developed by Prado.

			[units]		**Demands (D) on each run [units/week]**												
	Items	**Units**	**TB**	**PB**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**BL**	**B2**	**B3**	**B4**	**B5**
1	Space available for panels	Panels	8	40	40	45	50	55	60	65	70	75	80	85	90	95	100
2	EIFS panels	Panels	12	12	40	45	50	55	60	65	70	75	80	85	90	95	100
3	EIFS stored on site	Panels	12	12	40	45	50	55	60	65	70	75	80	85	90	95	100
4	EIFS installed	Panels	1	16	40	45	50	55	60	65	70	75	80	85	90	95	100
5	EIFS inspected	Panels	61	61	100	113	125	138	150	163	175	188	200	213	225	238	250
6	Windows	Window	10	10	15	17	19	21	23	24	26	28	30	32	34	36	38
7	Windows stored on site	Window	10	10	15	17	19	21	23	24	26	28	30	32	34	36	38
8	Windows installed	Window	1	5	10	11	13	14	15	16	18	19	20	21	23	24	25
9	Windows inspected	Window	12	12	15	17	19	21	23	24	26	28	30	32	34	36	38
10	Caulking 1 materials	Package	1	1	15	17	19	21	23	24	26	28	30	32	34	36	38
11	EIFS and windows caulked 1	Window	1	5	15	17	19	21	23	24	26	28	30	32	34	36	38
12	EIFS, windows and caulking 1 inspected	Window	13	13	30	34	38	41	45	49	53	56	60	64	68	71	75

Considering the values of Table 13, I conducted the production system analysis in Production Optimizer to find the respective OS metrics for each run and then applied the same logic in Table 12 to find the respective PM metrics. Table 14 shows the results (in terms of OS metrics and PM metrics) of the thirteen runs of this sensitivity analysis, which shows the principal parameter (D of EIFS panels installation) in green and how it changes in each run of this analysis. The detailed results sheets of all the runs are part of Appendix H.

Table 14: Demand Sensitivity Analysis Results. Developed by Prado.

		Runs												
Product Flow	**OS/PM metric**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**BL**	**B2**	**B3**	**B4**	**B5**
EIFS panels installation	**WIP [units]**	5.61	6.54	7.58	8.74	10.06	11.59	13.42	15.71	18.85	23.95	35.95	93.73	INF.
	TH [units/day]	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00
	u [%]	40.93	46.05	51.17	56.28	61.40	66.52	71.63	76.75	81.87	86.98	92.10	97.22	102.34
	CT [days]	0.70	0.73	0.76	0.79	0.84	0.89	0.96	1.05	1.18	1.41	2.00	4.93	INF.
	Duration [days]	30.40	27.04	24.35	22.15	20.31	18.76	17.43	16.28	15.27	14.38	13.59	12.88	INF.
	Cost [%]	1.99	1.77	1.59	1.45	1.33	1.23	1.14	1.07	1.00	0.94	0.89	0.84	-
EIFS panels inspection	**WIP [units]**	25.85	31.67	37.93	45.84	54.54	65.80	78.63	95.93	116.88	147.30	188.34	257.40	374.29
	TH [units/day]	20.00	22.60	25.00	27.60	30.00	32.60	35.00	37.60	40.00	42.60	45.00	47.60	50.00
	u [%]	35.48	40.04	44.35	48.91	53.22	57.78	62.08	66.65	70.95	75.51	79.82	84.38	88.69
	CT [days]	1.29	1.40	1.52	1.66	1.82	2.02	2.25	2.55	2.92	3.46	4.19	5.41	7.49
	Duration [days]	9.78	8.72	7.95	7.26	6.73	6.24	5.85	5.49	5.20	4.92	4.69	4.47	4.29
	Cost [%]	1.88	1.68	1.53	1.40	1.29	1.20	1.13	1.06	1.00	0.95	0.90	0.86	0.82
Windows installation	**WIP [units]**	2.03	2.34	3.05	3.46	3.91	4.44	5.81	6.80	8.22	10.51	25.77	96.79	INF.
	TH [units/day]	2.00	2.20	2.60	2.80	3.00	3.20	3.60	3.80	4.00	4.20	4.60	4.80	5.00
	u [%]	41.03	45.13	53.33	57.44	61.54	65.64	73.85	77.95	82.05	86.15	94.36	98.46	102.56
	CT [days]	1.02	1.06	1.17	1.23	1.30	1.39	1.61	1.79	2.06	2.50	5.60	20.16	INF.
	Duration [days]	24.67	22.44	19.01	17.67	16.50	15.48	13.78	13.06	12.42	11.83	10.82	10.37	INF.
	Cost [%]	1.99	1.81	1.53	1.42	1.33	1.25	1.11	1.05	1.00	0.95	0.87	0.84	-
Windows inspection	**WIP [units]**	3.31	3.96	4.67	5.47	6.36	6.85	7.90	9.10	10.46	12.02	13.82	15.93	18.42
	TH [units/day]	3.00	3.40	3.80	4.20	4.60	4.80	5.20	5.60	6.00	6.40	6.80	7.20	7.60
	u [%]	23.85	27.03	30.21	33.38	36.56	38.15	41.33	44.51	47.69	50.87	54.05	57.23	60.41
	CT [days]	1.10	1.16	1.23	1.30	1.38	1.43	1.52	1.62	1.74	1.88	2.03	2.21	2.42
	Duration [days]	13.29	11.80	10.63	9.67	8.89	8.54	7.93	7.41	6.96	6.56	6.21	5.90	5.63
	Cost [%]	1.91	1.70	1.53	1.39	1.28	1.23	1.14	1.07	1.00	0.94	0.89	0.85	0.81
Development of caulking 1	**WIP [units]**	0.73	0.83	0.93	1.04	1.14	1.09	1.30	1.41	1.52	1.64	1.75	1.87	2.00
	TH [units/day]	3.00	3.40	3.80	4.20	4.60	4.40	5.20	5.60	6.00	6.40	6.80	7.20	7.60
	u [%]	13.85	15.69	17.54	19.38	21.23	20.62	24.00	25.85	27.69	29.54	31.38	33.23	35.08
	CT [days]	0.24	0.24	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.26	0.26	0.26	0.26
	Duration [days]	16.40	14.47	12.96	11.73	10.71	11.20	9.49	8.81	8.23	7.72	7.27	6.87	6.51
	Cost [%]	1.99	1.76	1.57	1.43	1.30	1.36	1.15	1.07	1.00	0.94	0.88	0.83	0.79
Inspection of caulking 1	**WIP [units]**	8.33	10.36	12.77	14.90	18.28	22.48	27.83	32.90	41.75	54.33	73.46	95.68	148.10
	TH [units/day]	6.00	6.80	7.60	8.20	9.00	9.80	10.60	11.20	12.00	12.80	13.60	14.20	15.00
	u [%]	35.50	40.24	44.97	48.52	53.25	57.99	62.72	66.27	71.01	75.74	80.47	84.02	88.76
	CT [days]	1.39	1.52	1.68	1.82	2.03	2.29	2.63	2.94	3.48	4.24	5.40	6.74	9.87
	Duration [days]	6.96	6.21	5.63	5.26	4.85	4.50	4.21	4.02	3.79	3.59	3.42	3.30	3.16
	Cost [%]	1.84	1.64	1.48	1.39	1.28	1.19	1.11	1.06	1.00	0.95	0.90	0.87	0.83

In Table 14, I divided the results based on the six product flows as part of the production system analysis. The run BL (the original – in a blue cell) is the baseline for finding the impact on the cost, and I must mention that I am considering only the PUSH system of each run for this analysis. Table 14 shows the results for each of the product flows considered in this analysis, including the changes in the demand as the parameter that generates changes in OS metrics and PM metrics. Table 14 also shows scenarios with an "overdemand" that happens when D= {17 18, 19, 20}. These scenarios represent a "new challenge" to the existing production system as the objective is to understand its behavior under increasing D.

When D= {17 18, 19}, it generates that u goes extremely high, and therefore CT goes exceptionally high as well, negatively impacting the product flow duration compared with the original version of D=16. When D=20, the results show that the system cannot attend that demand as u goes over 100%, and OS metrics WIP and CT go infinite. Under this demand, the system needs a redesign to fulfill the D=20 EIFS panels/day requirement. To accomplish this demand, the production system needs to increase its capacity (which means a larger construction crew or improve PR/PT) in the bottleneck (orange cells in Table 14). Having a new capacity, the production model will provide different results in terms of OS metrics (reduced u and CT) which means that the production system can fulfill the demand. Figure 19 shows how the OS and PM metrics change due to the variation of D for the EIFS product flow.

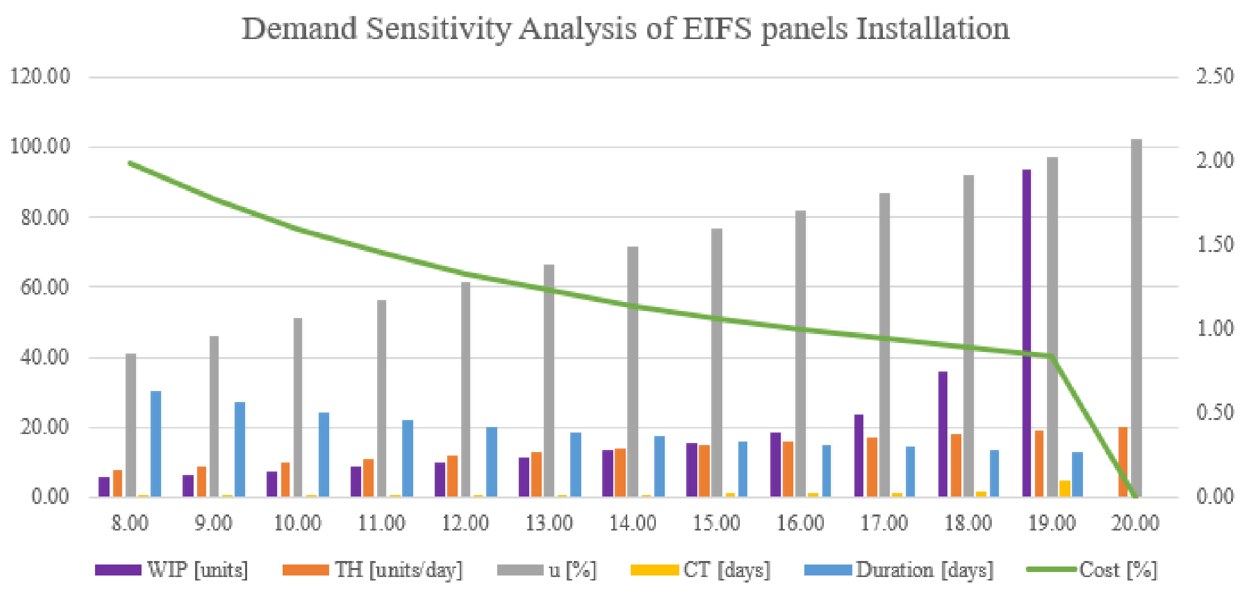


Figure 19: Changes in OS/PM Metrics Due to Variation in D. Developed by Prado.

Figure 19 has one horizontal axis, the value of D of the EIFS panels installation product flow. This figure also has two vertical axes; the left vertical axis shows the values of WIP, TH, u, CT, and Duration, which are represented as bars. The right vertical axis shows the values of cost change about the cost of D=16 (value of 1 in the right vertical axis). This analysis indicates that the production system can tolerate slightly more demand (until D=18) but cannot tolerate a D=20. The change of the variable u explains this "extra capacity" as the system increases u when there is more D. The PSD of this system also shows a buffer, which is the extra capacity described. Considering the changes of D for this analysis, the system can tolerate fluctuations of D between 8 to 18, with several considerations in terms of cost and time as the OS metrics change.

Considering the fluctuation of the OS/PM metrics due to a change in demand, the system performs properly with a D of EIFS panels installation between 15 to 17, as the u is still under 90%. Under these scenarios, the system can still perform for a more significant demand, but it will require an adjustment or redesign for D larger than 20. The results sheets of all the product flow of the sensitivity analysis are collected in 8.8.

Batch Size sensitivity analysis

Other parameters to change as part of the sensitivity analysis are TB and PB, which explain how the construction crew organizes its work and the batch sizes used for that purpose. I did four runs {C1, C2, E1, E2} changing either PB or TB to analyze how this impact the OS metrics of the product flows. Considering the parameters of run A1 as a baseline, I made the following changes in each run:

- C1 reduced TB to a half
- C2 doubled TB
- E1 reduced PB to a half
- E2 doubled PB

Table 15 shows the parameters considered for each run. Again, using the example I did on the demand sensitivity analysis, I am providing two types of results: a table with the values of OS/PM metrics for each product flow and a graph with the values of one product flow to see their changes.

Table 15: TB and PB of the Items of the Four Runs of the Sensitivity Analysis. Developed by Prado.

			C1		C2		E1		E2	
#	**Items**	**Demand**	**TB**	**PB**	**TB**	**PB**	**TB**	**PB**	**TB**	**PB**
1	Space available for panels	80	4	40	16	80	4	20	8	80
2	EIFS panels	80	6	12	24	24	6	6	12	24
3	EIFS stored on site	80	6	12	24	24	6	6	12	24
4	EIFS installed	80	1	8	2	8	1	4	1	16
5	EIFS inspected	200	30	60	122	122	30	30	61	122
6	Windows	30	5	10	20	20	5	5	10	20
7	Windows stored on site	30	5	10	20	20	5	5	10	20
8	Windows installed	20	1	5	2	6	1	3	1	10
9	Windows inspected	30	6	12	24	24	6	6	12	24
10	Caulking 1 materials	30	1	1	2	2	1	1	1	2
11	EIFS and windows caulked 1	30	1	5	2	6	1	3	1	10
12	EIFS, windows and caulking 1 inspected	60	6	12	26	26	7	7	13	26

Considering the values of Table 15, I conducted the production system analysis in Production Optimizer to find the OS metrics for each run. Table 16 shows the results (in terms of OS and PM metrics) of the four runs and the baseline (run BS) results. The detailed results sheets of all the runs are part of Appendix H. One interesting result of this sensitivity analysis section is that under a shorter CT, the duration of the process is larger than the case with a longer CT. One example of this situation is the EIFS panel inspection product flow that has:

- For BS: TH=61 and gives a duration of 5.18 days.
- For C1: TH=60 and gives a duration of 5.64 days.

Table 16: Batch Size Sensitivity Analysis Results. Developed by Prado.

		Runs				
Product Flow	**OS/PM metric**	**BL**	**C1**	**C2**	**E1**	**E2**
EIFS panels installation	**WIP [units]**	18.85	18.85	22.68	27.98	26.37
	TH [units/day]	16	16	16	16	16
	u [%]	81.87	81.87	81.87	93.41	76.1
	CT [days]	1.18	1.18	1.42	1.75	1.65
	Duration [days]	15.27	15.27	15.29	15.32	15.3
	Cost [%]	100%	100%	100%	100%	100%
EIFS panels inspection	**WIP [units]**	116.9	31.39	185.5	215.5	51.7
	TH [units/day]	40	40	40	40	40
	u [%]	70.95	46.15	60.7	92.31	35.48
	CT [days]	2.92	0.78	4.64	5.39	1.29
	Duration [days]	5.18	5.638	4.275	5.705	5.32
	Cost [%]	100%	109%	83%	110%	103%
Windows installation	**WIP [units]**	8.22	8.22	12.7	6.38	12.81
	TH [units/day]	4	4	4	4	4
	u [%]	82.05	82.05	82.05	82.05	82.05
	CT [days]	2.06	2.06	3.17	1.6	3.2
	Duration [days]	12.42	12.42	12.33	12.46	12.46
	Cost [%]	100%	100%	99%	100%	100%
Windows inspection	**WIP [units]**	10.46	3.59	19.33	6.47	6.61
	TH [units/day]	6	6	6	6	6
	u [%]	47.69	28.46	43.08	56.92	23.85
	CT [days]	1.74	0.6	3.22	1.08	1.1
	Duration [days]	6.96	7.646	5.583	7.713	7.103
	Cost [%]	100%	110%	80%	111%	102%
Development of caulking 1	**WIP [units]**	1.52	1.52	2.07	1.03	2.75
	TH [units/day]	6	6	6	6	6
	u [%]	27.69	27.69	27.69	27.69	27.69
	CT [days]	0.25	0.25	0.34	0.17	0.46
	Duration [days]	8.23	8.229	8.125	8.247	8.247
	Cost [%]	100%	100%	99%	100%	100%
Inspection of caulking 1	**WIP [units]**	41.75	8.82	83.49	17.43	16.66
	TH [units/day]	12	12	12	12	12
	u [%]	71.01	38.46	71.01	65.93	35.5
	CT [days]	3.48	0.74	6.96	1.45	1.39
	Duration [days]	3.79	3.979	3.25	3.963	3.853
	Cost [%]	100%	105%	86%	105%	102%

Since duration and cost (PM metrics) are related, the change in CT also affects cost. Since equation 7 considers only TH and RPT as the parameters, I believe that this result happens because TH remains the same for all the runs of one product flow. Since TH is a fixed value, RPT and TB are the only values that can affect the outcome of this formula. A shorter CT due to a smaller TB means a shorter RPT, but it also means that more items remain to complete after the RPT. Within the limitations of the model and the input, I found this the only logical explanation, despite that previous literature mentions that with a smaller batch size, we should obtain shorter durations (due to faster CT).

Figure 20 shows the variation of the OS/PM metrics in each of the runs of this sensitivity analysis considering the BL. I am using the EIFS panels installation as the product flow to represent the results, but that does not provide significant changes in the metrics. In fact, due to the slight change in duration between the runs, there is a minimal change in cost. In contrast, Figure 21 illustrates the same results for EIFS panels inspection product flow, showing significant differences in all OS/PM metrics.

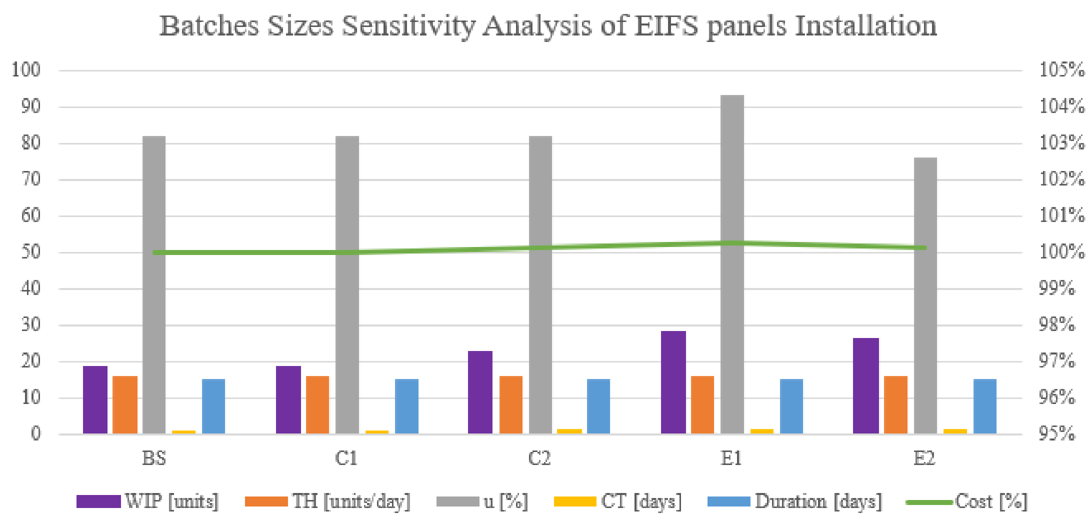


Figure 20: Changes in OS/PM Metrics Due to Variation in TB/PB of EIFS Panels Installation Product Flow. Developed by Prado.

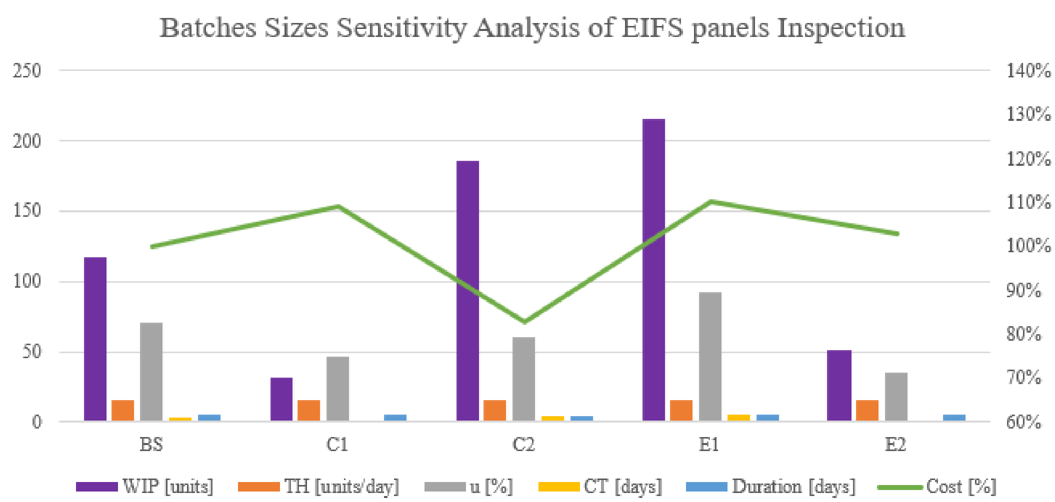


Figure 21: Changes in OS/PM Metrics Due to Variation in TB/PB of EIFS Panels Inspection Product Flow. Developed by Prado.

For Figure 20 and Figure 21, the horizontal axis shows the run code, and the graphs have two vertical axes. The left vertical axis shows the values (OS/PM metrics) as numbers in Table 16 for the metrics WIP, TH, u, CT, and duration. The right vertical axis shows the change of cost in %

as the remaining metric. Each graph shows how the metrics change due to the fluctuation of the batch's sizes (TB, PB). Moreover, comparing these two graphs also helps to see how the changes in batch sizes affect each product flow of the same production system.

4.5 Implications of the Results

4.5.1 Project-level Implications

This case study showed that OS applies to understand the impact of PSD on project performance. The numbers of the results should not be taken as fixed values because I used an analytical model, which shows the "optimal" solution with the data considered as input. However, the results related to the OS metrics of the product flows can help to guide what a project team should do regarding the process analyzed. I contrasted the model's and project's values, finding minor differences. Therefore, the model provided an appropriate approximation to understand the use of OS. Since the quality of the data is crucial for obtaining truthful results, working on data collection methods is essential to implement OS. The SSRRH project team provided data (i.e., working plans, schedules) that contained information to make assumptions about production parameters.

The metrics, graphs, and equations of OS helped to understand the relationship between PSD and project performance. OS metrics are useful for calculating PM metrics. Again, having these results as "ideal" may be helpful. Although, the "logic" of how OS metrics influence PM metrics remains for any project. Changing production parameters (under the assumptions of the analytical model) can affect OS and PM metrics. For example, the sensitivity analysis proved that the production system could install more EIFS panels. The project team mentioned that the initial rate of 8 EIFS panels/day was then replaced by 16 EIFS panels/day due to the results of the dry runs. This experience also implies that doing dry runs is essential to test the production systems created for construction processes. The fluctuations in the batch sizes are more challenging to understand as many factors can affect these changes (i.e., lack of expertise of the construction crew, lack of control, lack of materials). Although, the changes in batch sizes influence OS and PM metrics.

4.5.2 Supply Chain-level Implications

On a supply chain level, the implementation of the innovation as a team effort included not only the companies involved in the project team but also the fabricator of the EIFS panels, which was crucial for the success of this experience. Since the production system has different product flows, the coordination between the companies involved in the supply chain is essential for balancing the demands and the production rates to use. The analytical model only included onsite work, but the times and rates collected about the installation process were the results of the coordination beforehand. Because collecting data about project variability is difficult, it makes it more challenging to understand the values of variability at a supply chain level. Although, making reasonable assumptions is acceptable, as variability will impact the production system.

The sensitivity analysis showed changes in the bottleneck, which proved the need for buffers in the production system. The change in the demand showed a capacity buffer, which is crucial for attending to different orders of EIFS panels or other components per day. Since the construction process was developed by several companies, synchronizing the supply chain is fundamental to responding positively to this demand. The results show the need for finding the correct batch size that works for the supply chain, regardless of whether this happens by reducing or enlarging it.

CHAPTER 5 DISCUSSION

5.1 INTRODUCTION

In this chapter, I discuss three topics: (1) the applicability of OS in construction projects using the framework proposed in chapter three, (2) the impact of PSD on project performance using OS based on the results of the case study, and (3) the limitations of this thesis. The first topic covers the use of queueing theory as a foundation for applying OS, the complexity of using OS metrics in construction, and the data collection challenges for using the OS framework. The second topic covers the relationship between OS metrics and PM metrics, the application of OS graphs and equations, and the demand sensitivity analysis. I also comment on the assumptions made for the models created for these two topics. Finally, the third topic covers the limitations of using an analytical model, using OSC, and the delimitation of the production system to only the onsite assembly process.

5.2 APPLICATION OF OS IN CONSTRUCTION PROJECTS

To start understanding the application of OS, I used a stochastic model (from queueing theory) to understand the impact of variability on construction projects. To construct this model, I assumed that arrival and production rates were Markovian processes, which introduced variability from two sources: the items arriving in the system and the construction crew in charge of the operation.

The output of this model included two "performance metrics" (backlog on the last day and summation of backlogs), which were the starting point to optimize the performance of the system (model). The objective of the optimization was to see how the metrics change when the input data has less variability. After changing the distribution of the items arriving in the system (including changes in both mean and standard deviation), the metrics showed a significant improvement. This result meant that the construction process was more likely to finish within the scheduled duration. Optimizing performance by reducing the variability of the demand in the system aligns with the outcomes that, for example, Tommelein et al. (1998) presented as part of the Parade of Trades game. They stated that by having a more stable die, the system could perform with less waste of resources due to the optimization of capacity utilization.

I used the explanation provided by Pound et al. in their book Factory Physics for Managers (Pound et al., 2014) to apply OS. I considered OS metrics (CT, TH, WIP, u) as part of the framework to rationalize the behavior of production systems. I assumed projects could be considered connected production systems (Spearman & Choo, 2018) to apply OS. However, to use OS, I also acknowledged the following differences between manufacturing and construction production systems: (1) no infinite production system in AEC projects, (2) lack of efficient control of the detrimental variability in the system, (3) work plans are constantly changing, (4) AEC practitioners' misconception of OS metrics. The results of the OS application in construction interpret the use of OS under these constraints. Therefore, using OS provides an "ideal" scenario, which can be used as a reference for construction production systems.

The current data collection practices on construction projects need to provide means to collect production-related data for developing models under the OS umbrella. This is a significant challenge as the model's results' quality depends on the input's quality. To tackle this challenge, the framework proposed to collect data from project plans and interviews with project team members. Then, analyze and "translate" this data by making reasonable assumptions to go from "project plans" to "production parameters" (i.e., construction process duration to a production rate). Similarly, I assumed that the SCV value could represent the amount of variability in the system; SCV is also considered a production parameter. The quality of this "translation" is crucial for obtaining "reasonable" results from applying this OS framework in construction.

5.3 Impact of PSD On Project Performance Using OS

Using the framework presented in CHAPTER 3 allowed me to conduct a case study to rationalize the impact of PSD on project performance through OS lenses. I illustrated the relationship between the OS and PM metrics using OS in the analyzed process. I Collected data from the project team and translated it to production parameters for Production Optimizer. Based on the meetings with the project team, I made assumptions about the amount of variability (SCV parameter), PB, TB, D, and PR/PT. These parameters were the input for producing OS graphs and equations that, along with the OS metrics, explain the behavior of production systems in construction processes.

I used two OS graphs and two OS equations explaining the studied production system. Specifically, I used Little's Law and the VUT equation to find the relationship between the OS metrics CT, TH, WIP, and u. In addition, I used the Product Flow graph and the capacity utilization graph for the resources included in this production system. I was able to illustrate the impact of production parameters on OS metrics. It is essential to mention that the intuition presented in CHAPTER 3 allowed me to determine if the analytical model's results were reasonable. The assumptions made for the analytical model helped simplify the modeling process and still obtain accurate results. Here I comment on each of them:

1. I use SCV as a measure of the variability in the system: This is a parameter needed as input to the modeling software. I used a value of SCV=1.5 to replicate a scenario with high variability (based on the practice of SPS engineers).
2. The PR/PT parameters have a normal distribution: The project team shared with me the mean of the durations of the operations, and I assumed this distribution as it simplifies the calculations.
3. This is a steady-state system with no "warm-up" phase: I used the results to show an ideal scenario considering a steady-state system. Therefore, I pointed out that the model's results should be used as a reference, and these values might represent the reality after certain process repetitions.
4. The matching problem has been addressed through detailed coordination between the project team parties: The project team solved this problem with the coordination process. I explained the processes for successfully implementing the innovation (offsite cladding system) and the design and coordination process.
5. There is no rework between operations: The project team mentioned that there was almost "zero" rework due to the detailed coordination between the team members.
6. The resources work on the operations serially: This assumption was reflected in the team's practice as the project team claimed that the nature of the operations was to complete one activity to then go to the next one, which resembles no shared resources between processes.

These assumptions helped to simplify the model and the analysis of the results. During the modeling part, I used SPS' Production Optimizer software to develop an analytical model that simulates the behavior of this production system. I obtained directly from the results sheet of the modeling software CT, WIP, TH, and u. Using the individual components of CT (RPT) was also crucial for using equation 7 to calculate the duration of the activity, knowing the OS metrics. This equation related the OS metrics and PM metric "time," that I used later to find the impact of the PM metric "cost." It is important to mention that I only included the extension of the duration of the activity to find the relationship between OS metrics, as equation 8 shows. There should be more factors to consider while calculating the cost (i.e., rental periods of equipment, different payment rates due to overtime), but in this study, the only impact I considered was the extra time.

I also considered comparing a PUSH system and a CONWIP system, which generated results as expected: PUSH systems provided more CT and more WIP, whereas CONWIP systems provided less CT and WIP but with a higher u (see section 4.4.2). These results are aligned with previous research that showed the improvements that CONWIP systems provide to production systems as a control mechanism. For example, Arbulu (2006) showed the benefits of CONWIP as part of the development of the production system of the rebar structural installation construction process. I also analyze the relationship between OS metrics and PM metrics in six product flows of the production system. This analysis showed the need for fully balancing the production system instead of only improving one of the sections of the system.

The sensitivity analysis conducted by changing production-related parameters in the model provided meaningful insights into understanding the impact of these parameters on OS metrics. I changed one parameter at a time (either D or TB/PB) and maintained the other parameters the same (SCV was the same throughout the sensitivity analysis). This analysis helped visualize how these metrics change under fluctuations of D, which is quite common in construction. As D goes up, TH, WIP, and CT go up, having significant implications in time and cost, namely, duration and cost go down as with more D, the production of all the elements in the production system (temporal system) would finish earlier, also impacting costs. While I changed demand, the bottleneck of the production system changed from one product flow to another (also affected by variability), demonstrating that the optimization of the production system should happen considering all the product flows because they behave concurrently (see section 4.4.3). The results did not show a trend in how changes in TB/PB impact OS metrics. However, the sensitivity analysis illustrated diverse fluctuations in all the metrics (both OS and PM metrics) of different product flows.

5.4 Limitations of this Thesis

One of the limitations of the framework to apply OS is that I assumed the construction crews are single queueing systems and the arrival rates are Markovian processes. This assumption facilitates the calculation of OS metrics and provides reasonable results. However, a more complex construction process may not be applicable for making this assumption, and the method followed in this thesis may not be appropriate to replicate.

The assumptions I made to translate the project plans of the case study to production parameters as required by Production Optimizer is another limitation. Since the construction process was already completed, I could review the results of my assumptions after I contrasted my model's outcomes with the actual duration of the process. However, designing a production system from scratch before it starts to operate might be a problem as there is no "actual" duration to contrast with.

The selection of an offsite building construction process for the case study helped to obtain production-related parameters that are more stable than construction processes related to a "stick-and-built" onsite approach. In a stick-and-built onsite construction process, using SCV to represent variability might not be enough to accurately represent the reality of the process (i.e., uncontrolled environment, more time exposed to adverse weather conditions, fluctuations of labor). The results might also change if the construction process is from another type of infrastructure (i.e., roads, industrial). In addition, the construction process selected had 243 repetitions of the EIFS panels installation process, which provided enough repetitions to assume something close to a steady-state system. This assumption might not be applicable if the construction process has fewer repetitions or if the repetitions in the process are vastly different from one to another.

I modeled and analyzed only the onsite assembly process, which did not include the transportation of the materials or the design as part of the production system. Considering the implications on a supply-chain level, I analyzed only the installation process, so the results are related to only that production system. Including the transportation or design of the components of the production system can provide a more integrated analysis.

I used an analytical model that would provide different results from a DES model. Commenting on the theoretical differences between these two types of models is outside of the scope of this research but using a DES model would have provided results that include a warm-up phase. Another difference is that the DES would have provided a distribution of results based on many repetitions for running the model. These results can provide a statistical distribution of the metrics analyzed and developed probabilistic analyses to find the most probable scenario. Nonetheless, I used an analytical model because it provided an optimized result based on several assumptions. And as I mentioned in chapter 4, the analytical model results should be a guide to what the production system can accomplish and an intuition of the consequences of changing the parameters of the production system.

The assumptions of the case study commented on in 5.3 are also a limitation as they were stated to facilitate the modeling part of this study. Changing these assumptions and using another type of model can change the results. For example, in the sensitivity analysis, I assumed a consistent change in the parameters of the items and product flows I was analyzing and fixed values on the others. This assumption might not be accurate as the parameters can change freely without depending on others. However, altering more than one parameter at a time was separate from the scope of this analysis, but it can be interesting to include as a future experiment. Therefore, changing one parameter at a time was a significant limitation in this analysis.

All the limitations mentioned can be the starting point for future research, as changing the assumptions made in this research can generate other results. Therefore, it is essential to acknowledge the constraints in which this thesis has produced its results.

CHAPTER 6 CONCLUSIONS

6.1 RESEARCH QUESTIONS AND ANSWERS

This thesis had the research questions stated in chapter 1, and after developing this study, I provide these answers:

1. How can we gather production-related data (e.g., production rates, transfer batch, stock points, process batch) from a building construction project to apply OS?

Using reasonable assumptions about the amount of variability in the construction process and collecting relevant related to the plans of the project team to complete the process under analysis. Once the data is collected, it is required to interact with the project team to describe the details of the work developed by the construction crew members in terms of duration of operations and production rates. Then, running a preliminary model will be helpful to contrast the model results with the actual durations of the process if the process is done already. Otherwise, the critique of the project team is useful to validate the data used for constructing the model as part of the OS analysis. Asking the project team about the production parameters to include ca be challenging but proposing specific numbers for these parameters can facilitate the conversation with the team about the values to consider. Finally, the project team's experience will help determine if the results obtained from the model make sense.

2. To what degree and under what circumstances (assumptions) are the OS analysis, graphs, and equations applicable to find the impact of PSD on the performance of building projects?

Since this thesis explored the applicability of OS in a construction process that uses an offsite approach, I can argue that the use of OS is applicable to other OSC processes. Moreover, it would be interesting to explore the applicability of OS on diverse types of projects (i.e., houses, bridges, roads) that also use an offsite approach. Despite that I analyzed the installation process, the elements of the production system were fully assembled offsite, which had an environment with less variability. Therefore, using OS on onsite construction (meaning to assemble the elements on the project site) can be a point of discussion. The highly variable environment of an onsite approach can invalidate the assumption made in this thesis for using analytical models in a temporal production system.

Also, to use OS, there should be some repeatability of the process for providing meaningful results that can improve project performance. In this case study, the number of repetitions was 243 for EIFS panels and 50 for windows. However, these numbers can change depending on the production system of the construction process. To summarize, using OS metrics, graphs, and equations can serve as a tool for a project team to assess the implications of changing certain production system parameters of their construction projects.

6.2 RESEARCH FINDINGS

This research provided findings in the field of production management of construction projects. One significant finding is related to the linkage between OS metrics and PM metrics, which illustrates the impact of PSD on project performance. The most influential OS metric is CT, representing the changes in WIP and TH. The formulas used to find the impact of OS metrics on PM metrics include RPT (a CT component), which significantly impacts the construction process' duration and cost. The influence of OS metrics on PM metrics is essential to acknowledge as it can allow the project team to use production control methods (such as CONWIP signals) to control the WIP. This signal will control the CT of the production system and then positively impact the process' duration and cost.

I found the impact of changes in production parameters in OS metrics and PM metrics. The sensitivity analysis provided an intuition about how a production system can perform under a scenario where D changes daily. Therefore, having a production system with extra capacity as a buffer can stand increased demands if it does not reach a certain limit established by the max TH. If the production system needs to perform above this limit, the project team must improve PR/PT to reduce u and allow the production system to respond to the new larger demand.

Regarding the changes in the batch size, the sensitivity analysis showed heterogeneous fluctuations in the OS and PM metrics of the product flows with no visible trend. In contrast to the results of the change in D, the change in the batch size does not allow finding a logic of how the changes impact OS/PM metrics. Moreover, in some runs, batch size reduction generated a shorter CT but a longer duration of time when compared with the BL run. This surprising result may be explained by the value of TH used in equation 7. This value, along with the other metrics and assumptions, may generate a scenario in which the benefits of a reduced batch size are exceeded by the drawbacks of having more items left to complete after the first batch size is done.

6.3 Contributions to Knowledge

This research contributes to knowledge in the following ways:

1. Describes the innovation process to change from an onsite to an offsite approach for a construction process, which included negotiations with the inspection bodies and concurrent engineering to design, implement, and control this innovation.
2. Describes the use of OS to find the relationship of PSD on project performance, showing the benefits of this manufacturing approach by making certain assumptions that can be made to construction.
3. Uses OS metrics and PM metrics to illustrate PSD and project performance, respectively.
4. Explores how the change in production system demand can impact OS and PM metrics. In addition, it provides a better understanding of the capacity buffers that production systems would require under the scenarios of different demands.
5. Explores how the change in the batch size of a production system can affect OS metrics and PM metrics. Moreover, this research shows that under certain circumstances, a reduction in batch size does not always positively affect the duration of the process.

6.4 Future Research

This thesis has several limitations, so the future research proposal addresses this study's limitations, such as conducting a case study to apply OS with the remaining OS equations and graphs (subchapter 2.3) to complete the method proposed by Factory Physics. Other future research is related to exploring OS analysis construction projects under an onsite approach, which will include a construction environment with more variability. This will increase the difficulty level of collecting relevant production data for input to the analytical model. Yet other future research can be to analyze the impact of PSD to project performance using OS lenses of non-building construction projects (i.e., roads, wastewater facilities).

Other research can include conducting a sensitivity analysis of PB and TB with more runs and scenarios to illustrate the change in OS and PM metrics. Another research topic should consider the computation of not only the onsite portion of the production system (as I did in the case study of this thesis) but also the fabrication and transportation phases. As Arbulu (2002) and Arbulu et al. (2002) presented the study with pipe supports, analyzing more phases of the production system can lead to understanding the performance of the supply chain and not only the project. Moreover, a future research project can compare results from a production system that resembles the supply chain of a construction process using both an analytical model and a DES model.

OS analysis can be applied to design production systems in a complete project, which means analyzing all the construction processes as production systems. This future research would rationalize the idea proposed by Choo & Spearman (2018) that projects are a network of production systems. Finally, combining the production system analytical model with several technologies (i.e., sensors, internet of things, bar/QR codes) that provide real-time communication can be the baseline for developing a digital twin of the project production system. Developing this last future research proposal might enhance not only the performance of the production system during the project-delivery phase, but it can also be instrumental in strengthening the asset performance during its operational phase.

6.5 Final Remarks

One crucial remark is that there are more factors influencing project performance than only PSD, which were not part of the scope of this research. Another observation is that I used a specific software for modeling (Production Optimizer) with specific operating methods. Taking a deep look at its algorithms is out of this thesis's scope. Nevertheless, despite the way the software works can be considered a "black box," it provided remarkable results in understanding the application of OS in construction. Furthermore, using other software to develop the same type of analysis can give different results, which should be interesting to explore.

Finally, this thesis can influence more people to implement PSD and OS analysis in their toolkits while managing construction projects. This thesis helps to understand better the impact of PSD on project performance, which is fundamental for implementing and adopting Lean Construction as a common practice in our projects.

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CHAPTER 8 APPENDICES

<u>Appendix A</u>: Handouts of the SSRRH project team

Handouts of the SSRRH project team.

<u>Appendix B</u>: Innovation process map

Innovation process map.

<u>Appendix C</u>: Design and coordination process map

Design and coordination process map.

<u>Appendix D</u>: Production process map

Production process map.

<u>Appendix E:</u> Input of the production analytical model

Input of the PSD's production analytical model.

<u>Appendix F</u>: Result sheets of the 1st production analytical model

Results of the original production analytical model.

<u>Appendix G</u>: Result sheets of CONWIP scenarios of the 1st model

Result sheets of the CONWIP scenarios of the original production analytical model.

<u>Appendix H:</u> Result sheets of the sensitivity analysis runs

Result sheets of the sensitivity analysis runs of the production analytical model.

8.1 APPENDIX A: HANDOUTS OF THE SSRRH PROJECT TEAM

Sutter Santa Rosa Replacement Hospital - A3 Report

Prefabricated EFIS Exterior

1 Baseline

Problem: Find the best means and methods to design and install 30,000 SF of EFIS exterior

1) Our Validation Budget and schedule are based on 100% onsite EFIS construction with no prefabrication included
2) The existing Sutter Santa Rosa Hospital has Dryvit EFIS exterior

2 Analysis

The Baseline did not include the prefabricated EFIS Panels because of uncertainty finding a fabricator with the discipline for quality control and production capacity to successfully complete our project. Since then we have prequalified BayStone and our project team has toured their manufacturing facility.

a. Since our Validation Study the schedule has shifted 6 months. Our exterior dry will be complete in winter months.
b. We risk installing EFIS Exterior onsite during the wet season with possible weather delays.
c. Our project team prequalified and toured BayStone manufacturing facility to better understand a EFIS prefabricated panel alternative.
d. We have concluded that building EFIS panels in a controlled factory setting improves the quality of waterproofing and acrylic finishes. There is greater control of ambient temperature for material curing and improved ergonomics for assembly.
e. Structural attachments are the same for field and prefabricated EFIS panels.
f. The main difference between Prefabricated and field EFIS is additional double caulking waterproofing at panel to panel connections.

3 Advantages

Baseline – EFIS Field Installed	Alternative 2 – EFIS Prefab
• Slightly improved waterproofing due to less double caulking joints	• **Two months shorter schedule to complete onsite construction of EFIS exterior** • **Greater control of material cure time in a factory setting** • **Greater control of thickness and flatness of Acrylic finish** • **Improved safety due to 80% less Man hours installing work elevated on scaffolding** • Less man power and material congestion onsite • Less material wasted
$2,950,000	$2,408,227

Bold font indicates those advantages that we believe have greater importance to Sutter/CPMC. Core Group is asked to confirm assumption of importance.

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EFIS Mockup - Layers of standard Dryvit Assembly

Completed Panels – Ready to ship

4 Proposal

Use Prefabricated EFIS panels to reduces our costs by $500,000 and improve the exterior dry-in scheduled by two months.

☒ Yes ☐ No

a. HerreroBoldt to contract directly with BayStone to Furnish prefabricated EFIS Panels
b. California Drywall to Erect Prefabricated EFIS Panels

5 Action

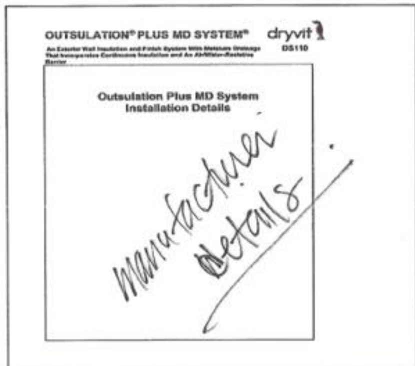
Cha

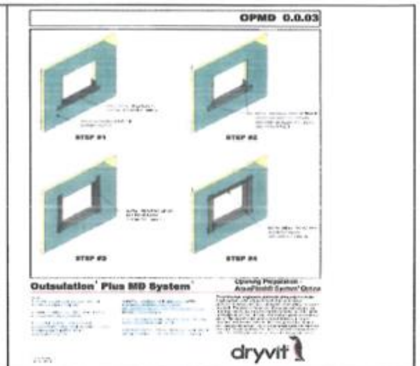
The path forward consists of : HB = HerreroBoldt

a. Stantec to provide BayStone the current Architectural Design Documents
b. Bay Stone to complete Detailed Cost Proposal to Furnish Dryvit EFIS prefabricated panels
c. HB to Contract BayStone –
d. BayStone to Provide Design Assist to FWC Structural Engineers to complete Increment 1 OSHPD submission – Construction Docs.
e. BayStone to Provide Design Assist to Stantec Architects to complete Waterproofing details
f. BayStone to Furnish Dryvit EFIS prefabricated panels –
g. Identify a UL listed firestopping solution or develop an E.J. ?
h. Develop a water test protocol & implement – Mock-up.

Sutter Santa Rosa Replacement Hospital - A3 Report

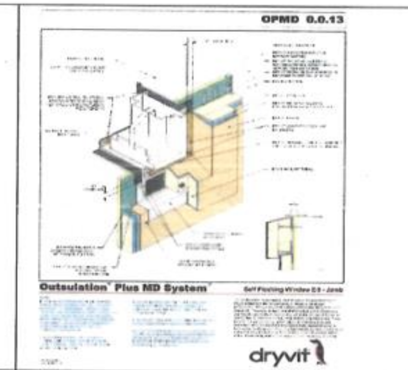
Dryvit EFIS Waterproofing Details



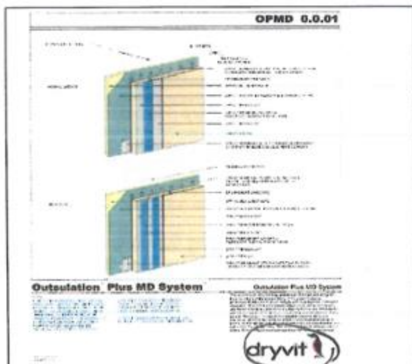


Window Flashing Detail

Punched Window Detail



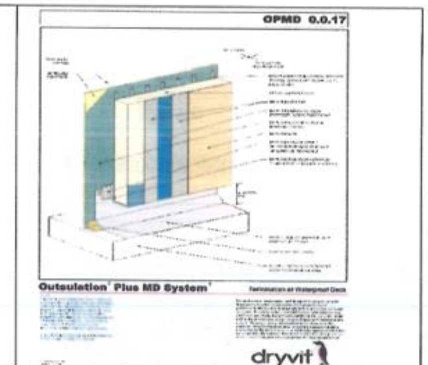
Window Trim Detail



Typical Dryvit Panels

Grade Termination Detail

Parapet Termination Detail



Termination of Waterproofing at Deck

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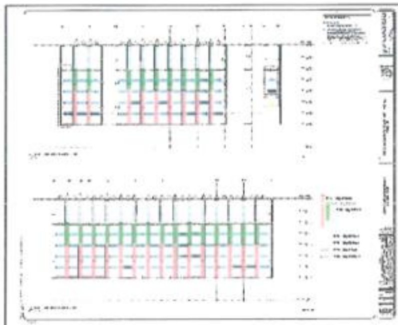
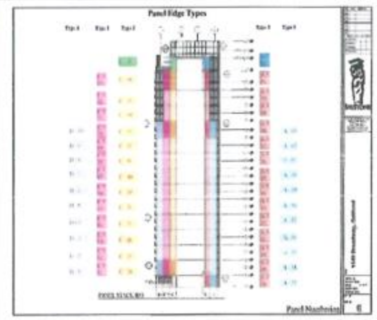
Sutter Santa Rosa Replacement Hospital - A3 Report

BayStone Prefabricated Waterproofing Details

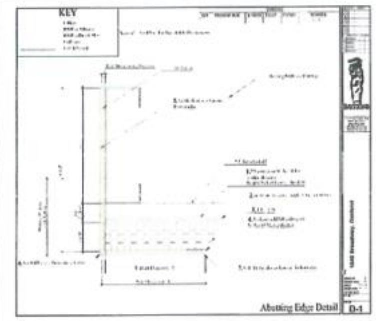


Panel Type Elevation

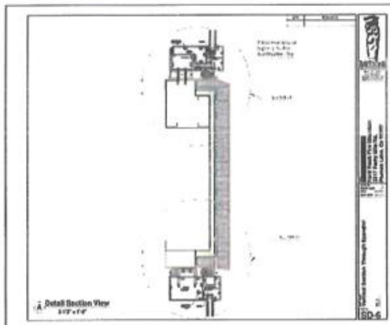
Elevation



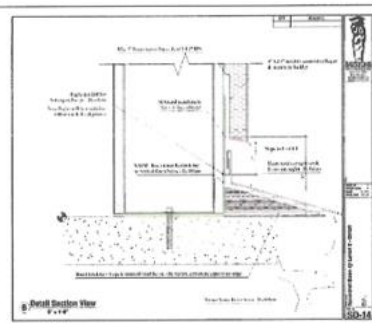
Panel Edge Types



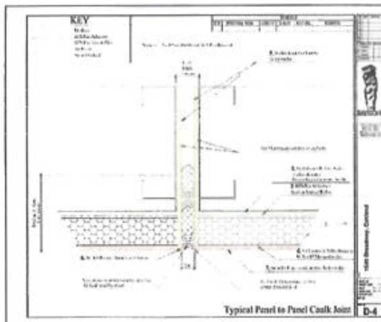
Abutting Edge Detail



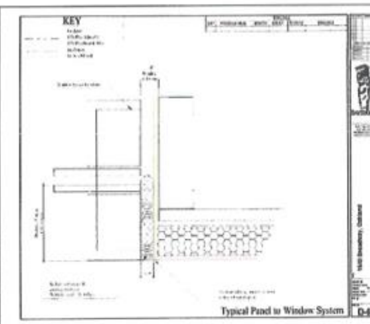
Punched Window Section



Bottom of Wall Section



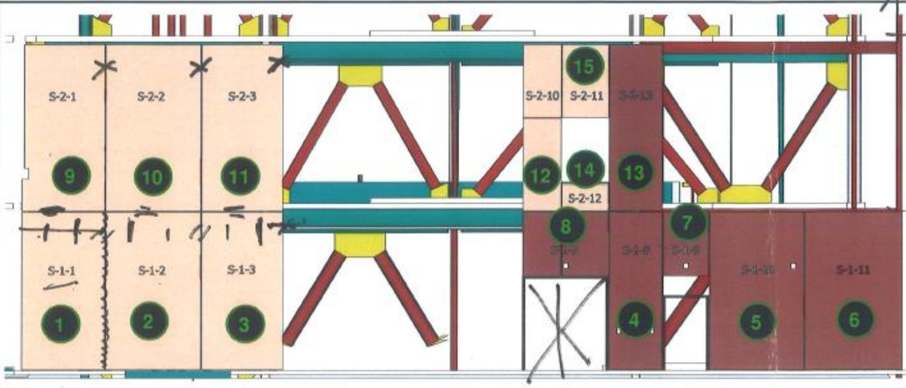
Typical Panel to Panel Caulk Joint



Typical Panel to Window System

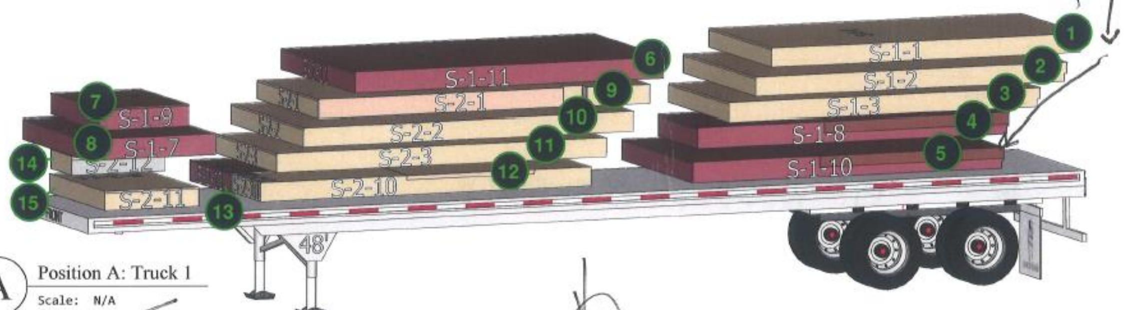
Author		
A3 No.: 003	Document Date: 01/15//2019	File: Use INSERT/FIELD/FILE NAME to insert file name

Stage 1 - Trucks 1 and 2



Elevation
Scale: N/A

Position B: Truck 2
Scale: N/A



Position A: Truck 1
Scale: N/A

Stage Seq	Elev Seq	PANEL #		Truck #	Stage	PANEL WIDTH	PANEL HEIGHT	Weight	
1	1	S-1-1	h	1	1	94 3/4	180 15/16	834	Enter Truck 1
2	2	S-1-2	h	1	1	109 3/4	180 15/16	966	Enter Truck 2
3	3	S-1-3	h	1	1	91 1/2	180 15/16	805	
4	4	S-1-8	h	1	1	61	180 15/16	545	
5	5	S-1-10	h	1	1	109	180 15/16	971	
6	6	S-1-11	h	1	1	111 1/2	180 15/16	993	
7	7	S-1-9	h	1	1	51 1/2	73 7/16	186	
8	8	S-1-7	h	1	1	99	73 7/16	358	
9	9	S-2-1	h	1	1	94 3/4	191 1/4	881	
10	10	S-2-2	h	1	1	110	191 1/4	1023	
11	11	S-2-3	h	1	1	91 1/2	191 1/4	851	
12	12	S-2-10	h	1	1	44 1/2	191 1/4	414	
13	13	S-2-13	h	1	1	61	191 1/4	575	
14	14	S-2-12	h	1	1	53 1/2	32 3/8	84	
15	15	S-2-11	h	1	1	53 1/2	84 1/2	220	Exit Truck 1

Pos	South Truck	South Stage
A	S1	1
B	S2	

BAYSTONE
1010 E. Commercial Row
Reno, NV. 89512
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www.baystone.com

Sutter Exterior Panels
South Trucking Maps

Stage 1 - Trucks 1 and 2

STAGING

RESTRICTION·

	Full Seq	Elev Seq	PANEL #		Truck #	Stage	PANEL WIDTH	PANEL HEIGHT	Weight			Pos	Truck	Stage
48	1	1	S-1-1	h	1	1	94 3/4	180 15/16	834	Enter Truck 1	19-Oct	A	S1	1
	2	2	S-1-2	h	1	1	109 3/4	180 15/16	966	Enter Truck 2	20-Oct	B	S2	
	3	3	S-1-3	h	1	1	91 1/2	180 15/16	805					
	4	4	S-1-8	h	1	1	61	180 15/16	545					
	5	5	S-1-10	h	1	1	109	180 15/16	971					
	6	6	S-1-11	h	1	1	111 1/2	180 15/16	993					
	7	7	S-1-9	h	1	1	51 1/2	73 7/16	186					
	8	8	S-1-7	h	1	1	99	73 7/16	358					
	9	9	S-2-1	h	1	1	94 3/4	191 1/4	881					
	10	10	S-2-2	h	1	1	110	191 1/4	1023					
	11	11	S-2-3	h	1	1	91 1/2	191 1/4	851					
	12	12	S-2-10	h	1	1	44 1/2	191 1/4	414					
	13	13	S-2-13	h	1	1	61	191 1/4	575					
	14	14	S-2-12	h	1	1	53 1/2	32 3/8	84				South	
	15	15	S-2-11	h	1	1	53 1/2	84 1/2	220	Exit Truck 1	20-Oct	Pos	Truck	Stage
45	16	16	S-2-14	h	2	2	51 1/2	191 1/4	479	Enter Truck 3	21-Oct	A	S3	2
	17	17	S-2-15	h	2	2	109	191 1/4	1026			B	S2	
	18	18	S-2-16	h	2	2	111 1/2	191 1/4	1050					
	19	19	S-3-1	h	2	2	91 3/4	191 1/4	853					
	20	20	S-3-2	h	2	2	110	191 1/4	1023					
	21	21	S-3-3	h	2	2	91 1/2	191 1/4	851					
	22	22	S-3-10	h	2	2	44 1/2	191 1/4	414					
	23	23	S-3-13	h	2	2	61	191 1/4	575					
	24	24	S-3-12	h	2	2	53 1/2	32 3/8	84					
	25	25	S-3-11	h	2	2	53 1/2	84 1/2	220					
	26	26	S-3-14	h	2	2	51 1/2	191 1/4	479					
	27	27	S-3-15	h	2	2	109	191 1/4	1026				South	
	28	28	S-3-16	h	2	2	111 1/2	191 1/4	1050	Exit Truck 2	21-Oct	Pos	Truck	Stage
40	29	29	S-4-1	h	3	3	91 3/4	227 1/2	1015			A	S3	3
	30	30	S-4-2	h	3	3	109 3/4	227 1/2	1214			B	W1	
	31	31	S-4-3	h	3	3	91 1/2	227 1/2	1012					
	32	32	S-4-7	h	3	3	99	177 1/4	859					
	33	33	S-4-8	h	3	3	61	177 1/4	532					
	34	34	S-4-9	h	3	3	51 1/2	171 1/4	429					
	35	35	S-4-10	h	3	3	109	177 1/4	951				West	
	36	36	S-4-11	h	3	3	111 1/2	177 1/4	973	Exit Truck 3	22-Oct	Pos	Truck	Stage
40	37	1	W-2-20	h	1	1	79 1/2	180 11/16	702	Enter Truck 1	22-Oct	A	W2	1
	38	2	W-2-19	h	1	1	79 1/2	180 11/16	702	Enter Truck 2	23-Oct	B	W1	
	39	3	W-2-17	h	1	1	100 1/2	180 11/16	888					
45	40	4	W-2-18a	h	2	1	53 1/2	37 3/4	95					
	41	5	W-2-18	h	2	1	53 1/2	76 1/2	199					
	42	6	W-2-16	h	1	1	109	180 11/16	963					
	43	7	W-2-14	h	1	1	109	180 11/16	963					
	44	8	W-2-15a	h	2	1	131	37 3/4	233					
	45	9	W-2-15	h	2	1	131	76 1/2	487					
	46	10	W-2-13	h	1	1	109	180 11/16	963					
	47	11	W-2-11	h	1	1	109	180 11/16	963					
	48	12	W-2-12a	h	2	1	131	37 3/4	233					
	49	13	W-2-12	h	2	1	131	76 1/2	487					
	50	14	W-2-10	h	1	1	109	180 11/16	963					
	51	15	W-2-8	h	1	1	109	180 11/16	963					
	52	16	W-2-9a	h	2	1	131	37 3/4	233					
	53	17	W-2-9	h	2	1	131	76 1/2	487					
	54	18	W-2-7	h	1	1	109	180 11/16	963	Exit Truck 1 / Crane Move	26-Oct			
	55	19	W-2-5	h	2	1	109	180 11/16	963		26-Oct			
	56	20	W-2-6a	h	2	1	131	37 3/4	233					
	57	21	W-2-6	h	2	1	131	76 1/2	487					
	58	22	W-2-4	h	2	1	109	180 11/16	963					
	59	23	W-2-2	h	2	1	108 7/16	180 11/16	958					
	60	24	W-2-3a	h	2	1	131	37 3/4	241				West	
	61	25	W-2-3	h	2	1	131	76 1/2	487	Exit Truck 2	26-Oct	Pos	Truck	Stage
45	62	26	W-1-1r	h	3	2	22 5/16	211 3/16	229	Enter Truck 3	27-Oct	A	W3	2
	63	27	W-1-4r	h	3	2	52	214 15/16	543	Enter Truck 4	27-Oct	B	W4	
	64	28	W-1-3r	h	3	2	219	82 1/16	574					
	65	29	W-1-2r	h	3	2	219	103 3/4	1105					
	66	30	W-1-5r	h	3	2	45 5/8	180 15/16	528					
	67	31	W-2-1	h	3	2	88 9/16	191 1/4	834					
	68	32	W-3-1	h	3	2	88 1/4	263 3/4	1146					
	69	33	W-3-2	h	3	2	117	253 7/16	1459				West	
	70	34	W-3-3	h	3	2	117	253 7/16	1459	Exit Truck 3	27-Oct	Pos	Truck	Stage
53	71	35	W-3-4	h	4	3	117	253 7/16	1459	Enter Truck 5	28-Oct	A	W5	3
	72	36	W-3-5	h	4	3	117	253 7/16	1459			B	W4	
	73	37	W-3-6	h	4	3	117	253 7/16	1459					
	74	38	W-3-7	h	4	3	117	253 7/16	1459					
	75	39	W-3-8	h	4	3	114	253 7/16	1246					
	76	40	W-3-9	h	4	3	108 1/2	263 3/4	1409					
	77	41	W-3-12	h	4	3	109	263 3/4	1416					
40	78	42	W-3-11	h	5	3	131	40 3/8	257					
	79	43	W-3-10	h	5	3	131	149	952					
	80	44	W-3-13	h	4	3	109	263 3/4	1416					
	81	45	W-3-16	h	4	3	109	263 3/4	1416					
	82	46	W-3-15	h	5	3	131	40 3/8	257					
	83	47	W-3-14	h	5	3	131	149	952				West	
	84	48	W-3-17	h	4	3	109	263 3/4	1416	Exit Truck 4 / Crane Move	28-Oct	Pos	Truck	Stage
51	85	49	W-3-20	h	6	4	109	263 3/4	1416	Enter Truck 6	28-Oct	A	W5	4
	86	50	W-3-19	h	5	4	131	40 3/8	257			B	W6	
	87	51	W-3-18	h	5	4	131	149	952					
	88	52	W-3-21	h	6	4	109	263 3/4	1416					
	89	53	W-3-24	h	6	4	109	263 3/4	1416					
	90	54	W-3-23	h	5	4	131	40 3/8	257					
	91	55	W-3-22	h	5	4	131	149	952					
	92	56	W-3-25	h	6	4	109	263 3/4	1416					
	93	57	W-3-28	h	6	4	109	263 3/4	1416					
	94	58	W-3-27	h	5	4	131	40 3/8	257					
	95	59	W-3-26	h	5	4	131	149	942					
	96	60	W-3-29	h	6	4	100 1/2	263 3/4	1305					
	97	61	W-3-32	h	6	4	79 1/2	191 1/4	749					
	98	62	W-3-31	h	5	4	53 1/2	40 3/8	105	Exit Truck 5	29-Oct			
	99	63	W-3-30	h	5	4	53 1/2	149	388	Enter Truck E1	29-Oct			
	100	64	W-3-33	h	6	4	79 1/2	191 1/4	749					
	101	65	W-4-2	h	6	4	80 1/16	227 1/2	1025				East	

per elevation

per Elevation

DAY 1 - 10/19 - 7 Panels

DAY 2 - 10/20 - 8 Panels

DAY 3 - 10/21 - 10 Panels

DAY 4 - 10/22 - 10 Panels

DAY 1 - 10/23 - 12 Panels

DAY 2 - 10/26 - 13 panels

DAY 3 - 10/27 - 14 Panels

DAY 4 - 10/28 - 14 Panels

DAY 5 - 10/29 - 13 Panels

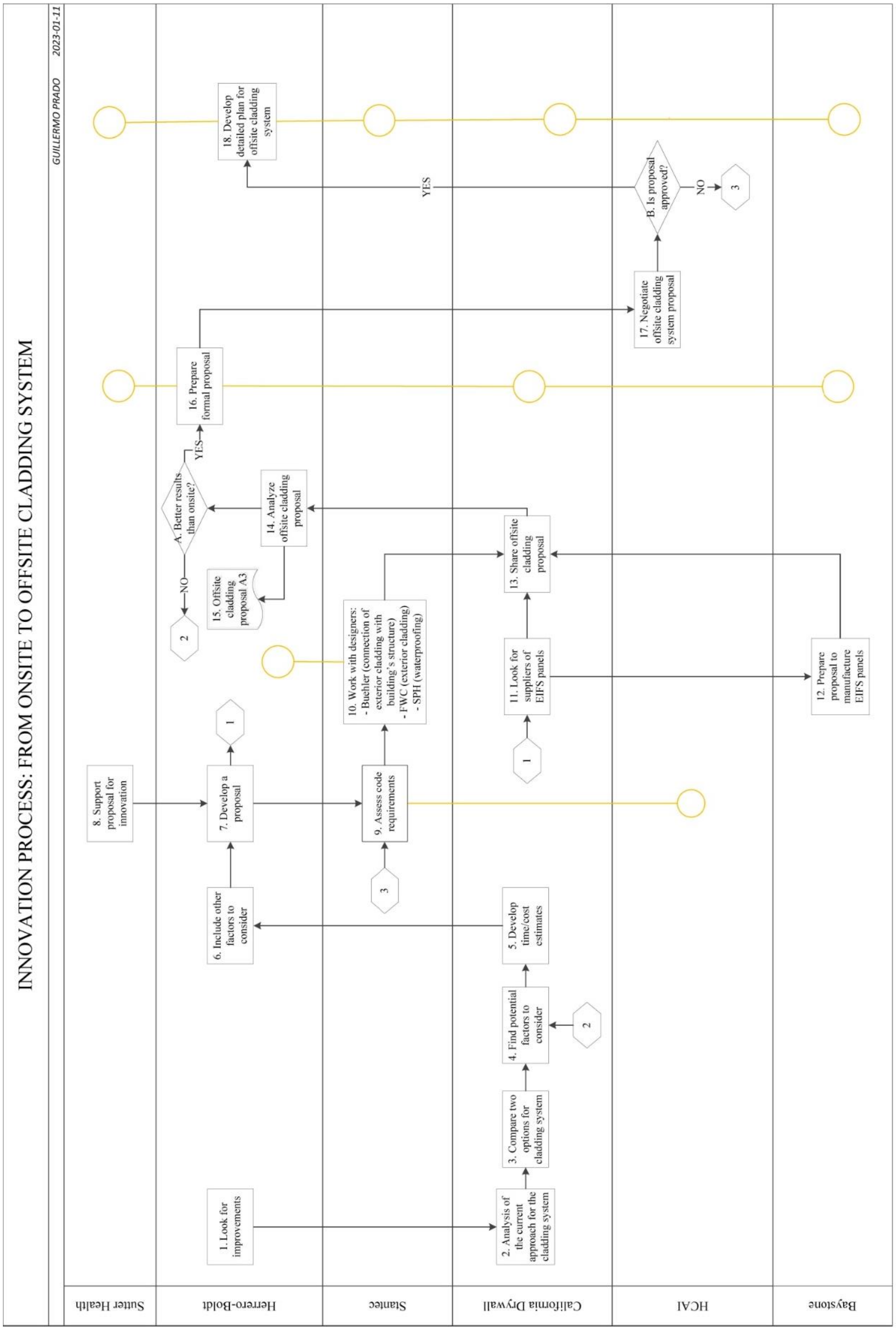
15

	102	66	W-4-1	h	6	4	79 1/2	227 1/2	891	Exit Truck 6	29-Oct	Pos	Truck	Stage	
18	103	1	E-1-1	h	1	1	88 3/8	180 15/16	765	Enter Truck 2	30-Oct	A	E1	1	DAY 1 - 10/30 - 11 panels
	104	2	E-1-2	h	1	1	86 3/4	180 15/16	761	Exit Truck 1		B	E2		
												Pos	East Truck	Stage	
42	105	3	N-1-1	h	2	2	25 9/16	180 15/16	235	Enter Truck 3	2-Nov	A	E3	2	
	106	4	N-1-1c	h	2	2	9 5/8	180 15/16	84			B	E2		
	107	5	E-1-3r	h	2	2	53 1/2	180 15/16	471						
	108	6	E-1-5r	h	2	2	108 1/2	180 15/16	954						
	109	7	E-1-4r	v	2	2	101	73 7/16	196						
	110	8	E-1-6r	h	2	2	131	180 15/16	925						
	111	9	E-1-7r	h	2	2	109	180 15/16	741						
	112	10	E-1-10r	h	2	2	131	180 15/16	1152						
	113	11	E-1-9r	v	2	2	109	82 1/8	434						
	114	12	E-1-8r	v	2	2	109	73 1/2	390						
	115	13	E-1-13r	h	2	2	131	180 15/16	1152						
40	116	14	E-1-12r	v	3	2	219	82 1/8	871						DAY 2 - 11/2 - 13 Panels
	117	15	E-1-11r	v	3	2	219	73 1/2	783						
	118	16	E-1-16r	h	2	2	53 1/2	180 15/16	471						
	119	17	E-1-15r	v	3	2	219	82 1/8	871						
	120	18	E-1-14r	v	3	2	219	73 1/2	783						
	121	19	E-1-19r	h	2	2	131	180 15/16	1152	Exit Truck 2	2-Nov				
	122	20	E-1-18r	v	3	2	219 5/16	82 1/8	563						
	123	21	E-1-17r	h	3	2	219 5/16	73 1/2	775						
	124	22	E-1-21r	h	3	2	109	180 15/16	501						
	125	23	E-1-22r	h	3	2	109	180 15/16	959						
	126	24	E-1-23r	h	3	2	53 1/2	180 15/16	471	Exit Truck 3 / Crane Move	2-Nov	Pos	East Truck	Stage	
40	127	25	E-1-26r	h	4	3	131	180 15/16	1152	Enter Truck 4	3-Nov	A	E5	3	DAY 3 - 11/3 - 13 Panels
	128	26	E-1-25r	v	4	3	219	82 1/8	871	Enter Truck 5	3-Nov	B	E4		
	129	27	E-1-24r	v	4	3	219	73 1/2	783						
	130	28	E-1-29r	h	4	3	33	180 15/16	289						
	131	29	E-1-28r	v	4	3	143 1/16	82 1/8	569						
	132	30	E-1-27r	v	4	3'	143 1/16	73 1/2	511						
	133	31	E-1-30r	h	4	3	76	180 15/16	669						
	134	32	E-1-33r	h	4	3	76 1/2	183 5/8	673						
	135	33	E-1-32r	v	4	3	219	82 1/8	871	Exit Truck 4	3-Nov	Pos	East Truck	Stage	
24	136	34	E-1-31r	h	5	4	219	58 1/8	630	Enter Truck 6	4-Nov	A	E5	4	
	137	35	E-1-36r	h	5	4	22 1/8	211 9/16	227			B	E6		
	138	36	E-1-35r	h	5	4	219	82 1/8	871						
	139	37	E-1-34r	h	5	4	219	183 3/4	1105	Exit Truck 5	3-Nov	Pos	East Truck	Stage	
40	140	38	E-2-34	h	6	5	41 15/16	191 1/4	384	Enter Truck 7	4-Nov	A	E7	5	DAY 4 - 11/4 - 11 Panels
Boat T	141	39	E-2-33	v	7	5	143 1/16	191 1/4	1347			B	E6		
	142	40	E-3-34	h	6	5	41 15/16	263 1/2	529						
	143	41	E-3-33	v	7	5	143 1/16	263 3/4	1858 ?	Exit Truck 7	4-Nov	Pos	East Truck	Stage	
40	144	42	E-2-30	h	8	6	109	191 1/4	1026	Enter Truck 8	4-Nov	A	E8	6	
	145	43	E-2-29	h	8	6	109	191 1/4	1026			B	E6		
	146	44	E-2-26	h	8	6	109	191 1/4	1026						
	147	45	E-2-28	h	6	6	53 1/2	40 3/8	106						
	148	46	E-2-27	h	6	6	53 1/2	76 1/2	199						
	149	47	E-2-25	h	8	6	109	191 1/4	1026						
	150	48	E-2-22	h	8	6	109	191 1/4	1026						
	151	49	E-2-24	h	6	6	131	40 3/8	260						DAY 5 - 11/5 - 10 Panels
	152	50	E-2-23	h	6	6	131	76 1/2	487						
	153	51	E-2-21	h	8	6	110 1/16	191 1/4	1008						
	154	52	E-2-18	h	8	6	109	191 1/4	1026						
	155	53	E-2-20	h	6	6	53 1/2	40 3/8	106						
	156	54	E-2-19	h	6	6	53 1/2	76 1/2	199						
	157	55	E-2-17	h	8	6	109	191 1/4	1026						
	158	56	E-2-14	h	8	6	109	191 1/4	1026						
	159	57	E-2-16	h	6	6	131	40 3/8	260						
	160	58	E-2-15	h	6	6	131	76 1/2	487	Exit Truck 8 / Crane Move	5-Nov	Pos	East Truck	Stage	
40	161	59	E-2-13	h	9	7	109	191 1/4	1026	Enter Truck 9	6-Nov	A	E9	7	DAY 6 - 11/6 - 12 Panels
	162	60	E-2-10	h	9	7	109	191 1/4	1026			B	E6		
	163	61	E-2-12	h	6	7	131	40 3/8	61						
	164	62	E-2-11	h	6	7	131	76 1/2	487						
	165	63	E-2-9	h	9	7	109	191 1/4	1026						
	166	64	E-2-6	h	9	7	108 1/2	191 1/4	1022						
	167	65	E-2-8	h	6	7	131	40 3/8	260						
	168	66	E-2-7	h	6	7	131	76 1/2	487						
	169	67	E-2-5	h	9	7	101	191 1/4	951						
	170	68	N-2-1c	h	6	7	9 5/8	191 1/4	89						
	171	69	E-2-4	h	6	7	53 1/2	40 3/8	108						
	172	70	E-2-3	h	6	7	53 1/2	76 1/2	199	Exit Truck 6	6-Nov	Pos	East Truck	Stage	
24	173	71	N-2-1	h	10	8	25 9/16	191 1/4	249	Enter Truck 10	6-Nov	A	E9	8	DAY 7 - 11/9 - 12 Panels
	174	72	E-2-2	h	9	8	86 3/4	191 1/4	804			B	E10		
	175	73	E-2-1	h	9	8	88 3/8	191 1/4	809						
	176	74	E-3-1	h	9	8	88 3/8	190 1/4	805						
	177	75	E-3-2	h	9	8	86 3/4	190 1/4	800						
	178	76	N-3-1	h	10	8	25 9/16	191 1/4	249						
	179	77	N-3-1c	h	10	8	9 5/8	191 1/4	89						
	180	78	E-4-1	h	10	8	88 3/8	177 1/4	750						
	181	79	E-4-2	h	10	8	86 3/4	177 1/4	745	Exit Truck 10	9-Nov		East		
	182	80	N-4-1	h	9	8	98 1/4	177 1/4	847	Exit Truck 9	9-Nov	Pos	Truck	Stage	
48	183	81	N-4-2	h	11	9	95	166 11/16	763	Enter Truck 11	9-Nov	A	E11	9	
	184	82	N-4-3	h	11	9	95	166 11/16	534	Enter Truck 12	10-Nov	B	E12		DAY 8 - 11/10 - 13 Panels
	185	83	N-4-4	h	11	9	95	166 11/16	763						
	186	84	N-4-5	h	11	9	95	166 11/16	763						
	187	85	N-4-6	h	11	9	95	166 11/16	763						
	188	86	N-4-7	h	11	9	55 3/4	166 11/16	448						
	189	87	N-4-9	h	11	9	92 1/2	216 15/16	969						
	190	88	N-4-8b	h	11	9	76	21 15/16	216						
	191	89	N-4-8a	h	11	9	76	57 1/2	216						
	192	90	N-4-10	h	11	9	128	216 15/16	1295						
	193	91	N-4-11	h	11	9	41 15/16	216 15/16	439						
	194	92	E-5-1	h	11	9	152 1/4	79 7/16	587	Exit Truck 11	10-Nov	Pos	East Truck	Stage	
53	195	93	E-3-5	h	12	10	101	263 3/4	1312	Enter Truck 13		A	E13	10	
45	196	94	E-3-4	h	13	10	53 1/2	40 3/8	113			B	E12		11 - 13 Panels
	197	95	E-3-3	h	13	10	53 1/2	149	295						
	198	96	E-3-6	h	12	10	108 1/2	263 3/4	1489						
	199	97	E-3-9	h	12	10	109	263 3/4	1416						
	200	98	E-3-8	h	13	10	131	40 3/8	257						
	201	99	E-3-7	h	13	10	131	149	952						
	202	100	E-3-10	h	12	10	109	263 3/4	1416						
	203	101	E-3-13	h	12	10	109	263 3/4	1416						
	204	102	E-3-12	h	13	10	131	40 3/8	257						

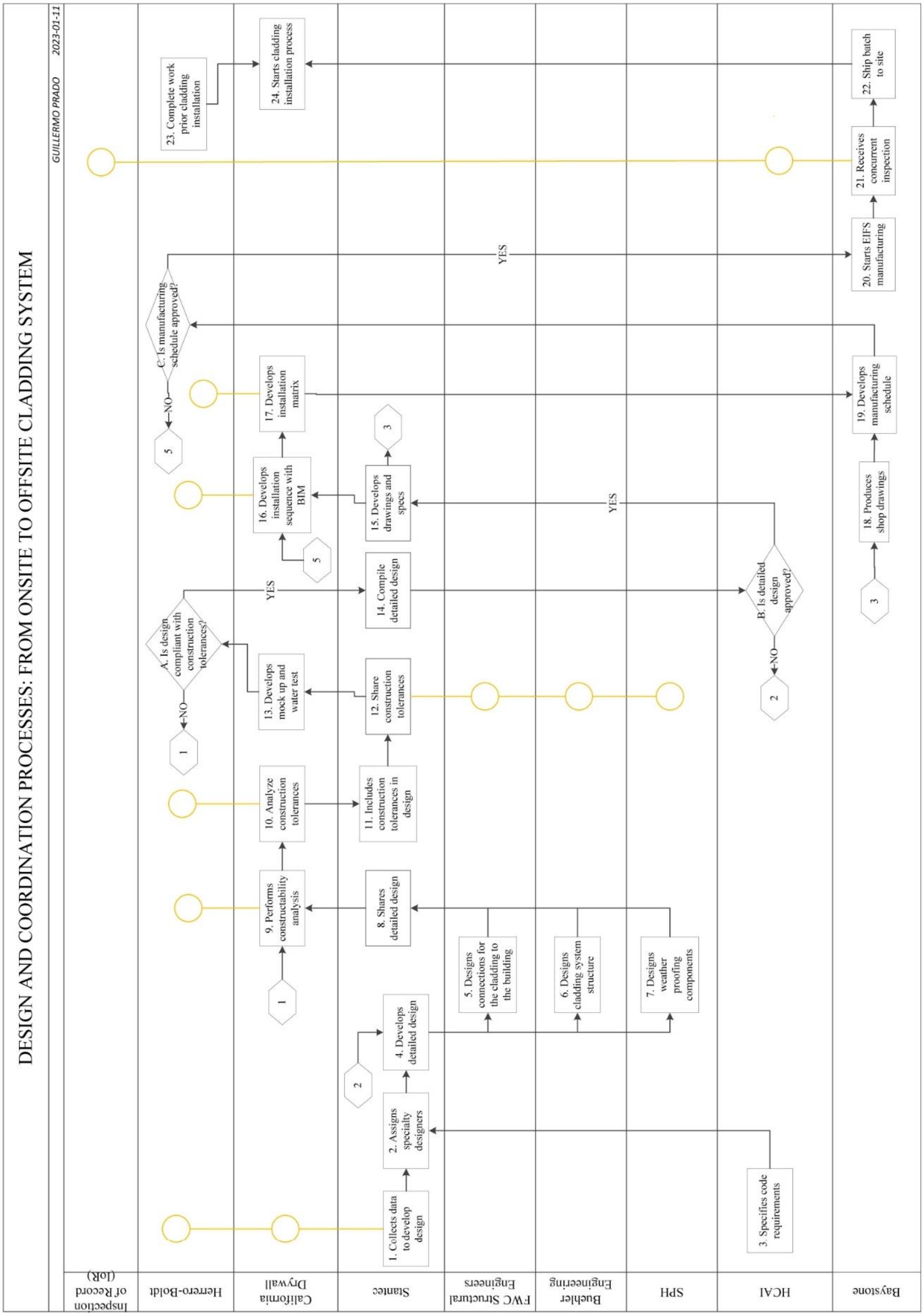
This

	205	103	E-3-11	h	13	10	131	149	952						DAY 9 - 11/
	206	104	E-3-14	h	12	10	109	263 3/4	1416						
	207	105	E-3-17	h	12	10	109	263 3/4	1416						
	208	106	E-3-16	h	13	10	131	40 3/8	257						
	209	107	E-3-15	h	13	10	131	149	952						
	210	108	E-3-18	h	12	10	109	263 3/4	1416	FINAL CRANE MOVE - BIGGER CRANE???					
	211	109	E-3-21	h	12	10	68 13/16	263 3/4	1394						DAY 10 - 11/12 - 13 Panels
	212	110	E-3-20	h	13	10	53 1/2	40 3/8	105				East		
	213	111	E-3-19	h	13	10	53 1/2	149	389	Exit Truck 12	12-Nov	Pos	Truck	Stage	
24	214	112	E-3-22	h	14	10	109	263 3/4	1416	Enter Truck 14	12-Nov	A	E13	11	
	215	113	E-3-25	h	14	11	109	263 3/4	1416			B	E14		
	216	114	E-3-24	h	13	11	131	40 3/8	257						
	217	115	E-3-23	h	13	11	131	149	952						
	218	116	E-3-26	h	14	11	109	263 3/4	1416						
	219	117	E-3-29	h	14	11	109	263 3/4	1416						
	220	118	E-3-28	h	13	11	53 1/2	40 3/8	105						
	221	119	E-3-27	h	13	11	53 1/2	149	389						
	222	120	E-3-30	h	14	11	109	263 3/4	1416	Exit Truck 14	12-Nov		North		
	223	121	E-3-31	h	13	11	131	149	952	Exit Truck 13	12-Nov	Pos	Truck	Stage	
48	224	1	N-1-12	h	1	1	84 3/4	180 15/16	754	Enter Truck 1	13-Nov	A	N1	1	DAY 1 - 11/13 - 10 Panels
	225	2	N-1-13	h	1	1	108	180 15/16	958	Enter Truck 2	13-Nov	B	N2		
	226	3	N-1-14	h	1	1	108	180 15/16	958						
	227	4	N-1-15	h	1	1	108	180 15/16	958						
	228	5	N-1-16	h	1	1	88 9/16	180 15/16	856						
	229	6	N-2-6	h	1	1	88 9/16	260 1/4	1231						
	230	7	N-2-5	h	1	1	108	260 1/4	1365						
	231	8	N-2-4	h	1	1	108	260 1/4	1365						
	232	9	N-2-3	h	1	1	108	260 1/4	1365				North		
	233	10	N-2-2	h	1	1	84 3/4	260 1/4	1084	Exit Truck 1		Pos	Truck	Stage	
40	234	11	N-1-11r	h	2	2	63 3/8	211 3/16	651	Enter Truck 3	16-Nov	A	N3	2	DAY 2 - 11/16 - 10 Panels
	235	12	N-1-8r	h	2	2	28	211 3/16	288			B	N2		
	236	13	N-1-10r	v	2	2	175	82 1/16	698						
24	237	14	N-1-9r	h	3	2	175	103 3/4	883						
	238	15	N-1-5r	h	2	2	28	211 3/16	180						
	239	16	N-1-7r	v	2	2	185	82 1/16	738						
	240	17	N-1-6r	h	3	2	185	103 3/4	933						
	241	18	N-1-2r	h	2	2	63 3/8	211 3/16	651						
	242	19	N-1-4r	v	2	2	175	82 1/16	698	Exit Truck 2	16-Nov				
	243	20	N-1-3r	h	3	2	175	103 3/4	883	Exit Truck 3	16-Nov				
			E-3-32				131	40 3/8	257						
			E-2-31				131	76 1/2	487						
			E-2-32				131	40 3/8	260						
			S-1-4				39 1/2	180 15/16	352						
			S-1-5				99	180 15/16	882						
			S-1-6				131	180 15/16	1167						
			S-2-4				39 1/2	191 1/4	372						
			S-2-5				53 1/2	84 1/2	220						
			S-2-6				53 1/2	32 3/8	84						
			S-2-7				44 1/2	191 1/4	414						
			S-2-8				131	84 1/2	538						
			S-2-9				131	32 3/8	206						
			S-3-4				39 1/2	191 1/4	372						
			S-3-5				53 1/2	84 1/2	220						
			S-3-6				53 1/2	32 3/8	84						
			S-3-7				44 1/2	191 1/4	414						
			S-3-8				131	84 1/2	538						
			S-3-9				131	32 3/8	206						
			S-4-4				39 1/2	177 1/4	345						
			S-4-5				99	177 1/4	859						
			S-4-6				131	177 1/4	1137						

8.2 Appendix B: Innovation process map

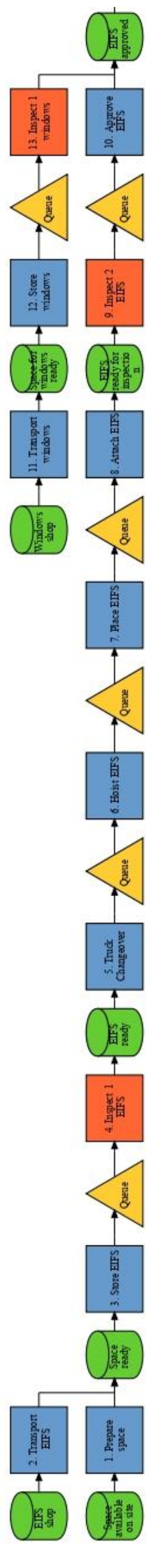


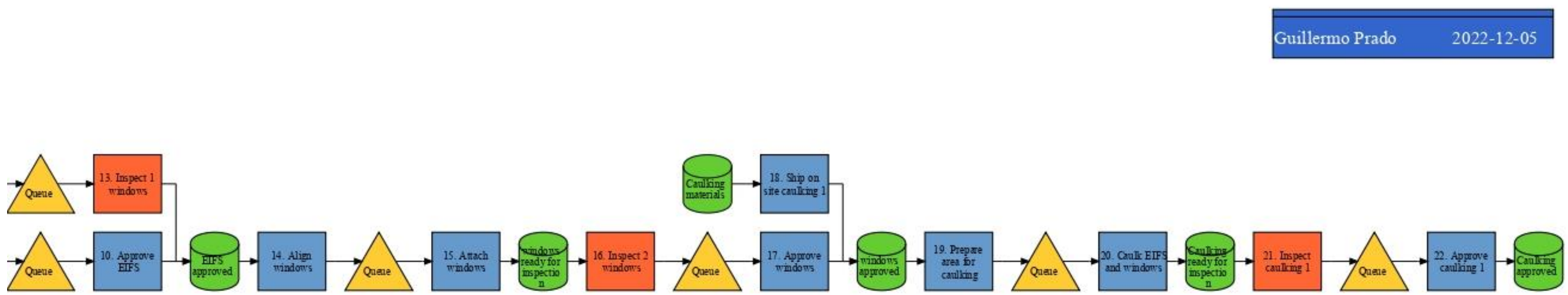
8.3 Appendix C: Design and coordination process map



8.4 APPENDIX D: PRODUCTION PROCESS MAP

Production process map from SPS's Production Optimizer.

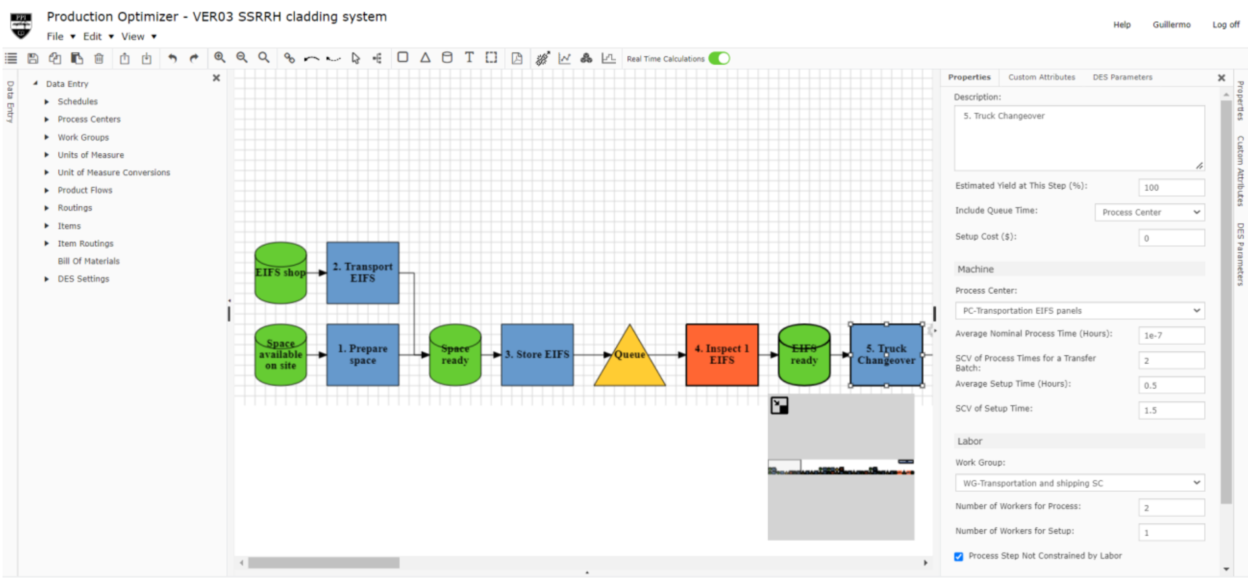



Guillermo Prado
2022-12-05
Queue
13. Inspect 1 windows
Queue
10. Approve EIFS
EIFS approved
14. Align windows
Queue
15. Attach windows
windows ready for inspectio n
16. Inspect 2 windows
Queue
Caulking materials
18. Ship on site caulking 1
17. Approve windows
windows approved
19. Prepare area for caulking
Queue
20. Caulk EIFS and windows
Caulking ready for inspectio n
21. Inspect caulking 1
Queue
22. Approve caulking 1
Caulking approved

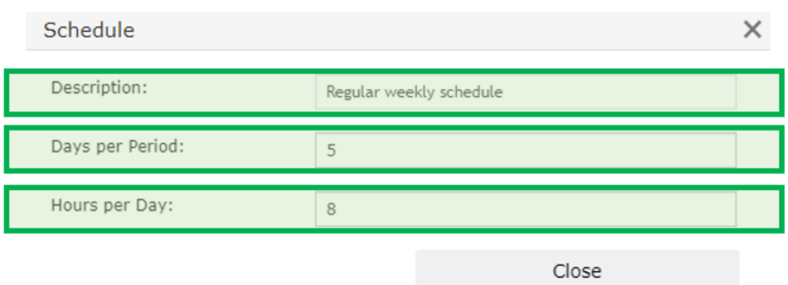
8.5 APPENDIX E: INPUT OF THE PRODUCTION ANALYTICAL MODEL

The input of the PSD based on SPS's Production Optimizer Interface. The green boxes in the following figures represent the parameters considered as input for the production model.

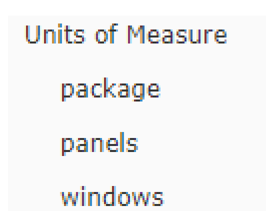
SPS Production Optimizer interface



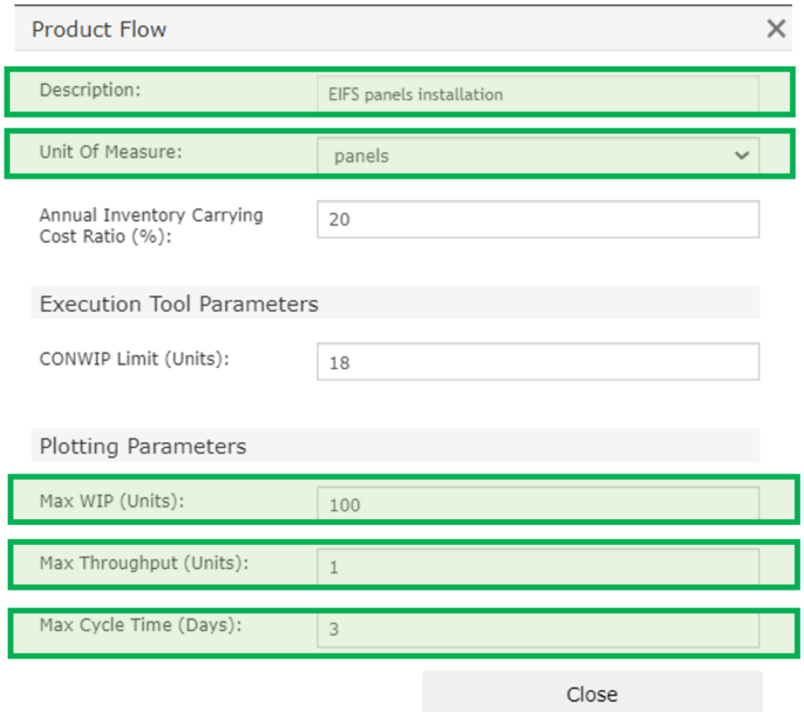
Schedule

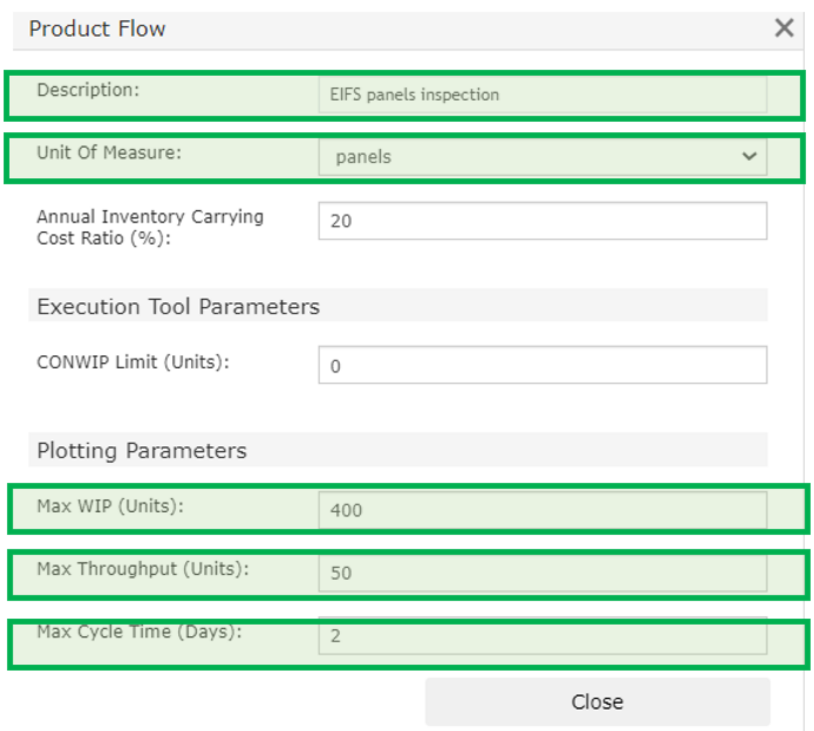


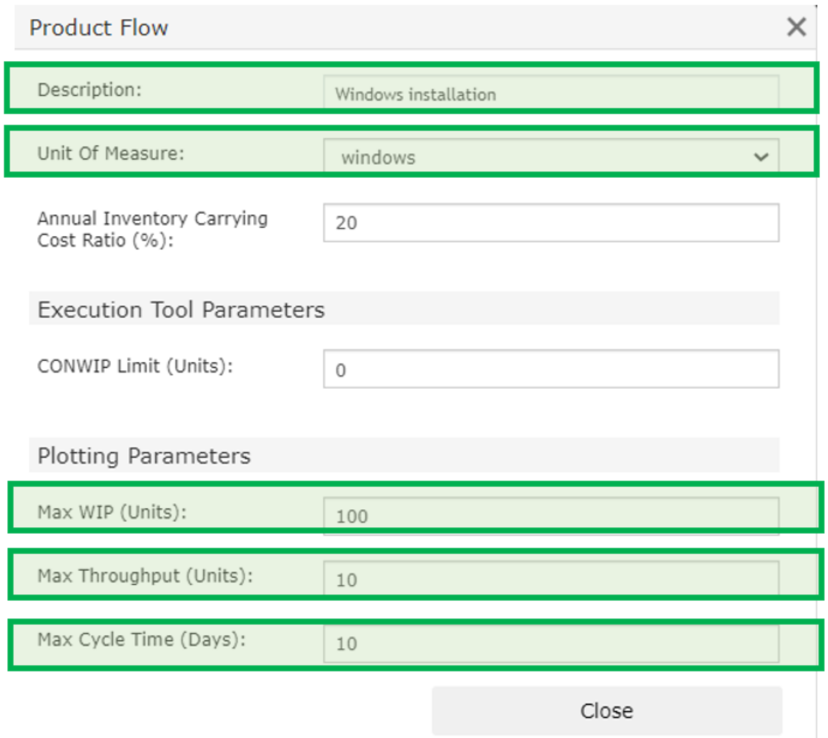
Units of measure

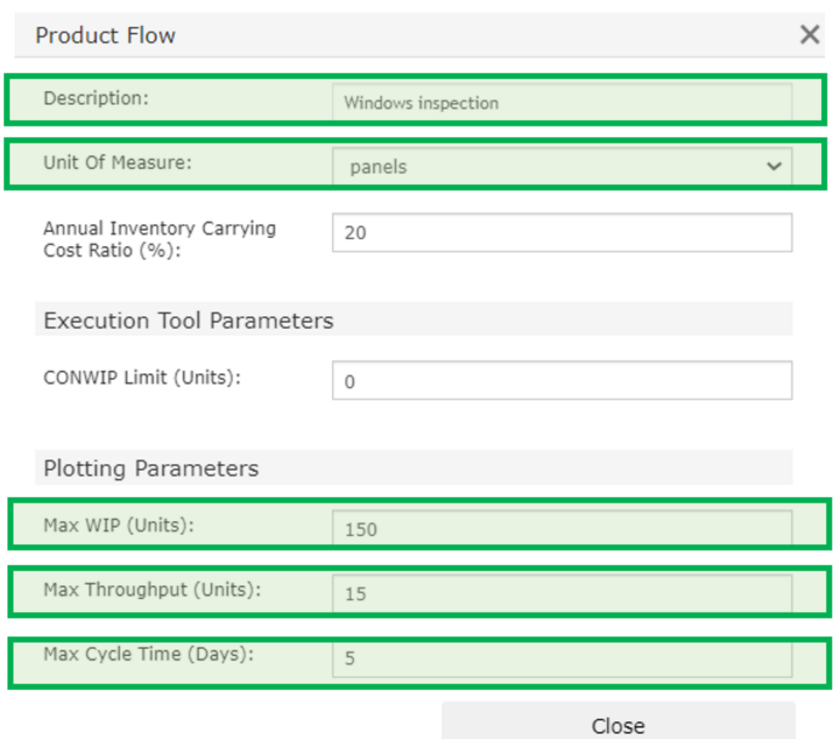


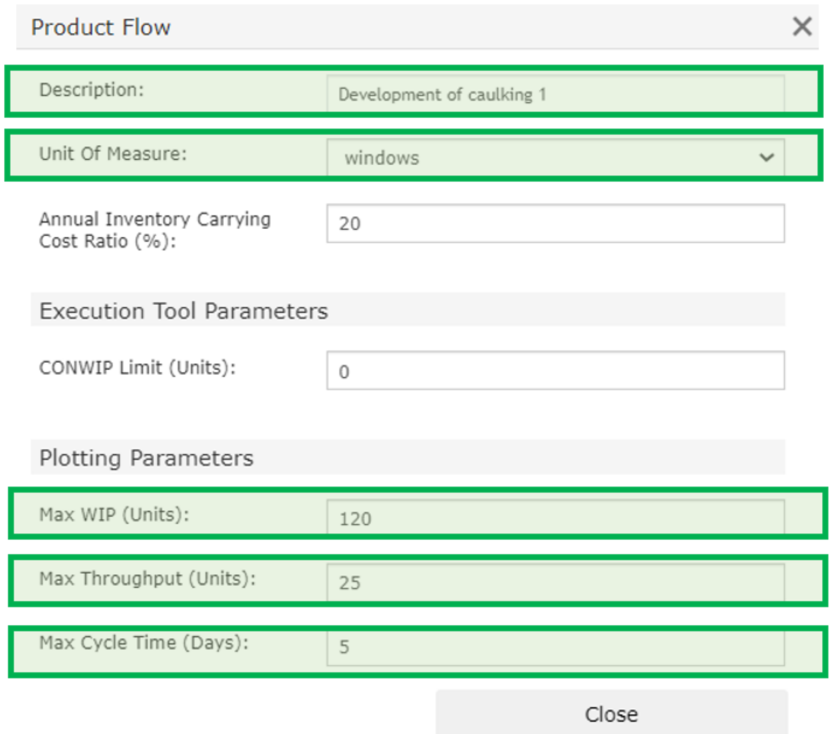
Product Flows

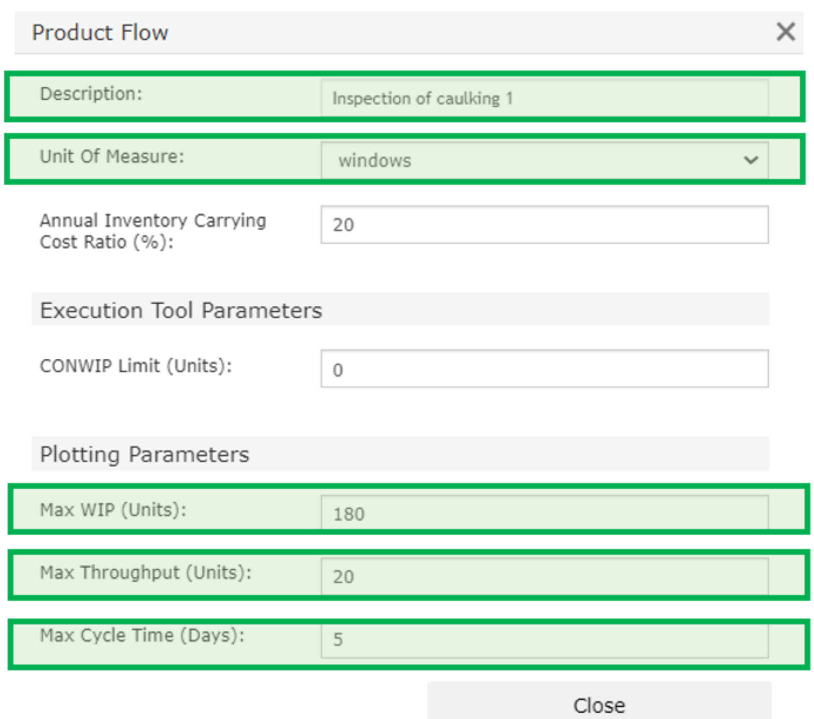




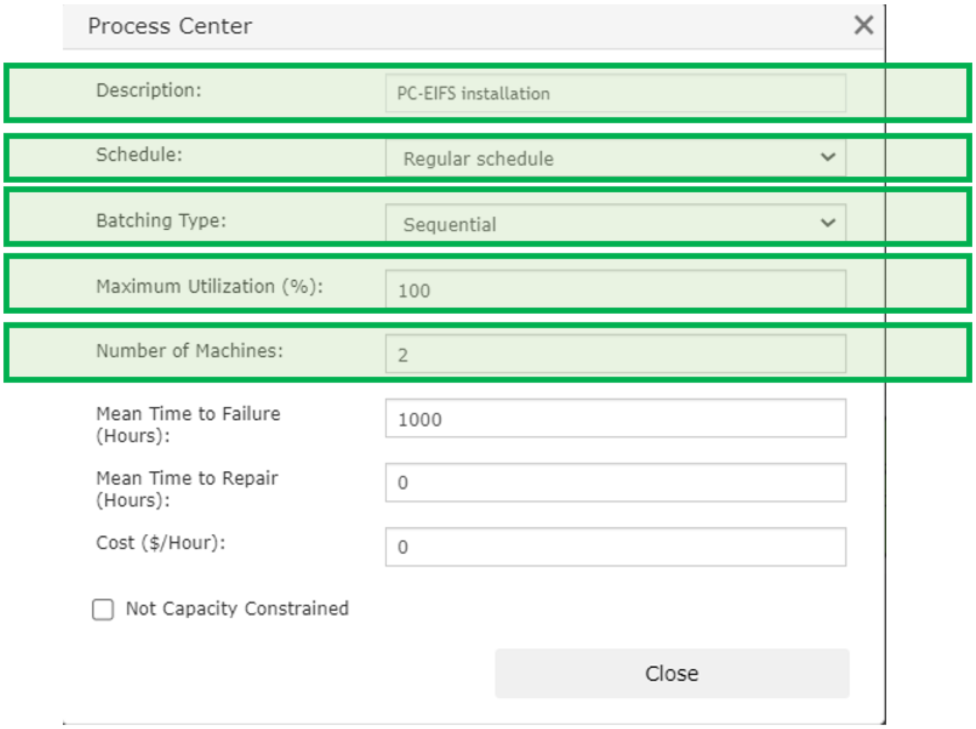

Product Flow
Description:
Windows installation
Unit Of Measure:
windows
Annual Inventory Carrying Cost Ratio (%):
20
Execution Tool Parameters
CONWIP Limit (Units):
0
Plotting Parameters
Max WIP (Units):
100
Max Throughput (Units):
10
Max Cycle Time (Days):
10
Close

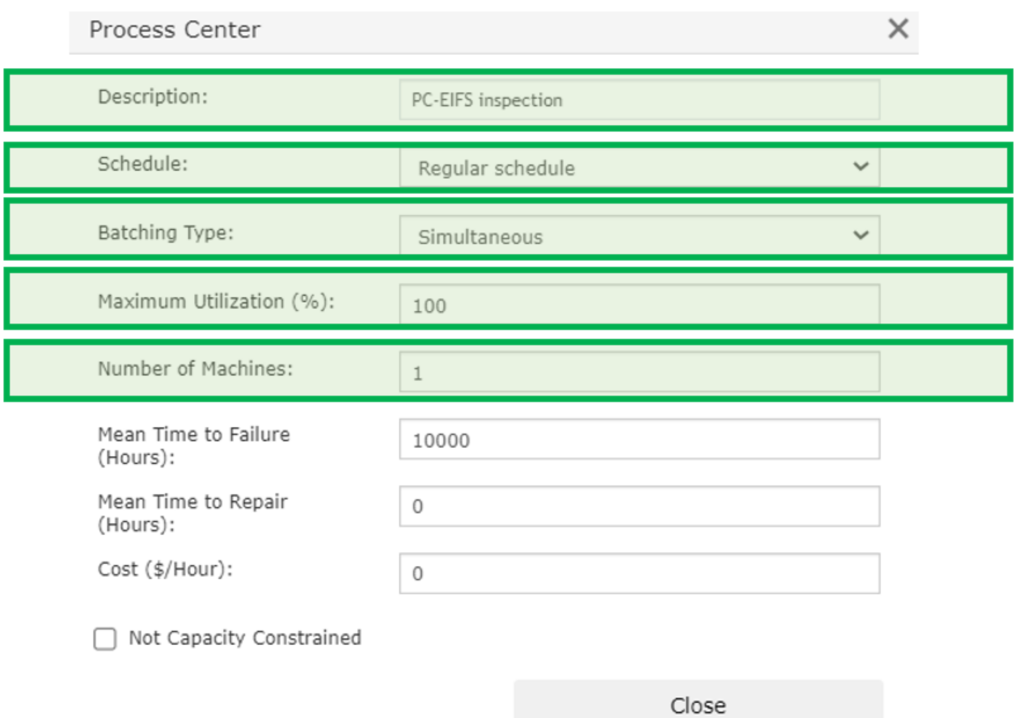

Product Flow
Description:
Windows inspection
Unit Of Measure:
panels
Annual Inventory Carrying Cost Ratio (%):
20
Execution Tool Parameters
CONWIP Limit (Units):
0
Plotting Parameters
Max WIP (Units):
150
Max Throughput (Units):
15
Max Cycle Time (Days):
5
Close

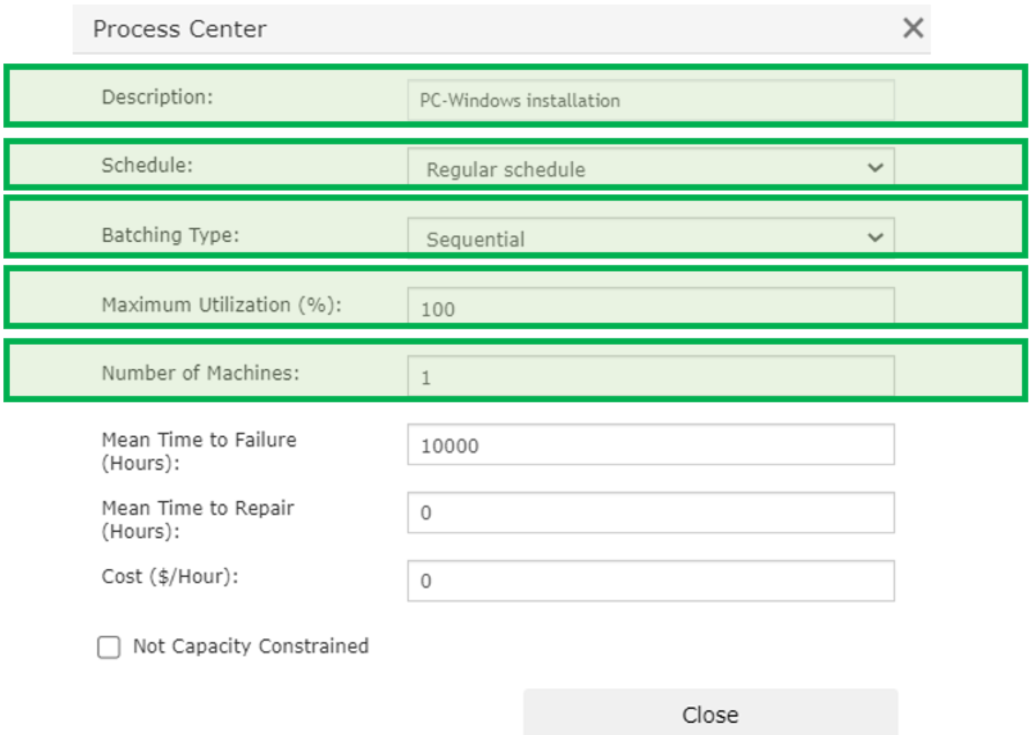

Product Flow
Description:
Development of caulking 1
Unit Of Measure:
windows
Annual Inventory Carrying Cost Ratio (%):
20
Execution Tool Parameters
CONWIP Limit (Units):
0
Plotting Parameters
Max WIP (Units):
120
Max Throughput (Units):
25
Max Cycle Time (Days):
5
Close

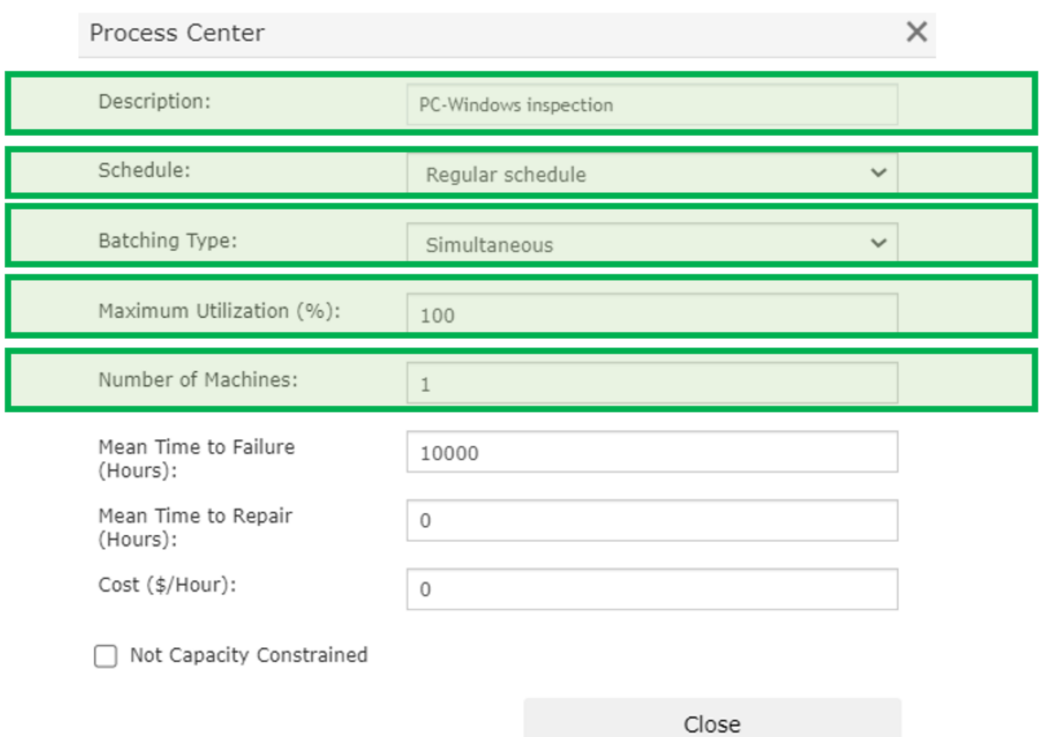

Product Flow
Description:
Inspection of caulking 1
Unit Of Measure:
windows
Annual Inventory Carrying Cost Ratio (%):
20
Execution Tool Parameters
CONWIP Limit (Units):
0
Plotting Parameters
Max WIP (Units):
180
Max Throughput (Units):
20
Max Cycle Time (Days):
5
Close

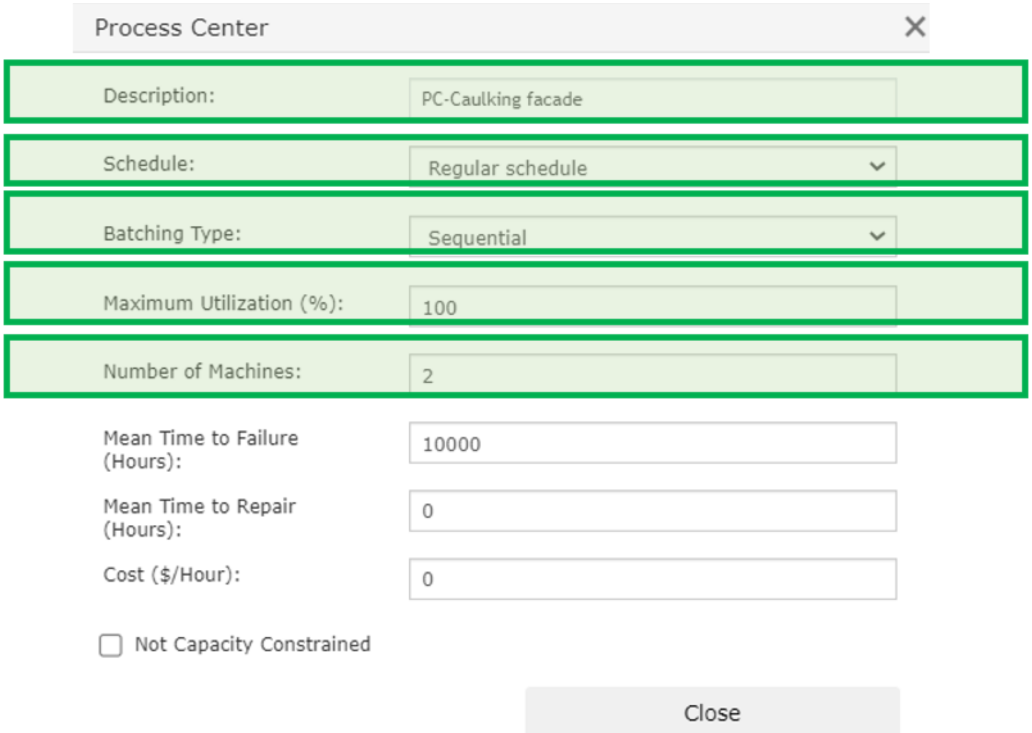
Process Centers

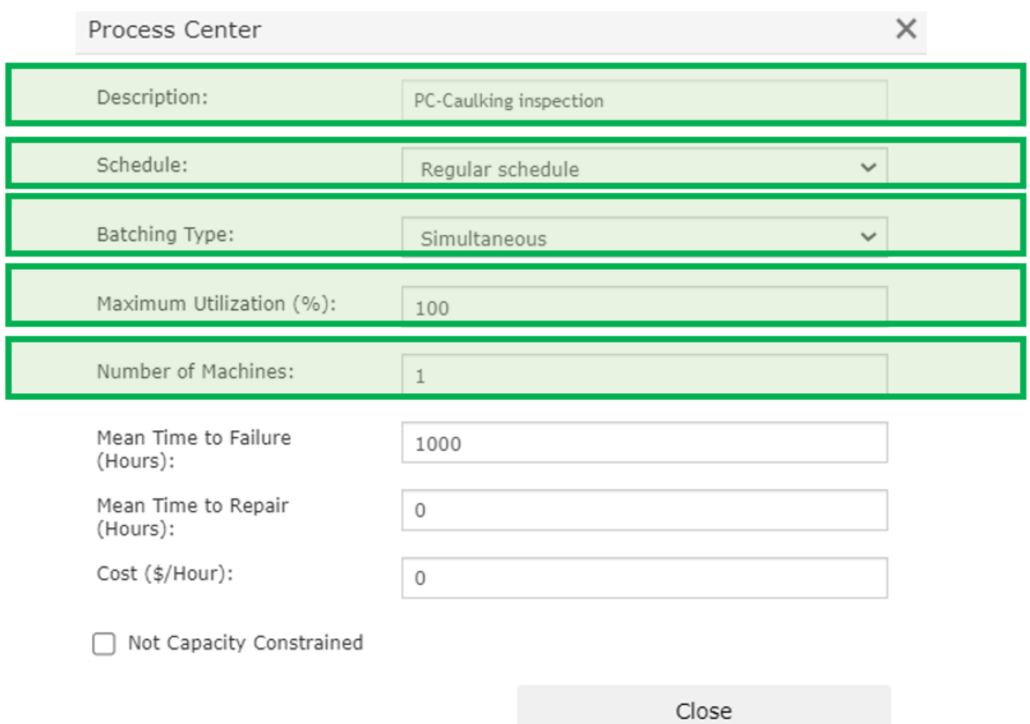




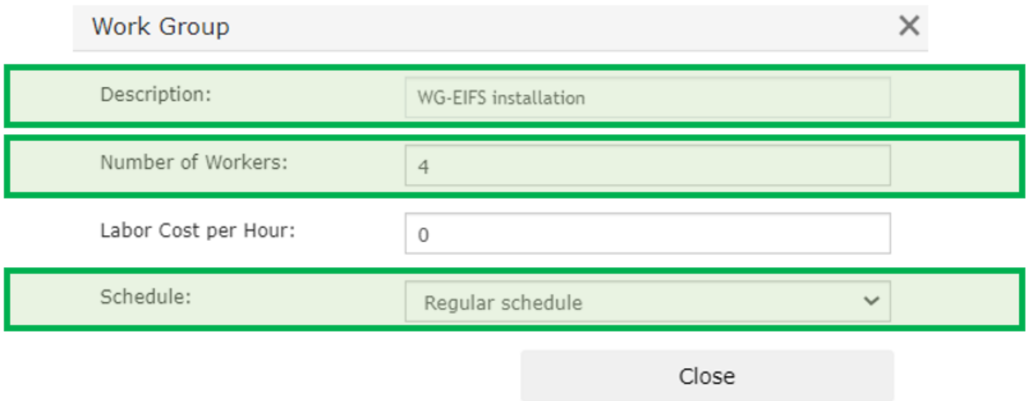

Process Center
Description:
PC-Windows installation
Schedule:
Regular schedule
Batching Type:
Sequential
Maximum Utilization (%):
100
Number of Machines:
1
Mean Time to Failure (Hours):
10000
Mean Time to Repair (Hours):
0
Cost ($/Hour):
0
Not Capacity Constrained
Close

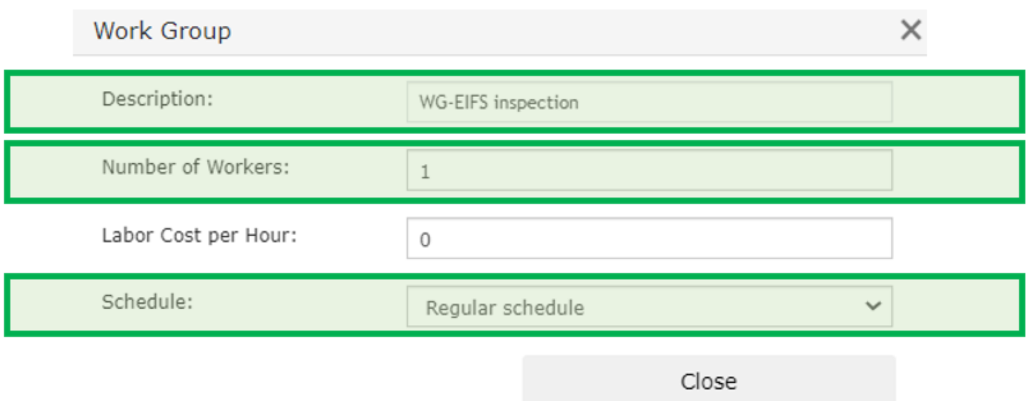

Process Center
Description:
PC-Windows inspection
Schedule:
Regular schedule
Batching Type:
Simultaneous
Maximum Utilization (%):
100
Number of Machines:
1
Mean Time to Failure (Hours):
10000
Mean Time to Repair (Hours):
0
Cost ($/Hour):
0
Not Capacity Constrained
Close

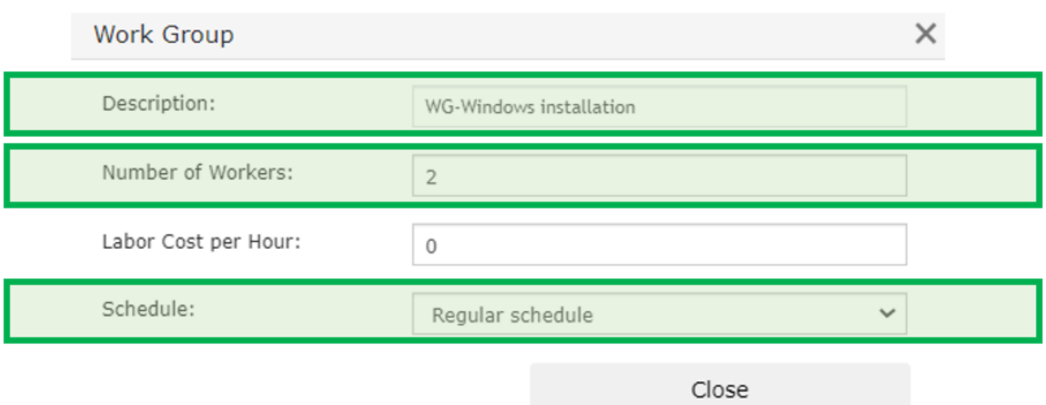

Process Center
Description:
PC-Caulking facade
Schedule:
Regular schedule
Batching Type:
Sequential
Maximum Utilization (%):
100
Number of Machines:
2
Mean Time to Failure (Hours):
10000
Mean Time to Repair (Hours):
0
Cost ($/Hour):
0
Not Capacity Constrained
Close

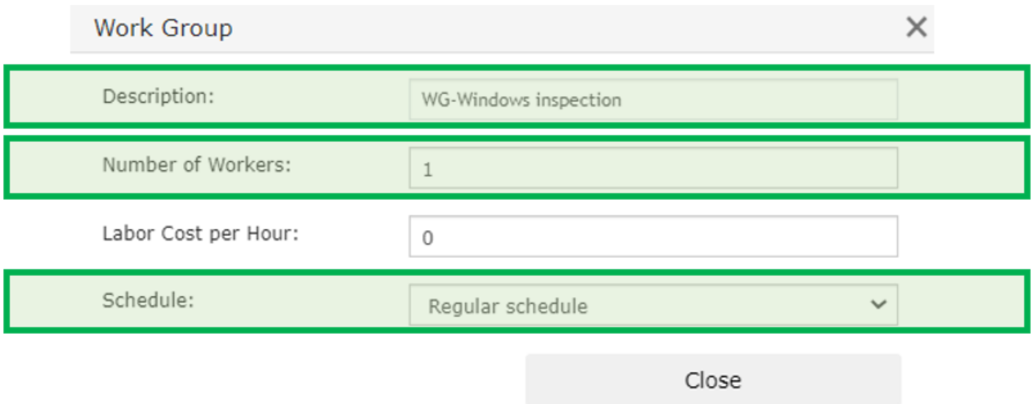

Process Center
Description:
PC-Caulking inspection
Schedule:
Regular schedule
Batching Type:
Simultaneous
Maximum Utilization (%):
100
Number of Machines:
1
Mean Time to Failure (Hours):
1000
Mean Time to Repair (Hours):
0
Cost ($/Hour):
0
Not Capacity Constrained
Close

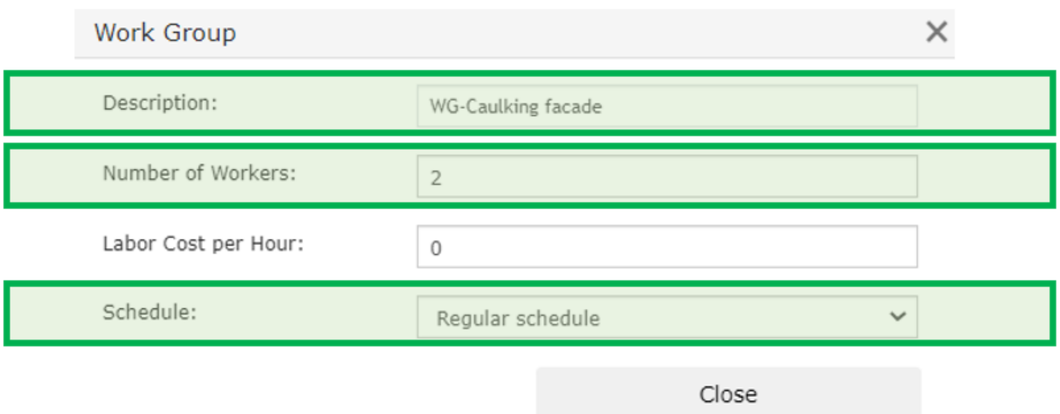
Work Groups

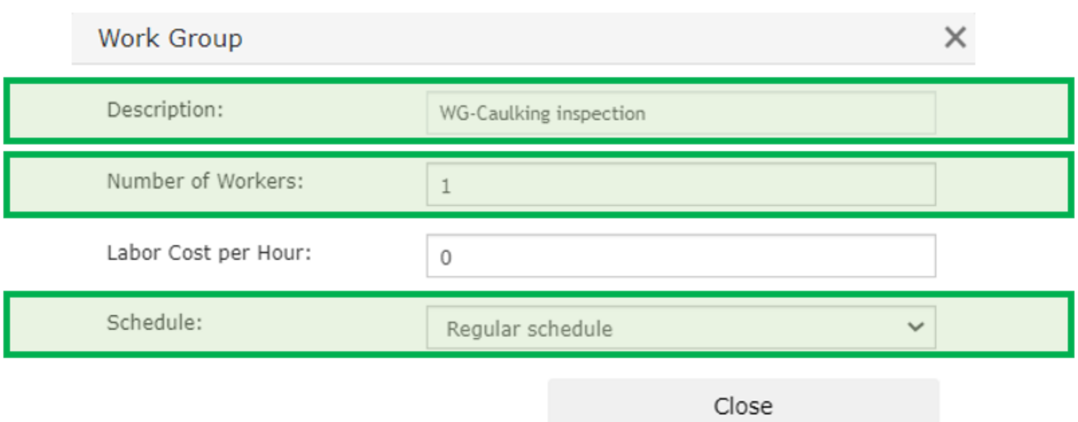

Work Group
Description:
WG-EIFS installation
Number of Workers:
4
Labor Cost per Hour:
0
Schedule:
Regular schedule
Close


Work Group
Description:
WG-EIFS inspection
Number of Workers:
1
Labor Cost per Hour:
0
Schedule:
Regular schedule
Close

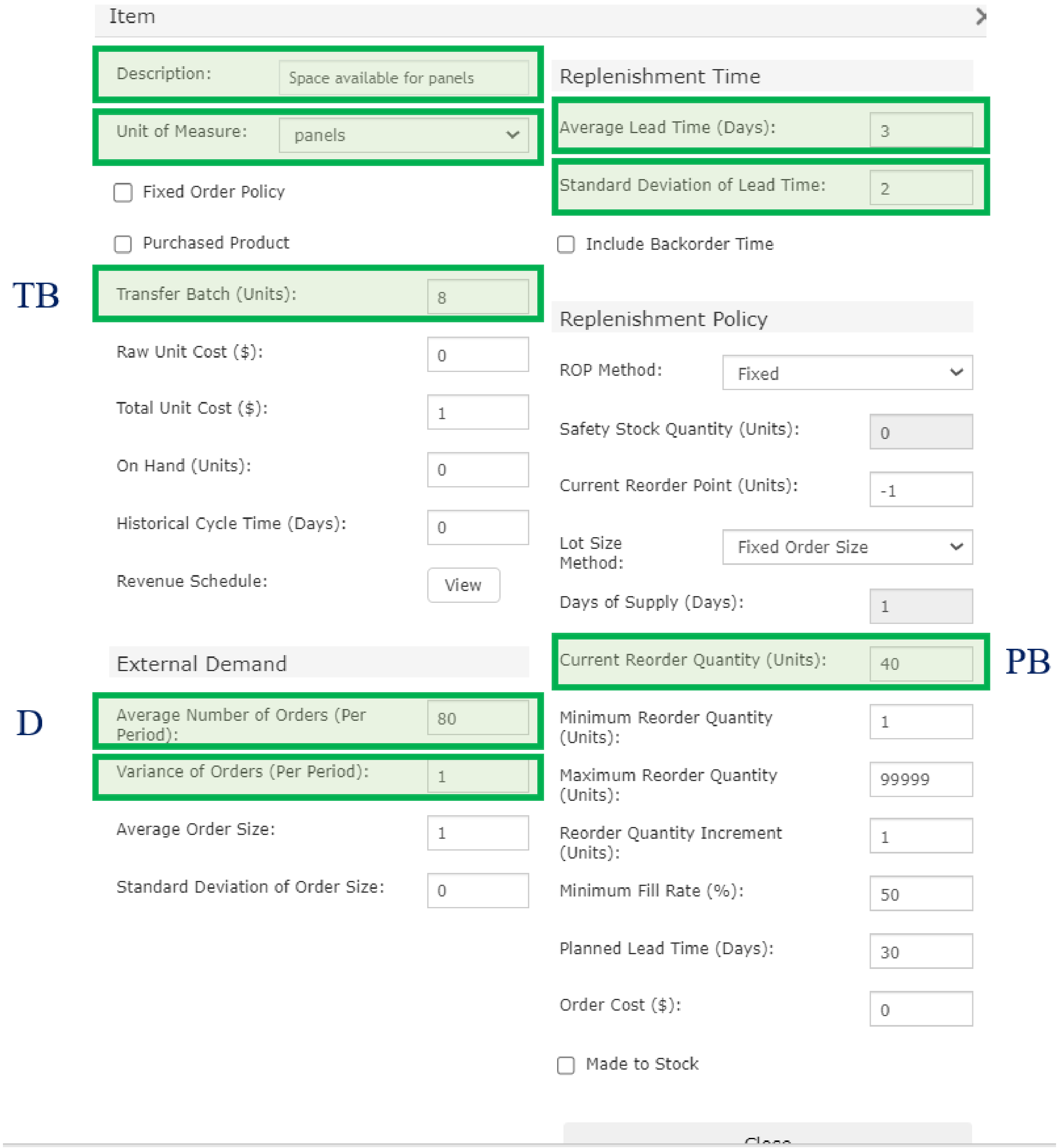

Work Group
Description:
WG-Windows installation
Number of Workers:
2
Labor Cost per Hour:
0
Schedule:
Regular schedule
Close


Work Group
Description:
WG-Windows inspection
Number of Workers:
1
Labor Cost per Hour:
0
Schedule:
Regular schedule
Close


Work Group
Description:
WG-Caulking facade
Number of Workers:
2
Labor Cost per Hour:
0
Schedule:
Regular schedule
Close


Work Group
Description:
WG-Caulking inspection
Number of Workers:
1
Labor Cost per Hour:
0
Schedule:
Regular schedule
Close

__Items__



Item

Description: Space available for panels

Unit of Measure: panels

Fixed Order Policy

Purchased Product

TB Transfer Batch (Units): 8

Raw Unit Cost ($): 0

Total Unit Cost ($): 1

On Hand (Units): 0

Historical Cycle Time (Days): 0

Revenue Schedule: View

External Demand

D Average Number of Orders (Per Period): 80

Variance of Orders (Per Period): 1

Average Order Size: 1

Standard Deviation of Order Size: 0

Replenishment Time

Average Lead Time (Days): 3

Standard Deviation of Lead Time: 2

Include Backorder Time

Replenishment Policy

ROP Method: Fixed

Safety Stock Quantity (Units): 0

Current Reorder Point (Units): -1

Lot Size Method: Fixed Order Size

Days of Supply (Days): 1

Current Reorder Quantity (Units): 40 PB

Minimum Reorder Quantity (Units): 1

Maximum Reorder Quantity (Units): 99999

Reorder Quantity Increment (Units): 1

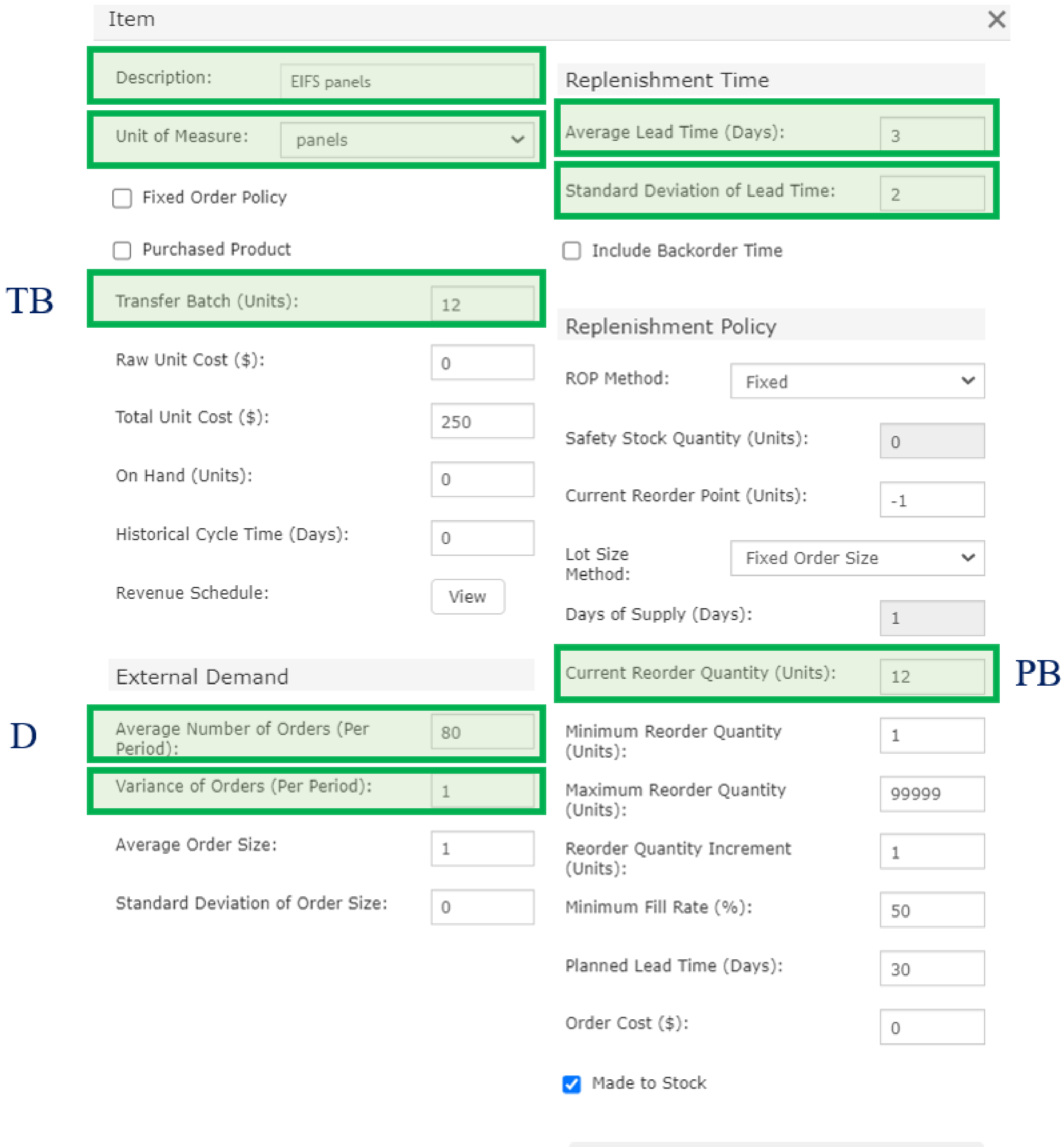
Minimum Fill Rate (%): 50

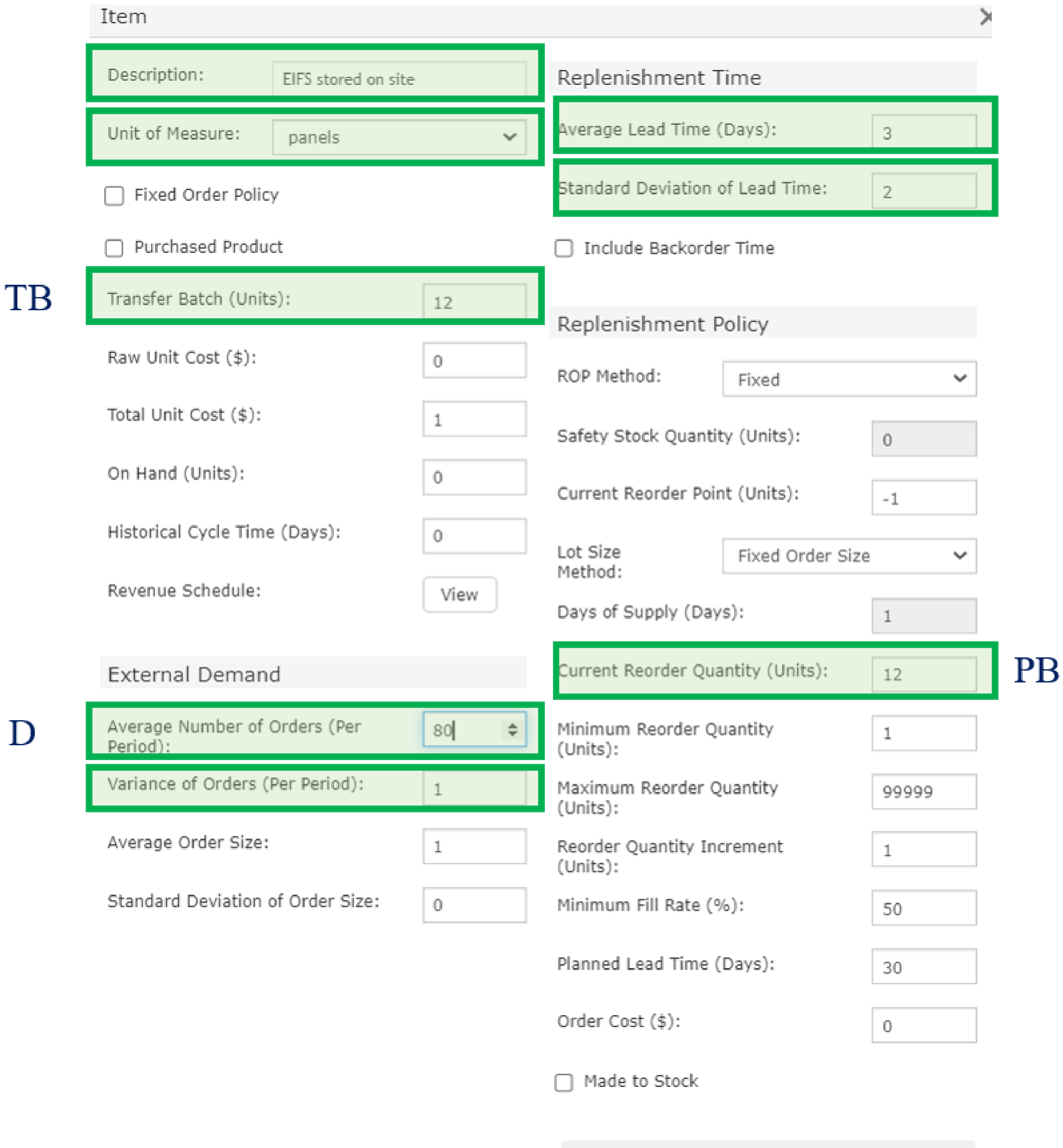
Planned Lead Time (Days): 30

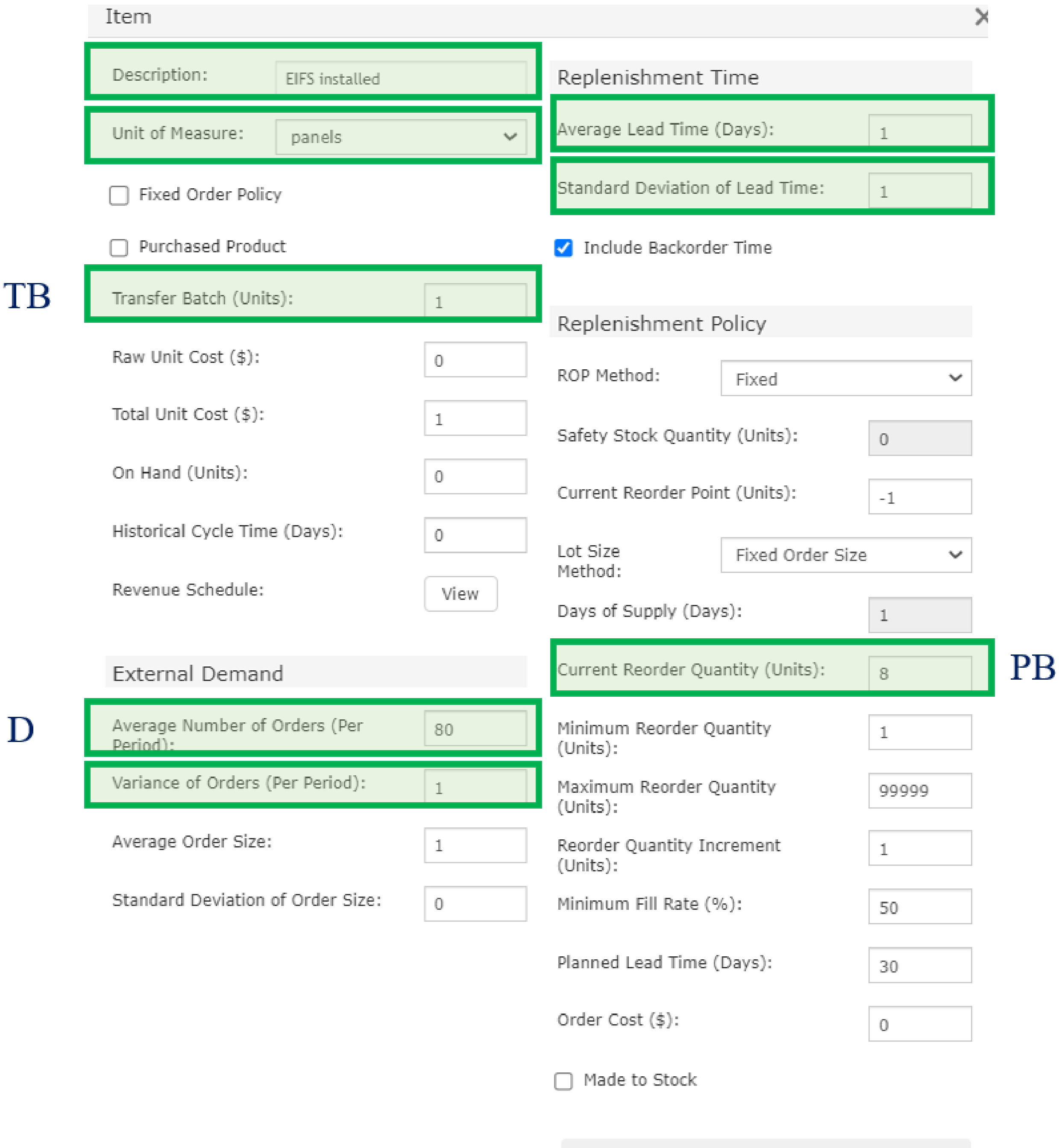
Order Cost ($): 0

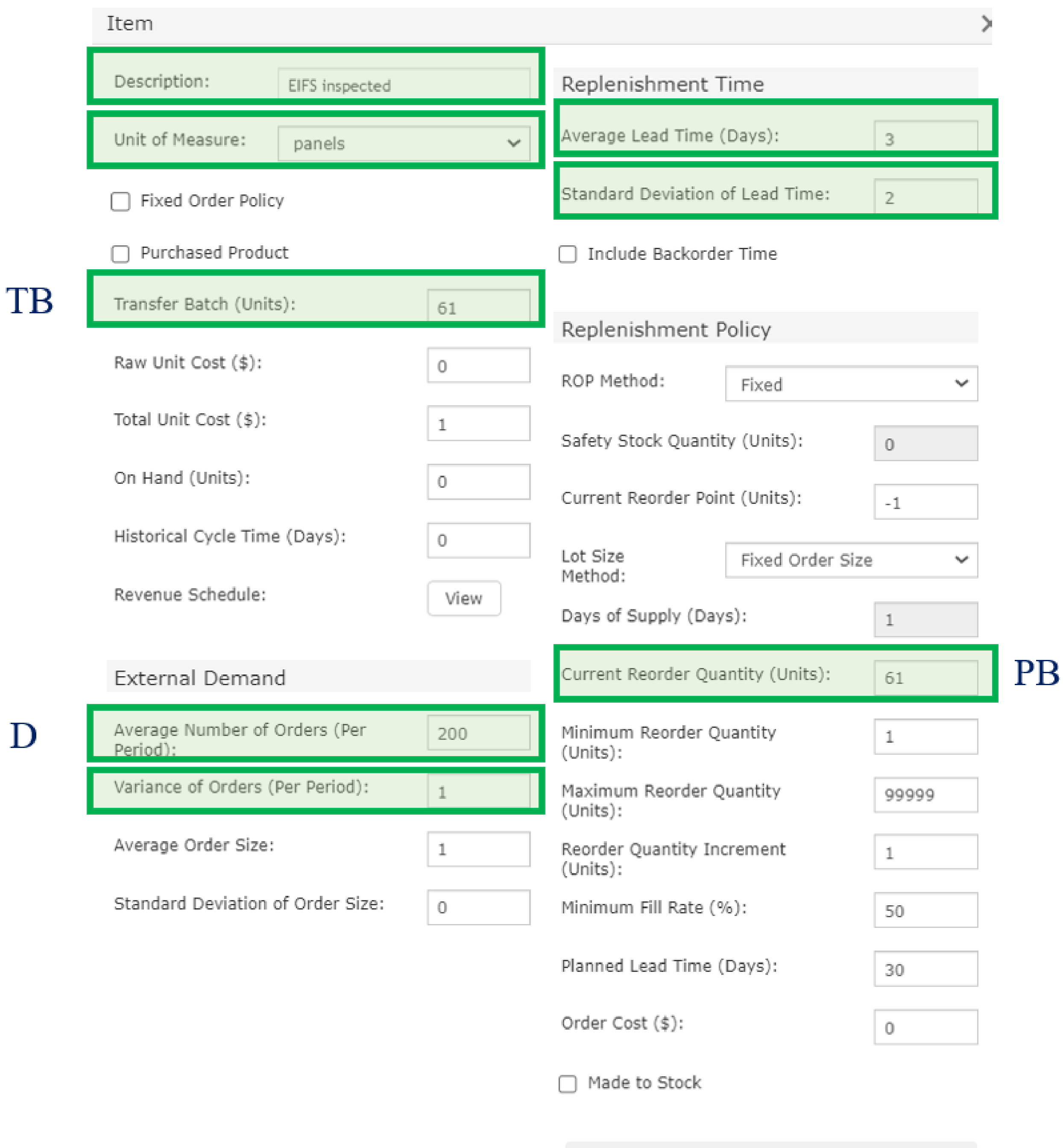
Made to Stock

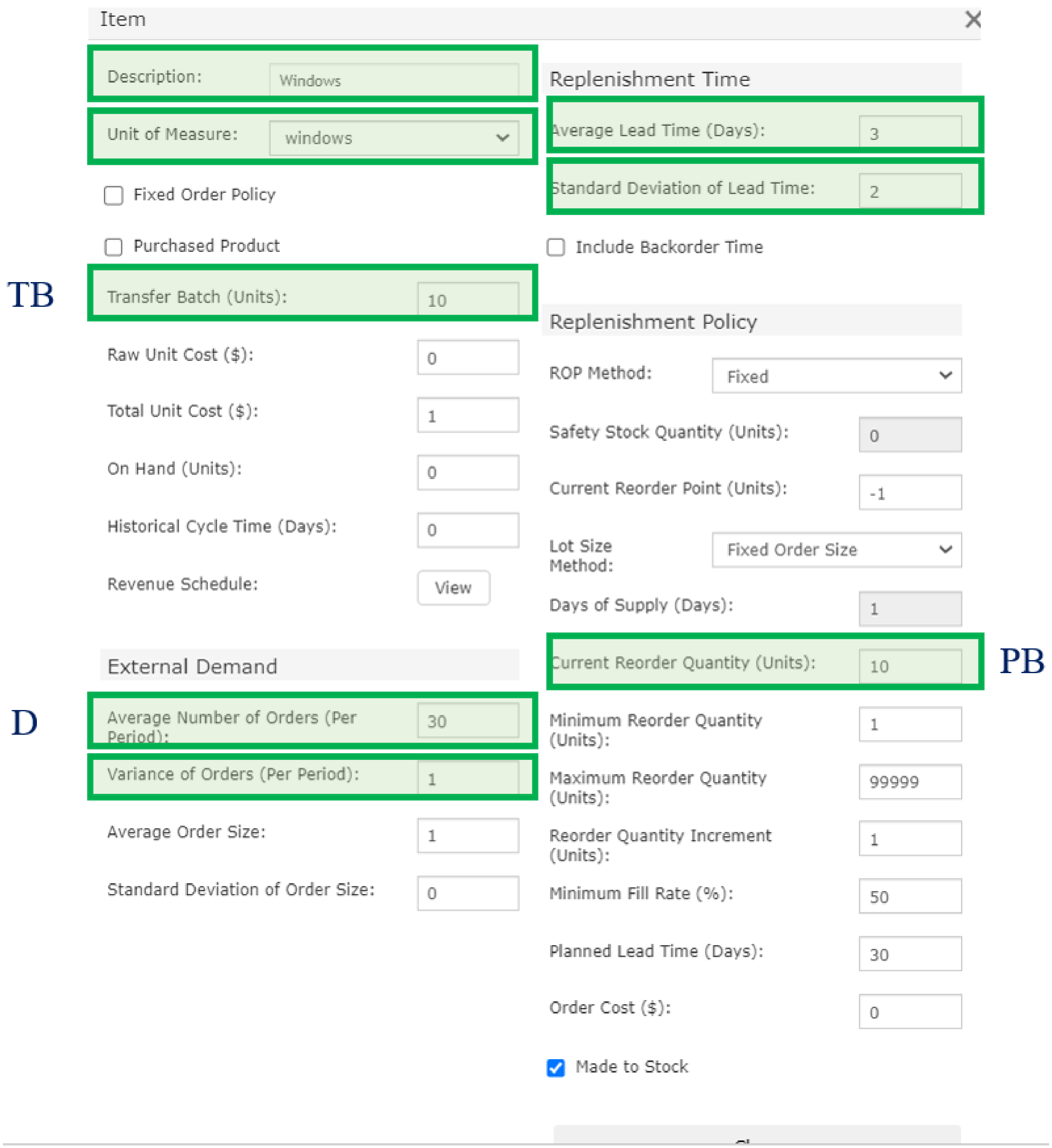
Close

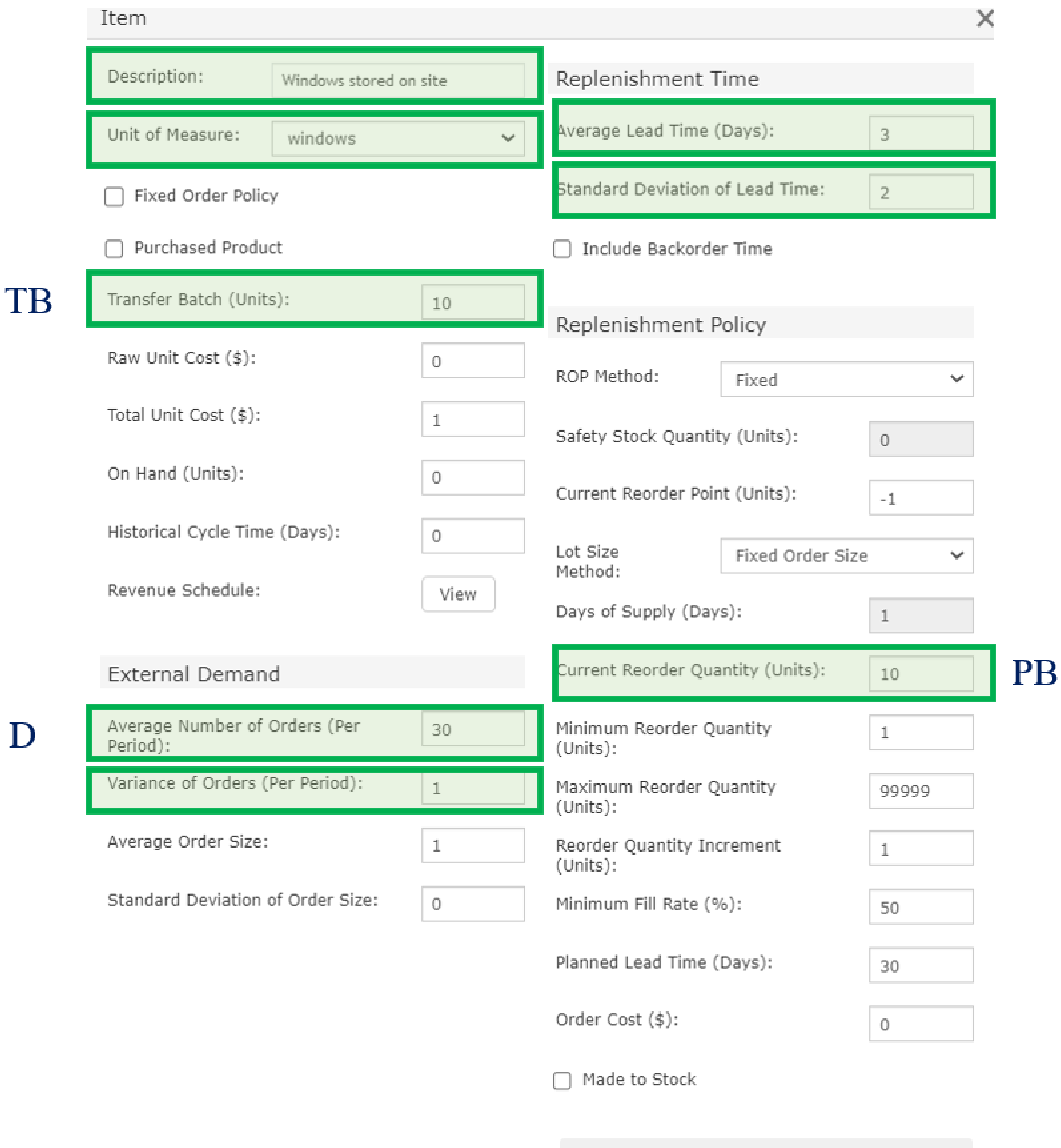

Item
Description: EIFS panels
Unit of Measure: panels
Fixed Order Policy
Purchased Product
TB
Transfer Batch (Units): 12
Raw Unit Cost ($): 0
Total Unit Cost ($): 250
On Hand (Units): 0
Historical Cycle Time (Days): 0
Revenue Schedule: View
External Demand
D
Average Number of Orders (Per Period): 80
Variance of Orders (Per Period): 1
Average Order Size: 1
Standard Deviation of Order Size: 0
Replenishment Time
Average Lead Time (Days): 3
Standard Deviation of Lead Time: 2
Include Backorder Time
Replenishment Policy
ROP Method: Fixed
Safety Stock Quantity (Units): 0
Current Reorder Point (Units): -1
Lot Size Method: Fixed Order Size
Days of Supply (Days): 1
Current Reorder Quantity (Units): 12
PB
Minimum Reorder Quantity (Units): 1
Maximum Reorder Quantity (Units): 99999
Reorder Quantity Increment (Units): 1
Minimum Fill Rate (%): 50
Planned Lead Time (Days): 30
Order Cost ($): 0
Made to Stock

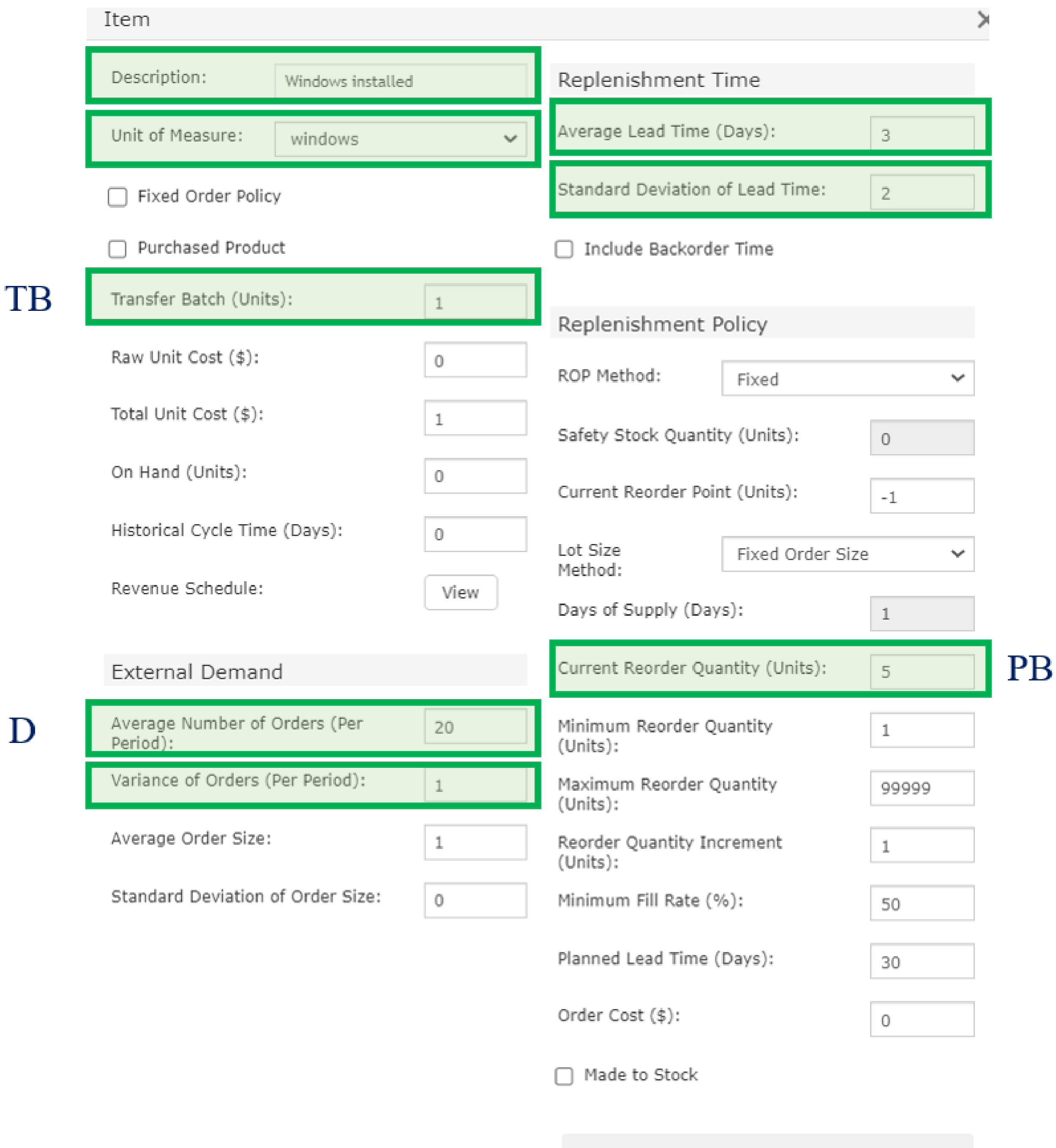

Item
Description:
EIFS stored on site
Unit of Measure:
panels
Fixed Order Policy
Purchased Product
TB
Transfer Batch (Units):
12
Raw Unit Cost ($):
0
Total Unit Cost ($):
1
On Hand (Units):
0
Historical Cycle Time (Days):
0
Revenue Schedule:
View
External Demand
D
Average Number of Orders (Per Period):
80
Variance of Orders (Per Period):
1
Average Order Size:
1
Standard Deviation of Order Size:
0
Replenishment Time
Average Lead Time (Days):
3
Standard Deviation of Lead Time:
2
Include Backorder Time
Replenishment Policy
ROP Method:
Fixed
Safety Stock Quantity (Units):
0
Current Reorder Point (Units):
-1
Lot Size Method:
Fixed Order Size
Days of Supply (Days):
1
Current Reorder Quantity (Units):
12
PB
Minimum Reorder Quantity (Units):
1
Maximum Reorder Quantity (Units):
99999
Reorder Quantity Increment (Units):
1
Minimum Fill Rate (%):
50
Planned Lead Time (Days):
30
Order Cost ($):
0
Made to Stock

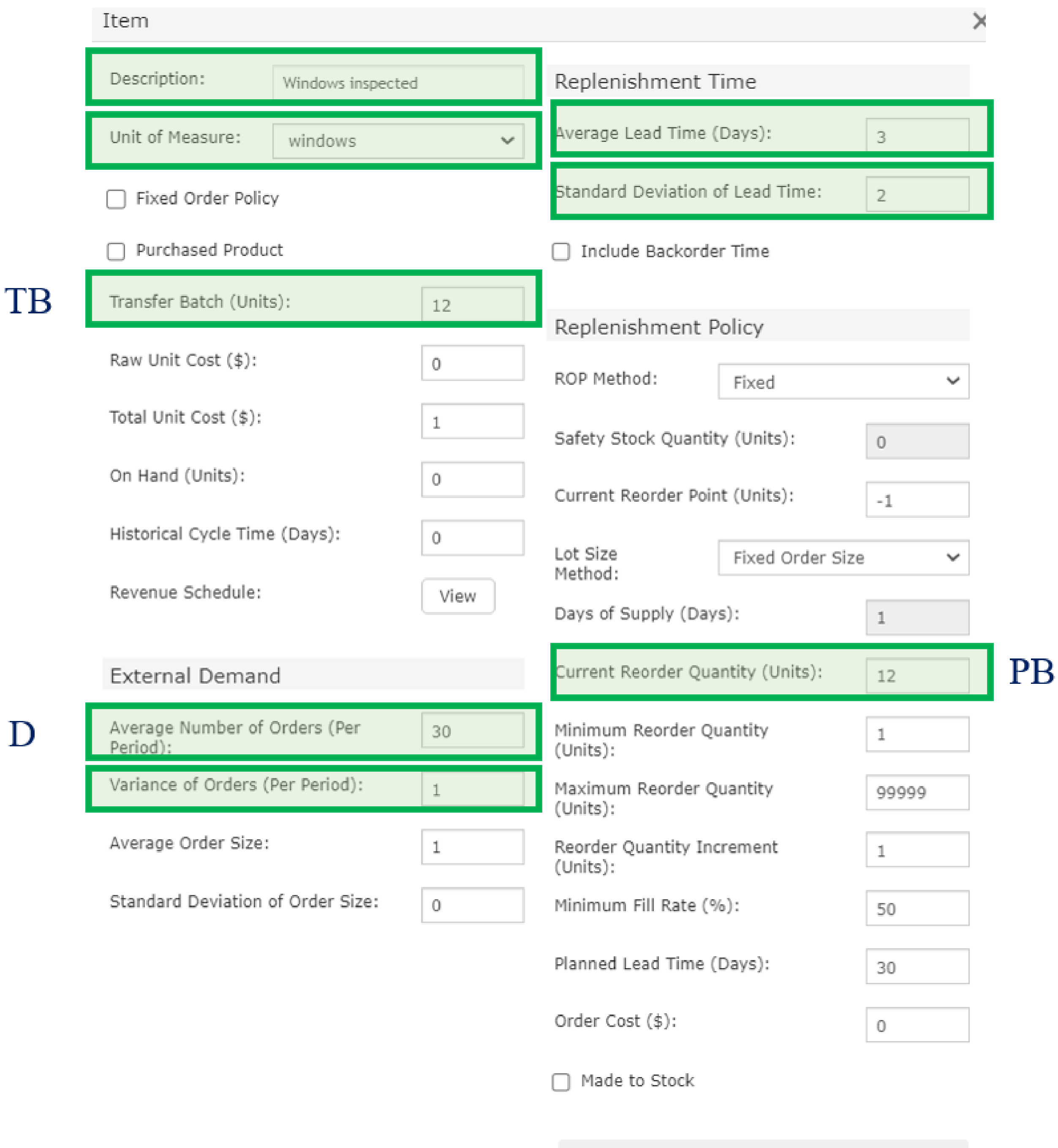

Item
Description:
EIFS installed
Unit of Measure:
panels
Fixed Order Policy
Purchased Product
TB
Transfer Batch (Units):
1
Raw Unit Cost ($):
0
Total Unit Cost ($):
1
On Hand (Units):
0
Historical Cycle Time (Days):
0
Revenue Schedule:
View
External Demand
D
Average Number of Orders (Per Period):
80
Variance of Orders (Per Period):
1
Average Order Size:
1
Standard Deviation of Order Size:
0
Replenishment Time
Average Lead Time (Days):
1
Standard Deviation of Lead Time:
1
Include Backorder Time
Replenishment Policy
ROP Method:
Fixed
Safety Stock Quantity (Units):
0
Current Reorder Point (Units):
-1
Lot Size Method:
Fixed Order Size
Days of Supply (Days):
1
Current Reorder Quantity (Units):
8
PB
Minimum Reorder Quantity (Units):
1
Maximum Reorder Quantity (Units):
99999
Reorder Quantity Increment (Units):
1
Minimum Fill Rate (%):
50
Planned Lead Time (Days):
30
Order Cost ($):
0
Made to Stock

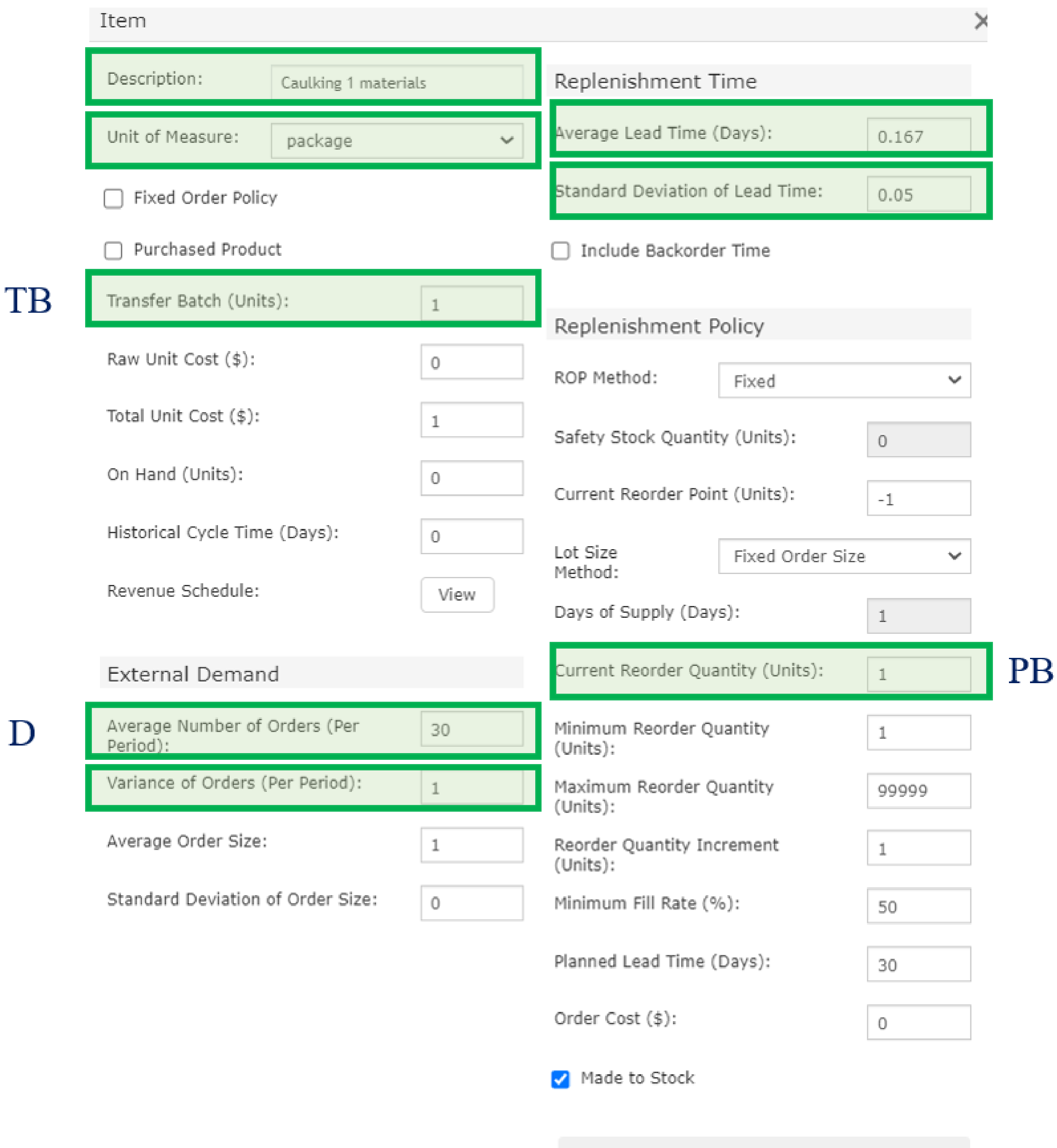

Item
Description: EIFS inspected
Unit of Measure: panels
Fixed Order Policy
Purchased Product
TB
Transfer Batch (Units): 61
Raw Unit Cost ($): 0
Total Unit Cost ($): 1
On Hand (Units): 0
Historical Cycle Time (Days): 0
Revenue Schedule: View
External Demand
D
Average Number of Orders (Per Period): 200
Variance of Orders (Per Period): 1
Average Order Size: 1
Standard Deviation of Order Size: 0
Replenishment Time
Average Lead Time (Days): 3
Standard Deviation of Lead Time: 2
Include Backorder Time
Replenishment Policy
ROP Method: Fixed
Safety Stock Quantity (Units): 0
Current Reorder Point (Units): -1
Lot Size Method: Fixed Order Size
Days of Supply (Days): 1
Current Reorder Quantity (Units): 61
PB
Minimum Reorder Quantity (Units): 1
Maximum Reorder Quantity (Units): 99999
Reorder Quantity Increment (Units): 1
Minimum Fill Rate (%): 50
Planned Lead Time (Days): 30
Order Cost ($): 0
Made to Stock

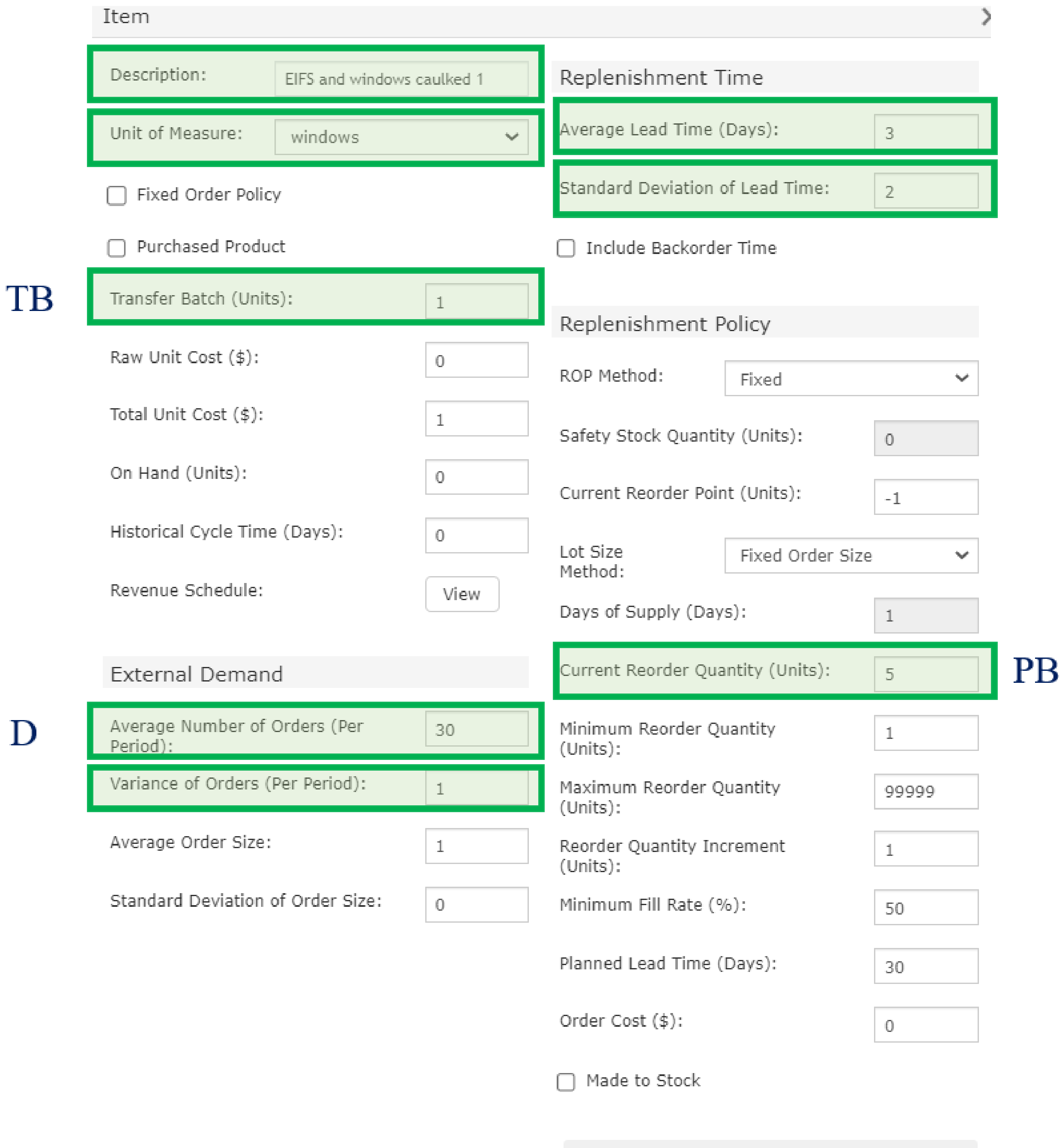

Item
Description:
Windows
Unit of Measure:
windows
Fixed Order Policy
Purchased Product
TB
Transfer Batch (Units):
10
Raw Unit Cost ($):
0
Total Unit Cost ($):
1
On Hand (Units):
0
Historical Cycle Time (Days):
0
Revenue Schedule:
View
External Demand
D
Average Number of Orders (Per Period):
30
Variance of Orders (Per Period):
1
Average Order Size:
1
Standard Deviation of Order Size:
0
Replenishment Time
Average Lead Time (Days):
3
Standard Deviation of Lead Time:
2
Include Backorder Time
Replenishment Policy
ROP Method:
Fixed
Safety Stock Quantity (Units):
0
Current Reorder Point (Units):
-1
Lot Size Method:
Fixed Order Size
Days of Supply (Days):
1
Current Reorder Quantity (Units):
10
PB
Minimum Reorder Quantity (Units):
1
Maximum Reorder Quantity (Units):
99999
Reorder Quantity Increment (Units):
1
Minimum Fill Rate (%):
50
Planned Lead Time (Days):
30
Order Cost ($):
0
Made to Stock

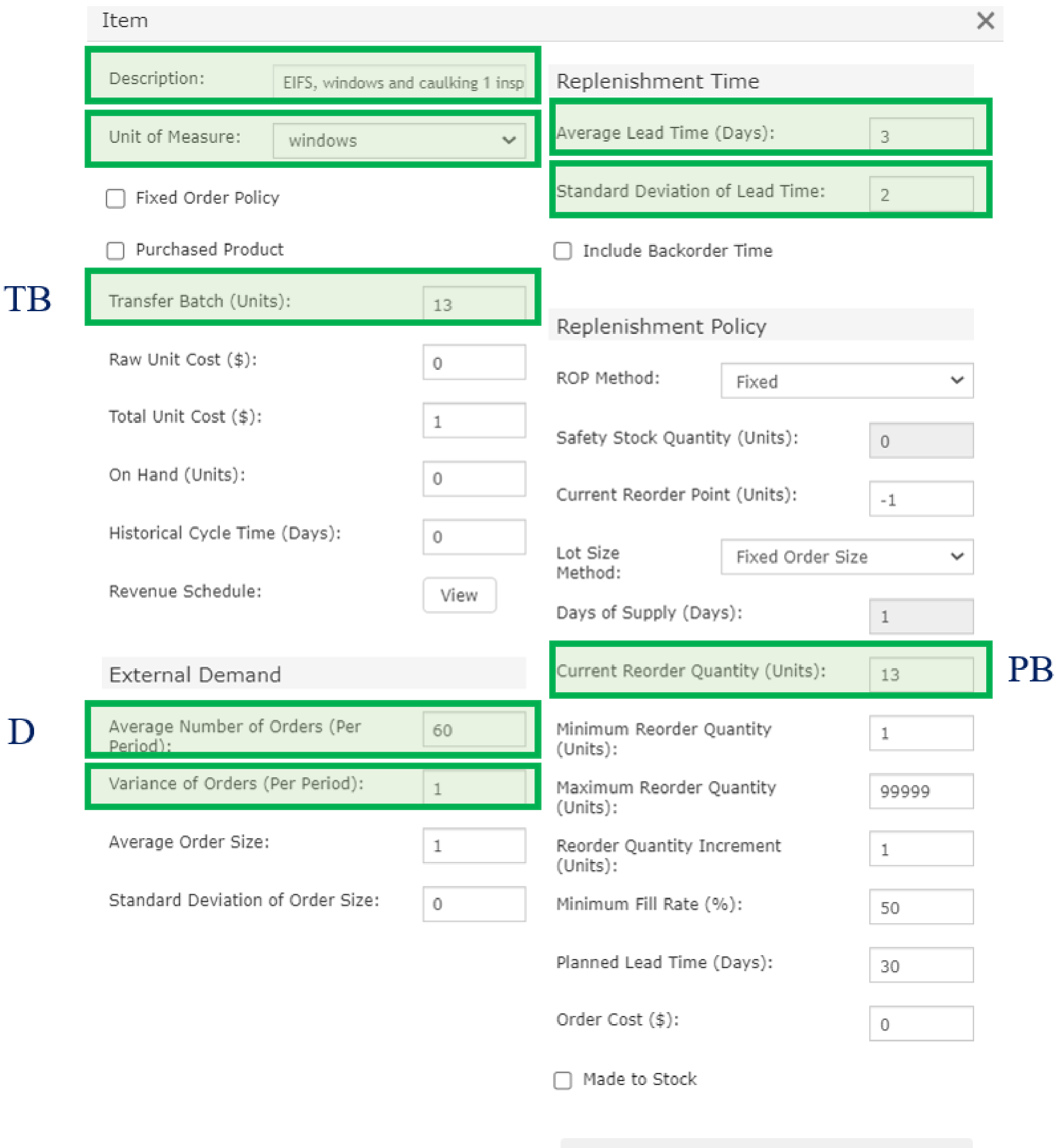

Item
Description:
Windows stored on site
Unit of Measure:
windows
Fixed Order Policy
Purchased Product
TB
Transfer Batch (Units):
10
Raw Unit Cost ($):
0
Total Unit Cost ($):
1
On Hand (Units):
0
Historical Cycle Time (Days):
0
Revenue Schedule:
View
External Demand
D
Average Number of Orders (Per Period):
30
Variance of Orders (Per Period):
1
Average Order Size:
1
Standard Deviation of Order Size:
0
Replenishment Time
Average Lead Time (Days):
3
Standard Deviation of Lead Time:
2
Include Backorder Time
Replenishment Policy
ROP Method:
Fixed
Safety Stock Quantity (Units):
0
Current Reorder Point (Units):
-1
Lot Size Method:
Fixed Order Size
Days of Supply (Days):
1
Current Reorder Quantity (Units):
10
PB
Minimum Reorder Quantity (Units):
1
Maximum Reorder Quantity (Units):
99999
Reorder Quantity Increment (Units):
1
Minimum Fill Rate (%):
50
Planned Lead Time (Days):
30
Order Cost ($):
0
Made to Stock


Item
Description: Windows installed
Unit of Measure: windows
Fixed Order Policy
Purchased Product
TB
Transfer Batch (Units): 1
Raw Unit Cost ($): 0
Total Unit Cost ($): 1
On Hand (Units): 0
Historical Cycle Time (Days): 0
Revenue Schedule: View
External Demand
D
Average Number of Orders (Per Period): 20
Variance of Orders (Per Period): 1
Average Order Size: 1
Standard Deviation of Order Size: 0
Replenishment Time
Average Lead Time (Days): 3
Standard Deviation of Lead Time: 2
Include Backorder Time
Replenishment Policy
ROP Method: Fixed
Safety Stock Quantity (Units): 0
Current Reorder Point (Units): -1
Lot Size Method: Fixed Order Size
Days of Supply (Days): 1
Current Reorder Quantity (Units): 5
PB
Minimum Reorder Quantity (Units): 1
Maximum Reorder Quantity (Units): 99999
Reorder Quantity Increment (Units): 1
Minimum Fill Rate (%): 50
Planned Lead Time (Days): 30
Order Cost ($): 0
Made to Stock

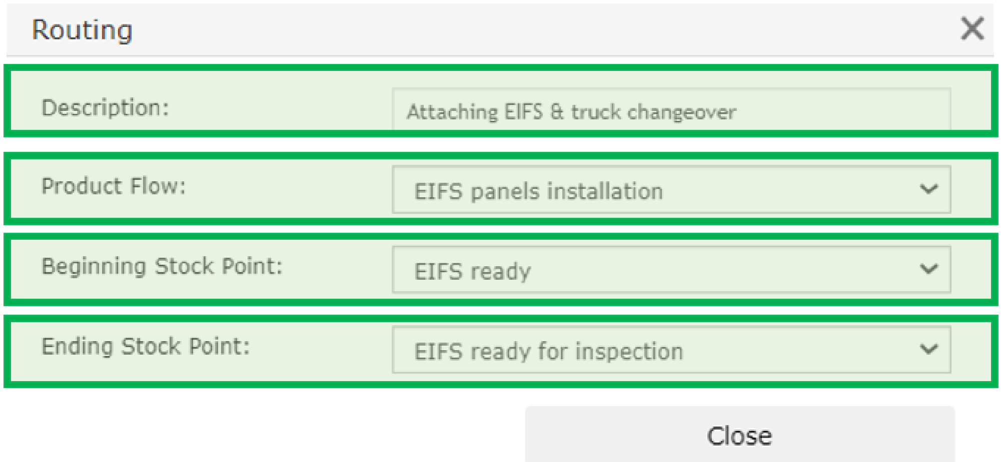

Item
Description: Windows inspected
Unit of Measure: windows
Fixed Order Policy
Purchased Product
TB
Transfer Batch (Units): 12
Raw Unit Cost ($): 0
Total Unit Cost ($): 1
On Hand (Units): 0
Historical Cycle Time (Days): 0
Revenue Schedule: View
External Demand
D
Average Number of Orders (Per Period): 30
Variance of Orders (Per Period): 1
Average Order Size: 1
Standard Deviation of Order Size: 0
Replenishment Time
Average Lead Time (Days): 3
Standard Deviation of Lead Time: 2
Include Backorder Time
Replenishment Policy
ROP Method: Fixed
Safety Stock Quantity (Units): 0
Current Reorder Point (Units): -1
Lot Size Method: Fixed Order Size
Days of Supply (Days): 1
Current Reorder Quantity (Units): 12
PB
Minimum Reorder Quantity (Units): 1
Maximum Reorder Quantity (Units): 99999
Reorder Quantity Increment (Units): 1
Minimum Fill Rate (%): 50
Planned Lead Time (Days): 30
Order Cost ($): 0
Made to Stock

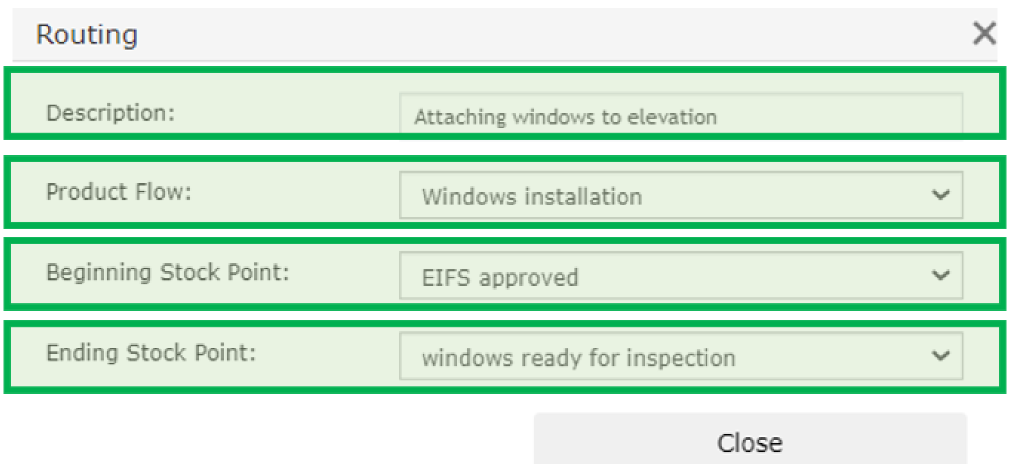

Item
Description:
Caulking 1 materials
Unit of Measure:
package
Fixed Order Policy
Purchased Product
TB
Transfer Batch (Units):
1
Raw Unit Cost ($):
0
Total Unit Cost ($):
1
On Hand (Units):
0
Historical Cycle Time (Days):
0
Revenue Schedule:
View
External Demand
D
Average Number of Orders (Per Period):
30
Variance of Orders (Per Period):
1
Average Order Size:
1
Standard Deviation of Order Size:
0
Replenishment Time
Average Lead Time (Days):
0.167
Standard Deviation of Lead Time:
0.05
Include Backorder Time
Replenishment Policy
ROP Method:
Fixed
Safety Stock Quantity (Units):
0
Current Reorder Point (Units):
-1
Lot Size Method:
Fixed Order Size
Days of Supply (Days):
1
Current Reorder Quantity (Units):
1
PB
Minimum Reorder Quantity (Units):
1
Maximum Reorder Quantity (Units):
99999
Reorder Quantity Increment (Units):
1
Minimum Fill Rate (%):
50
Planned Lead Time (Days):
30
Order Cost ($):
0
Made to Stock

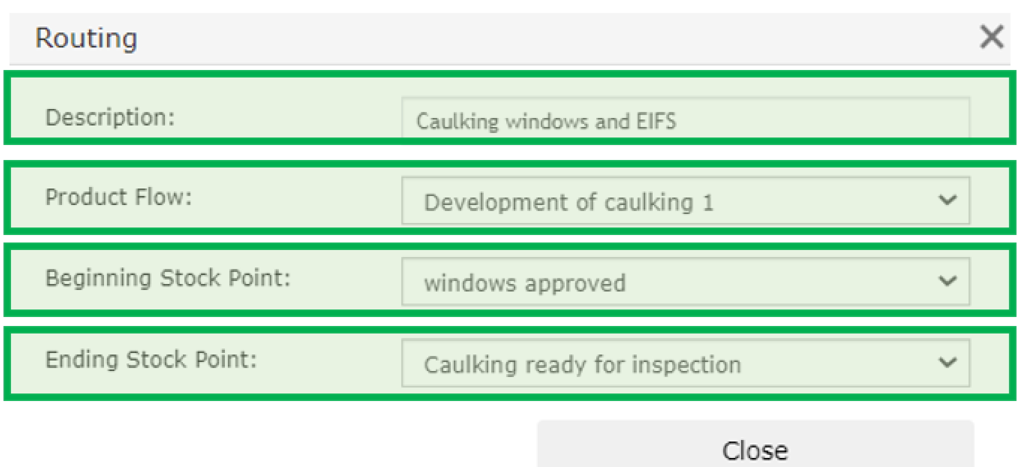

Item
Description: EIFS and windows caulked 1
Unit of Measure: windows
Fixed Order Policy
Purchased Product
TB
Transfer Batch (Units): 1
Raw Unit Cost ($): 0
Total Unit Cost ($): 1
On Hand (Units): 0
Historical Cycle Time (Days): 0
Revenue Schedule: View
External Demand
D
Average Number of Orders (Per Period): 30
Variance of Orders (Per Period): 1
Average Order Size: 1
Standard Deviation of Order Size: 0
Replenishment Time
Average Lead Time (Days): 3
Standard Deviation of Lead Time: 2
Include Backorder Time
Replenishment Policy
ROP Method: Fixed
Safety Stock Quantity (Units): 0
Current Reorder Point (Units): -1
Lot Size Method: Fixed Order Size
Days of Supply (Days): 1
Current Reorder Quantity (Units): 5
PB
Minimum Reorder Quantity (Units): 1
Maximum Reorder Quantity (Units): 99999
Reorder Quantity Increment (Units): 1
Minimum Fill Rate (%): 50
Planned Lead Time (Days): 30
Order Cost ($): 0
Made to Stock

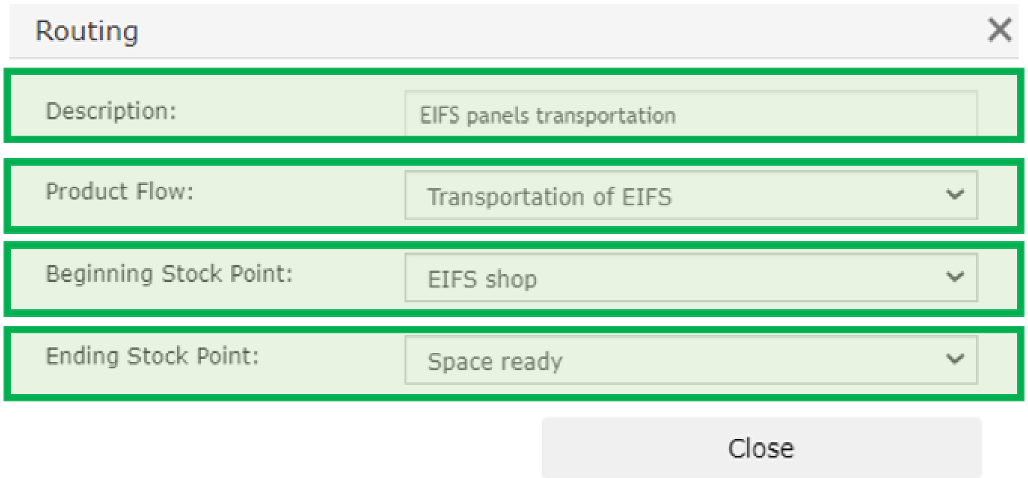

Item
Description:
EIFS, windows and caulking 1 insp
Unit of Measure:
windows
Fixed Order Policy
Purchased Product
TB
Transfer Batch (Units):
13
Raw Unit Cost ($):
0
Total Unit Cost ($):
1
On Hand (Units):
0
Historical Cycle Time (Days):
0
Revenue Schedule:
View
External Demand
D
Average Number of Orders (Per Period):
60
Variance of Orders (Per Period):
1
Average Order Size:
1
Standard Deviation of Order Size:
0
Replenishment Time
Average Lead Time (Days):
3
Standard Deviation of Lead Time:
2
Include Backorder Time
Replenishment Policy
ROP Method:
Fixed
Safety Stock Quantity (Units):
0
Current Reorder Point (Units):
-1
Lot Size Method:
Fixed Order Size
Days of Supply (Days):
1
Current Reorder Quantity (Units):
13
PB
Minimum Reorder Quantity (Units):
1
Maximum Reorder Quantity (Units):
99999
Reorder Quantity Increment (Units):
1
Minimum Fill Rate (%):
50
Planned Lead Time (Days):
30
Order Cost ($):
0
Made to Stock

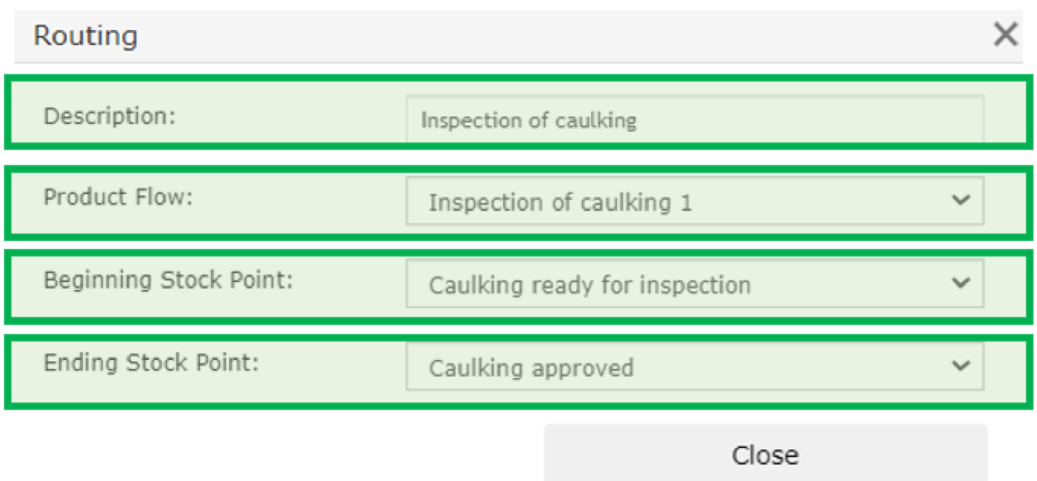
Routings

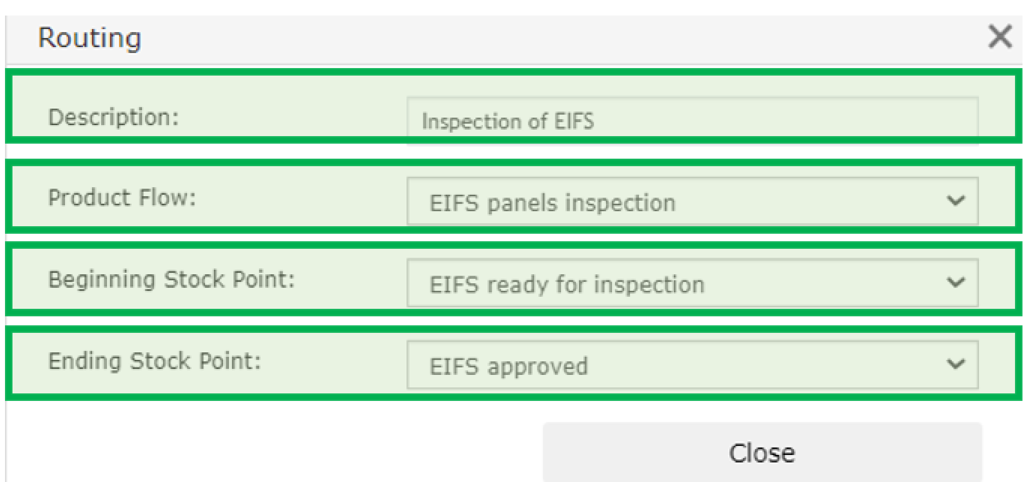

Routing
Description:
Attaching EIFS & truck changeover
Product Flow:
EIFS panels installation
Beginning Stock Point:
EIFS ready
Ending Stock Point:
EIFS ready for inspection
Close

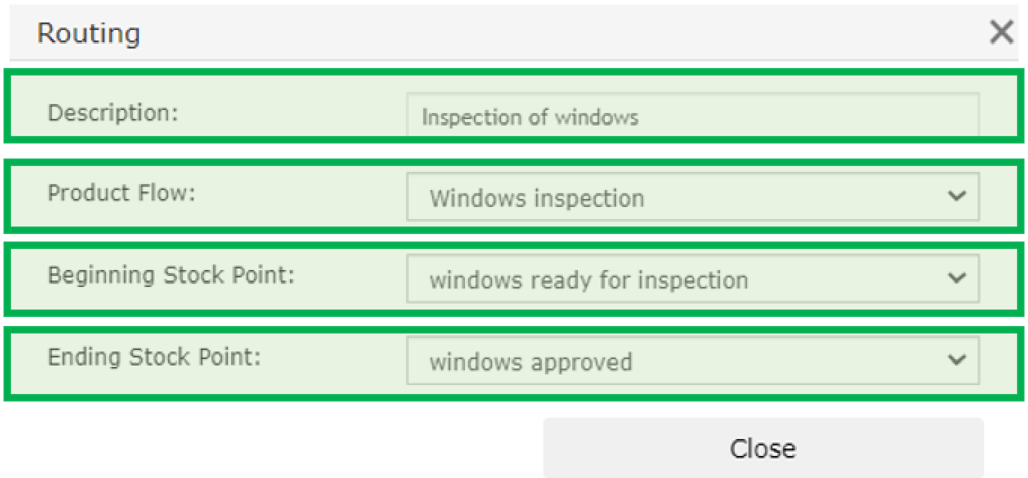

Routing
Description:
Attaching windows to elevation
Product Flow:
Windows installation
Beginning Stock Point:
EIFS approved
Ending Stock Point:
windows ready for inspection
Close

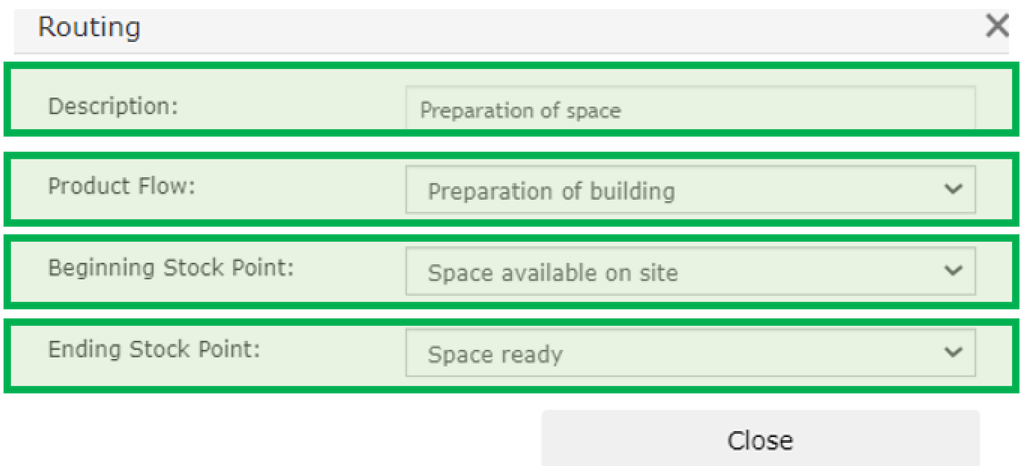

Routing
Description:
Caulking windows and EIFS
Product Flow:
Development of caulking 1
Beginning Stock Point:
windows approved
Ending Stock Point:
Caulking ready for inspection
Close

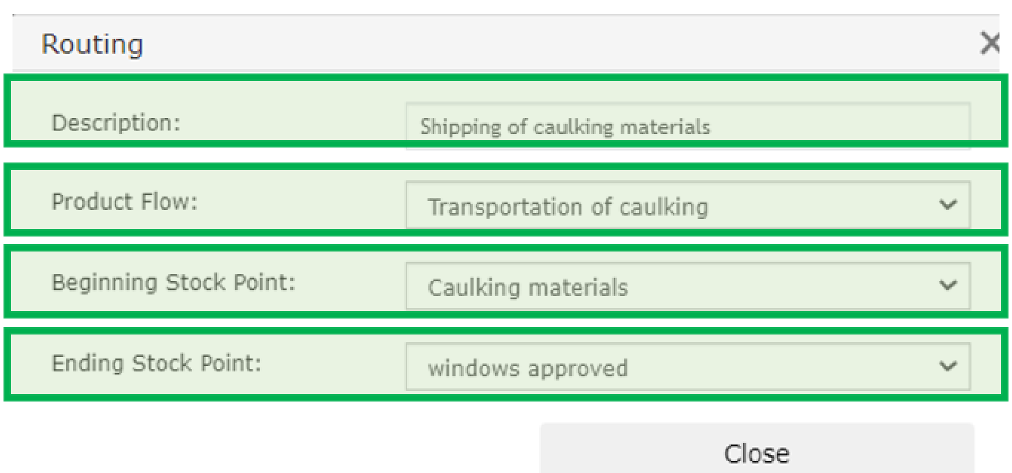

Routing
Description:
EIFS panels transportation
Product Flow:
Transportation of EIFS
Beginning Stock Point:
EIFS shop
Ending Stock Point:
Space ready
Close

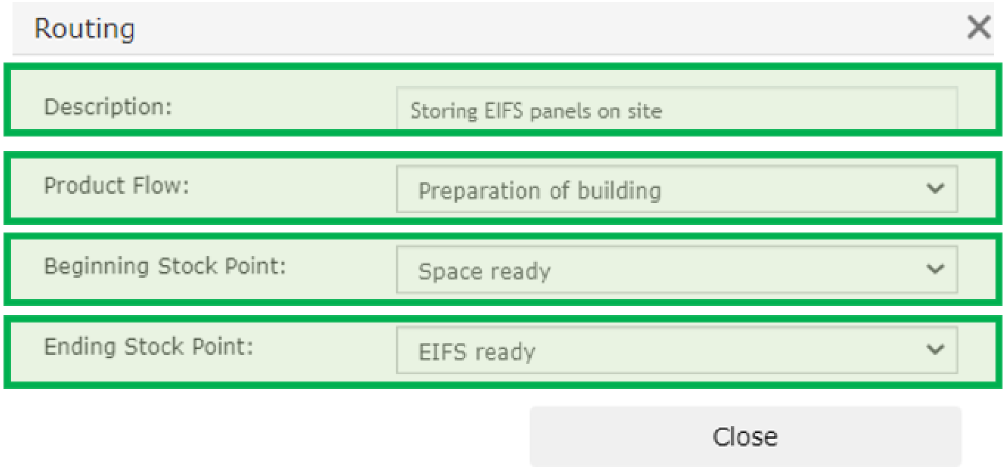

Routing
Description:
Inspection of caulking
Product Flow:
Inspection of caulking 1
Beginning Stock Point:
Caulking ready for inspection
Ending Stock Point:
Caulking approved
Close

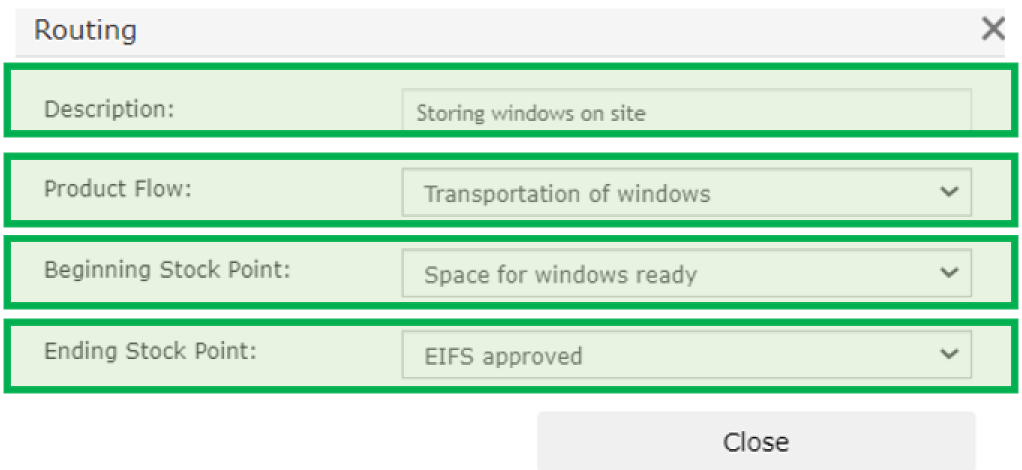

Routing
Description:
Inspection of EIFS
Product Flow:
EIFS panels inspection
Beginning Stock Point:
EIFS ready for inspection
Ending Stock Point:
EIFS approved
Close

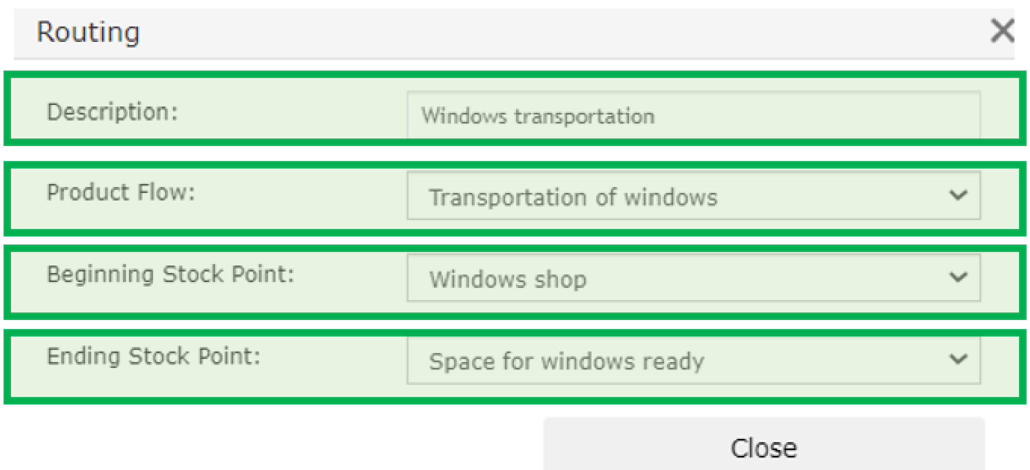

Routing
Description:
Inspection of windows
Product Flow:
Windows inspection
Beginning Stock Point:
windows ready for inspection
Ending Stock Point:
windows approved
Close


Routing
Description:
Preparation of space
Product Flow:
Preparation of building
Beginning Stock Point:
Space available on site
Ending Stock Point:
Space ready
Close

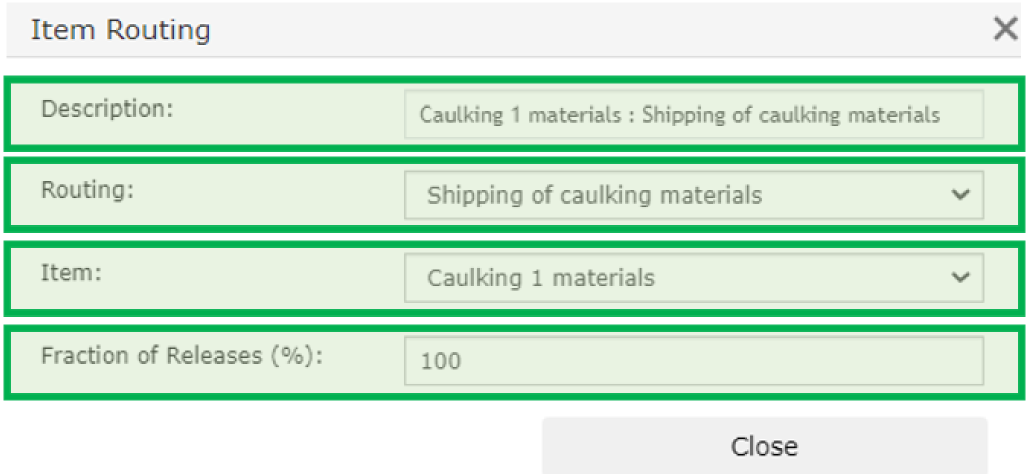

Routing
Description:
Shipping of caulking materials
Product Flow:
Transportation of caulking
Beginning Stock Point:
Caulking materials
Ending Stock Point:
windows approved
Close


Routing
Description:
Storing EIFS panels on site
Product Flow:
Preparation of building
Beginning Stock Point:
Space ready
Ending Stock Point:
EIFS ready
Close


Routing
Description:
Storing windows on site
Product Flow:
Transportation of windows
Beginning Stock Point:
Space for windows ready
Ending Stock Point:
EIFS approved
Close


Routing
Description:
Windows transportation
Product Flow:
Transportation of windows
Beginning Stock Point:
Windows shop
Ending Stock Point:
Space for windows ready
Close

__Item Routings__



Item Routing

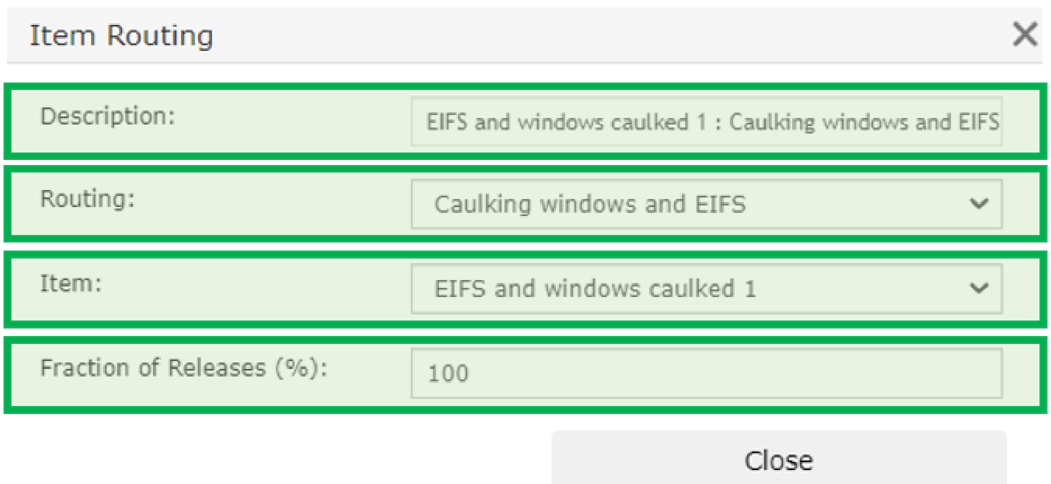
Description: Caulking 1 materials : Shipping of caulking materials

Routing: Shipping of caulking materials

Item: Caulking 1 materials

Fraction of Releases (%): 100

Close



Item Routing

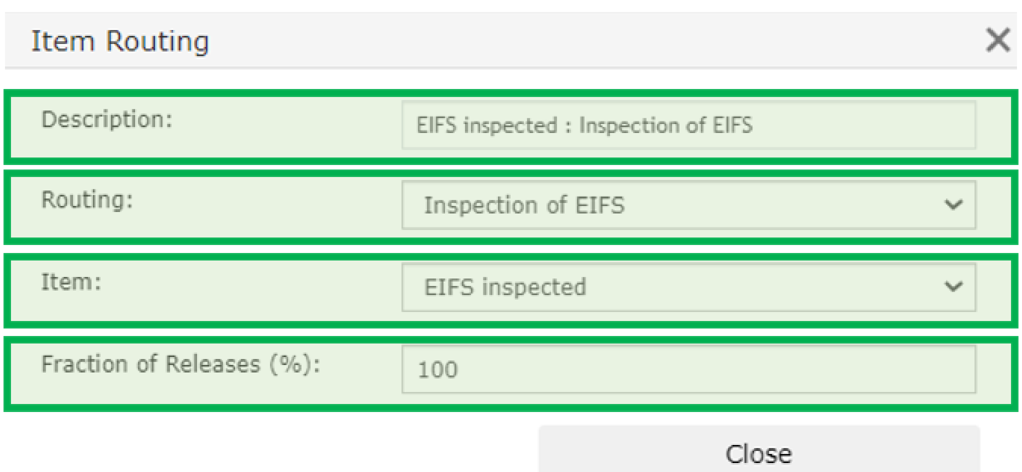
Description: EIFS and windows caulked 1 : Caulking windows and EIFS

Routing: Caulking windows and EIFS

Item: EIFS and windows caulked 1

Fraction of Releases (%): 100

Close



Item Routing

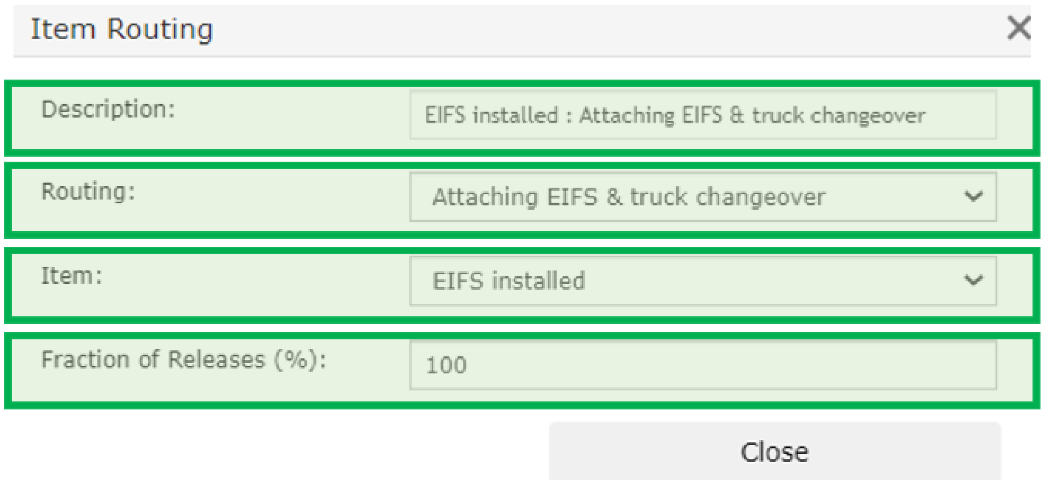
Description: EIFS inspected : Inspection of EIFS

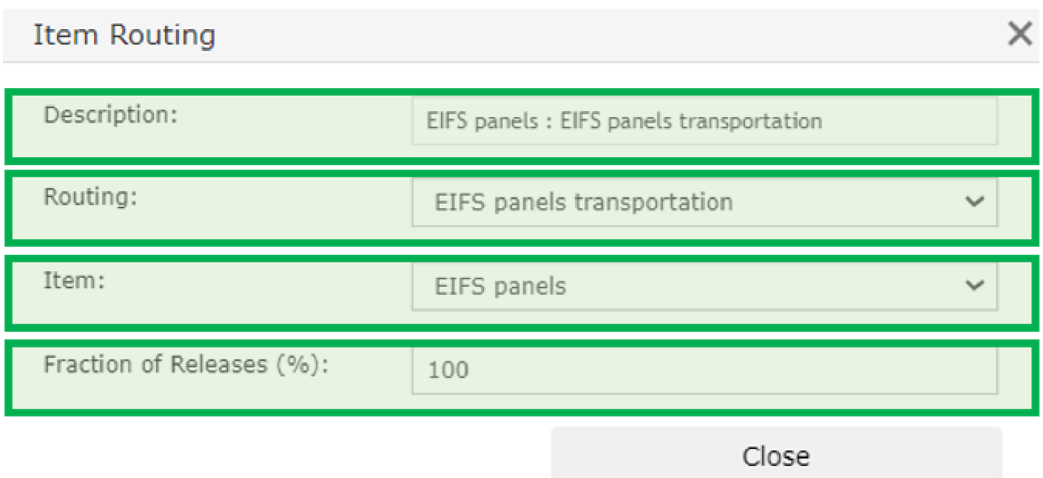
Routing: Inspection of EIFS

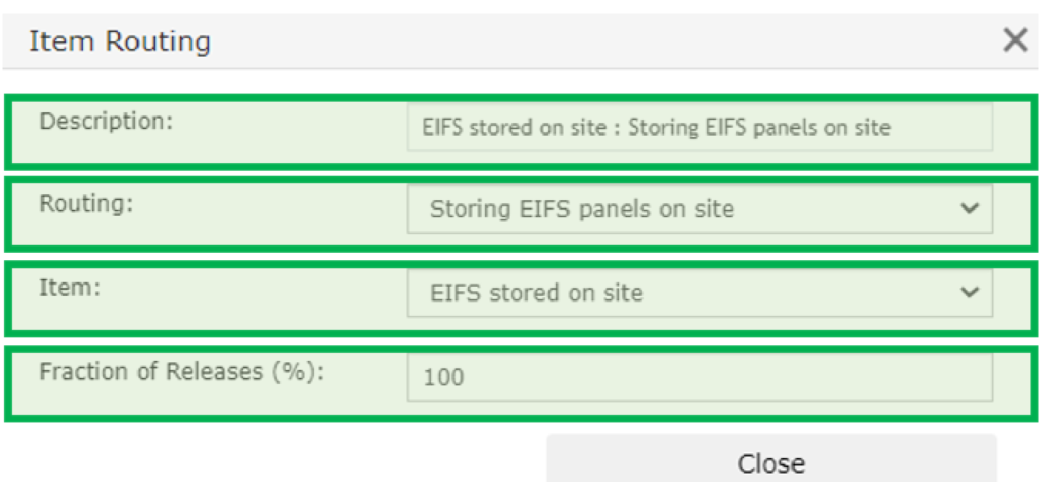
Item: EIFS inspected

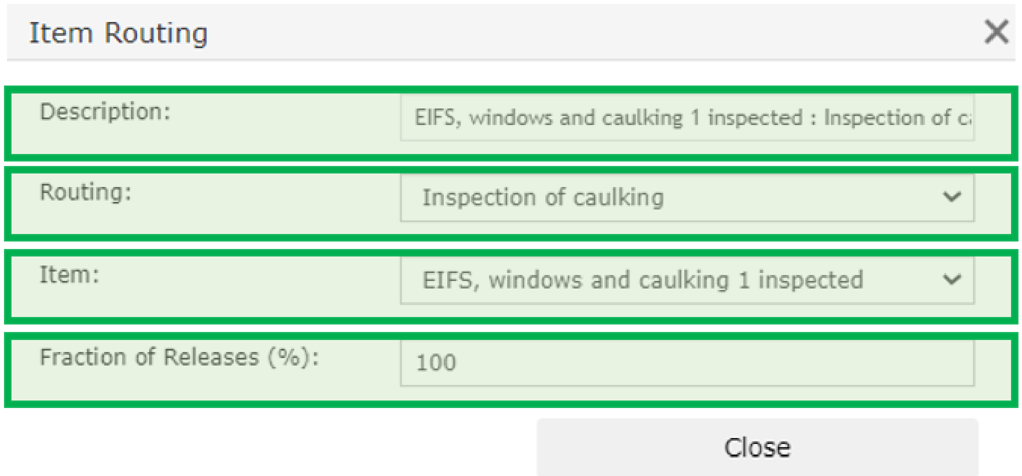
Fraction of Releases (%): 100

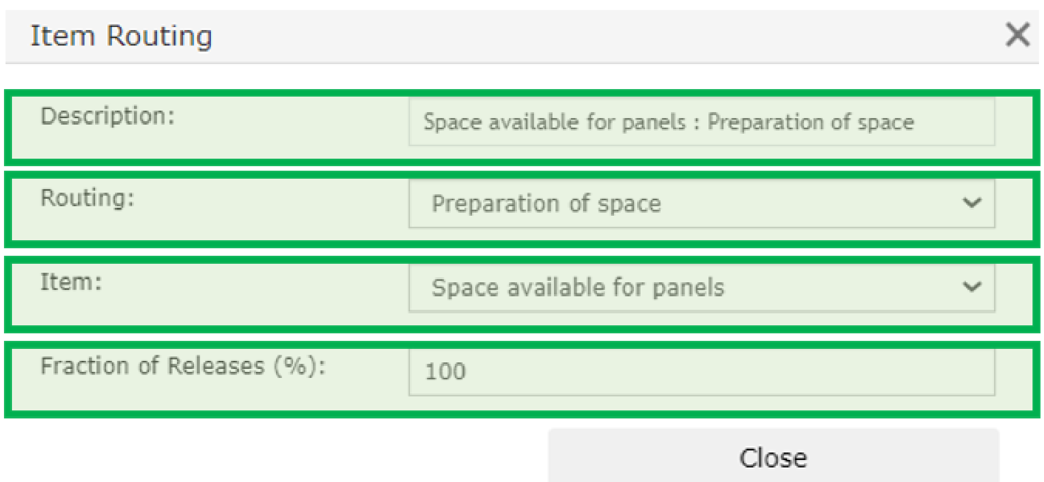
Close

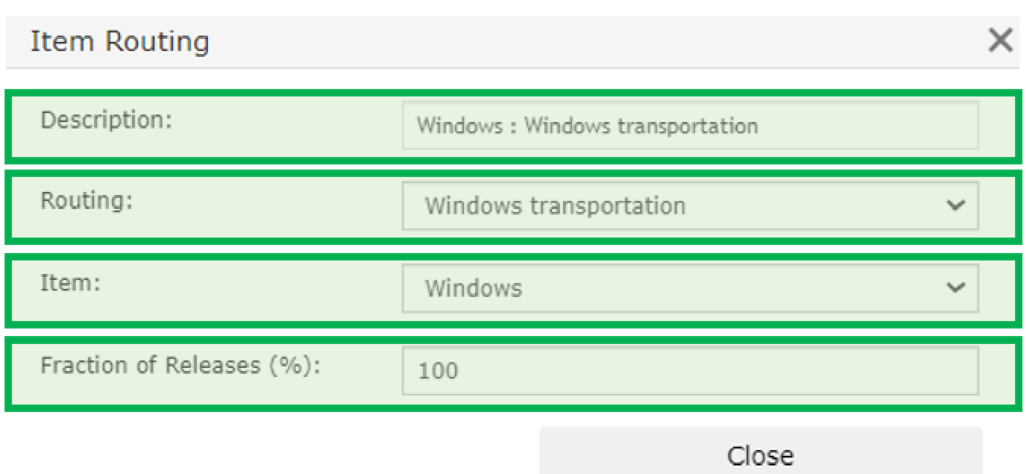

Item Routing
Description:
EIFS installed : Attaching EIFS & truck changeover
Routing:
Attaching EIFS & truck changeover
Item:
EIFS installed
Fraction of Releases (%):
100
Close

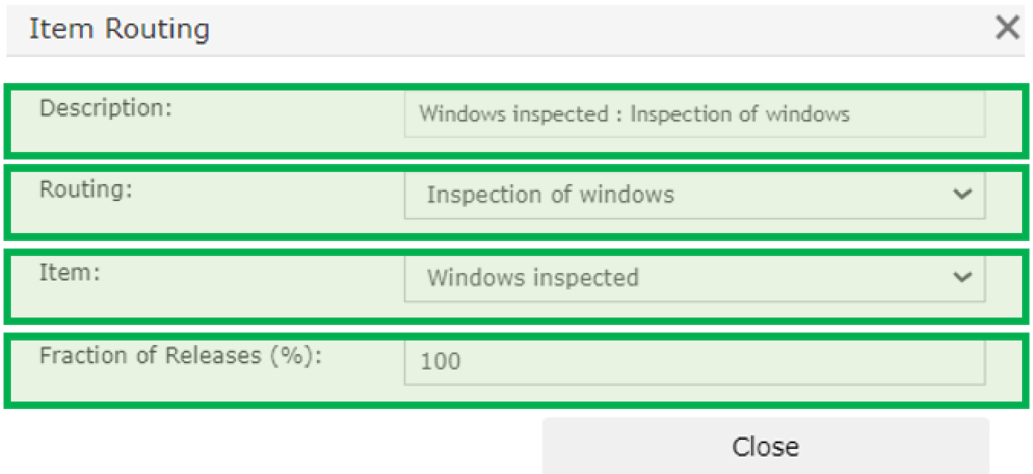

Item Routing
Description:
EIFS panels : EIFS panels transportation
Routing:
EIFS panels transportation
Item:
EIFS panels
Fraction of Releases (%):
100
Close

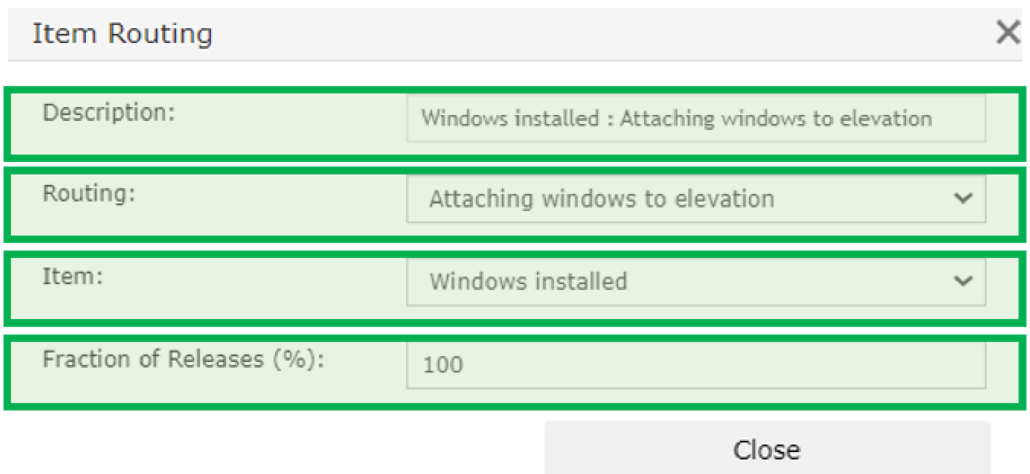

Item Routing
Description:
EIFS stored on site : Storing EIFS panels on site
Routing:
Storing EIFS panels on site
Item:
EIFS stored on site
Fraction of Releases (%):
100
Close

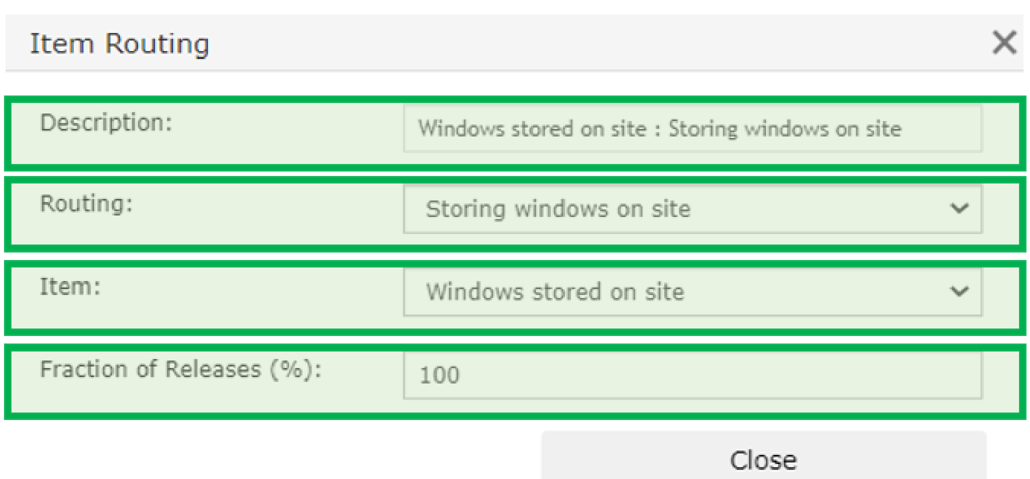

Item Routing
Description:
EIFS, windows and caulking 1 inspected : Inspection of c
Routing:
Inspection of caulking
Item:
EIFS, windows and caulking 1 inspected
Fraction of Releases (%):
100
Close


Item Routing
Description:
Space available for panels : Preparation of space
Routing:
Preparation of space
Item:
Space available for panels
Fraction of Releases (%):
100
Close

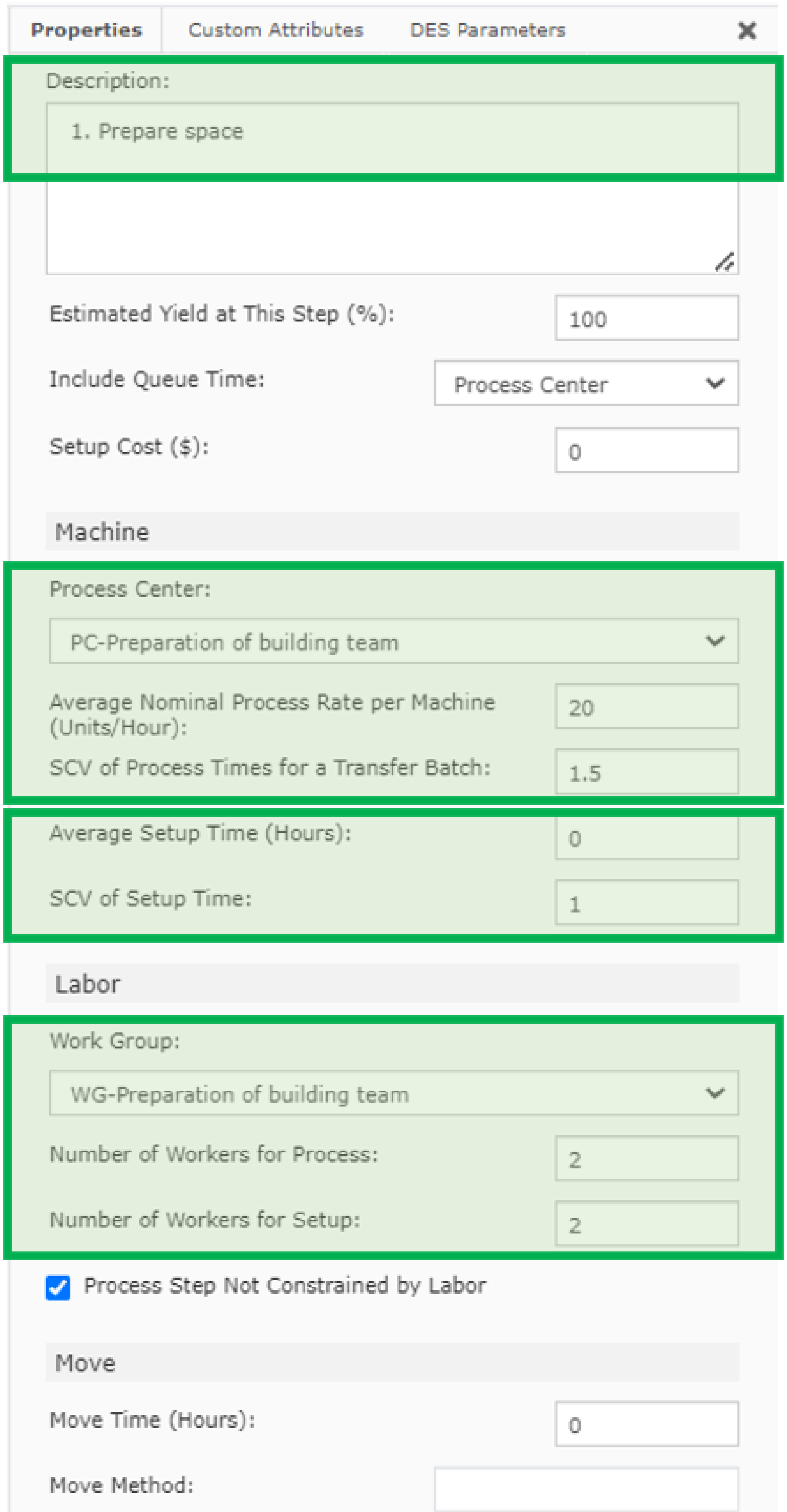

Item Routing
Description:
Windows : Windows transportation
Routing:
Windows transportation
Item:
Windows
Fraction of Releases (%):
100
Close


Item Routing
Description:
Windows inspected : Inspection of windows
Routing:
Inspection of windows
Item:
Windows inspected
Fraction of Releases (%):
100
Close

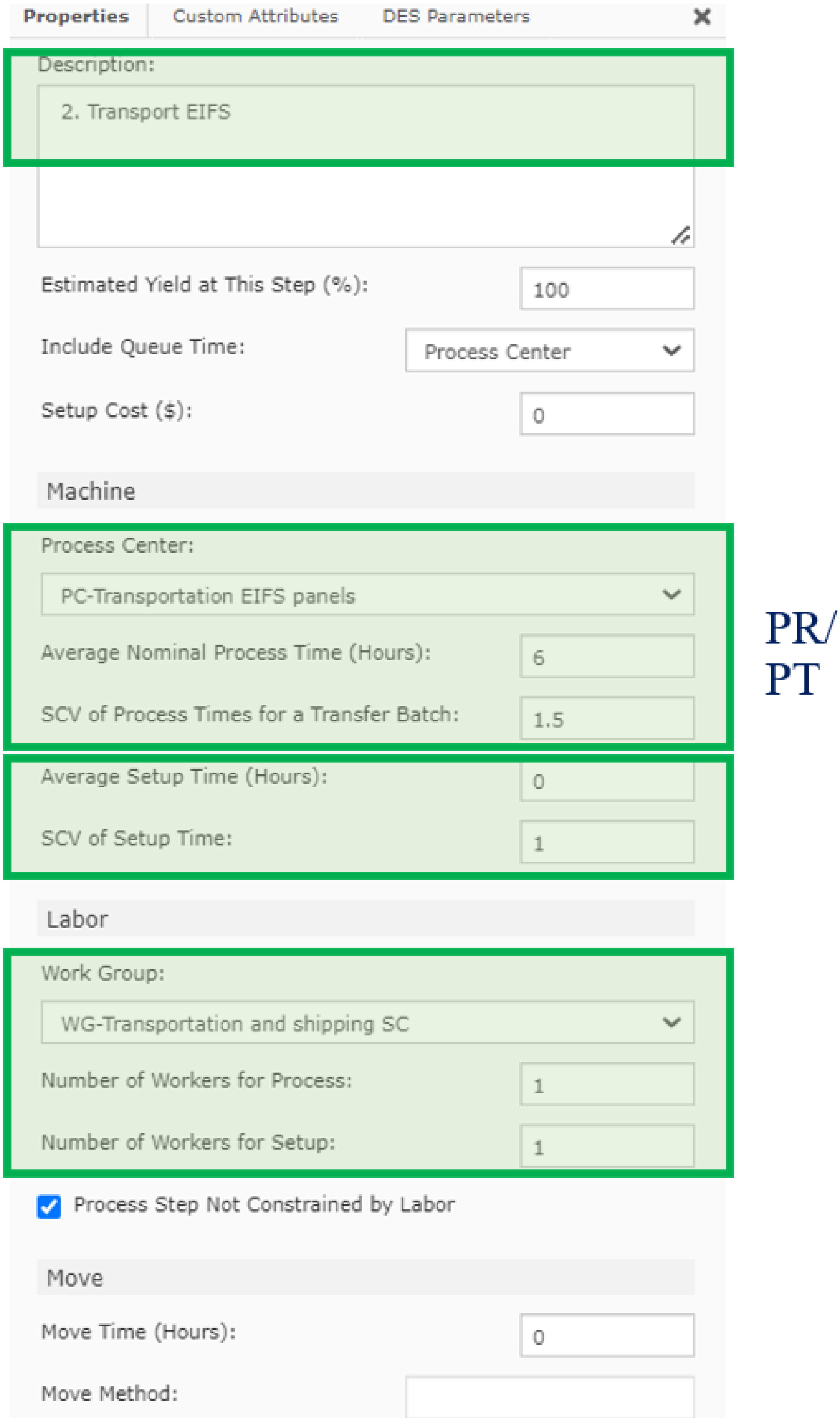

Item Routing
Description:
Windows installed : Attaching windows to elevation
Routing:
Attaching windows to elevation
Item:
Windows installed
Fraction of Releases (%):
100
Close

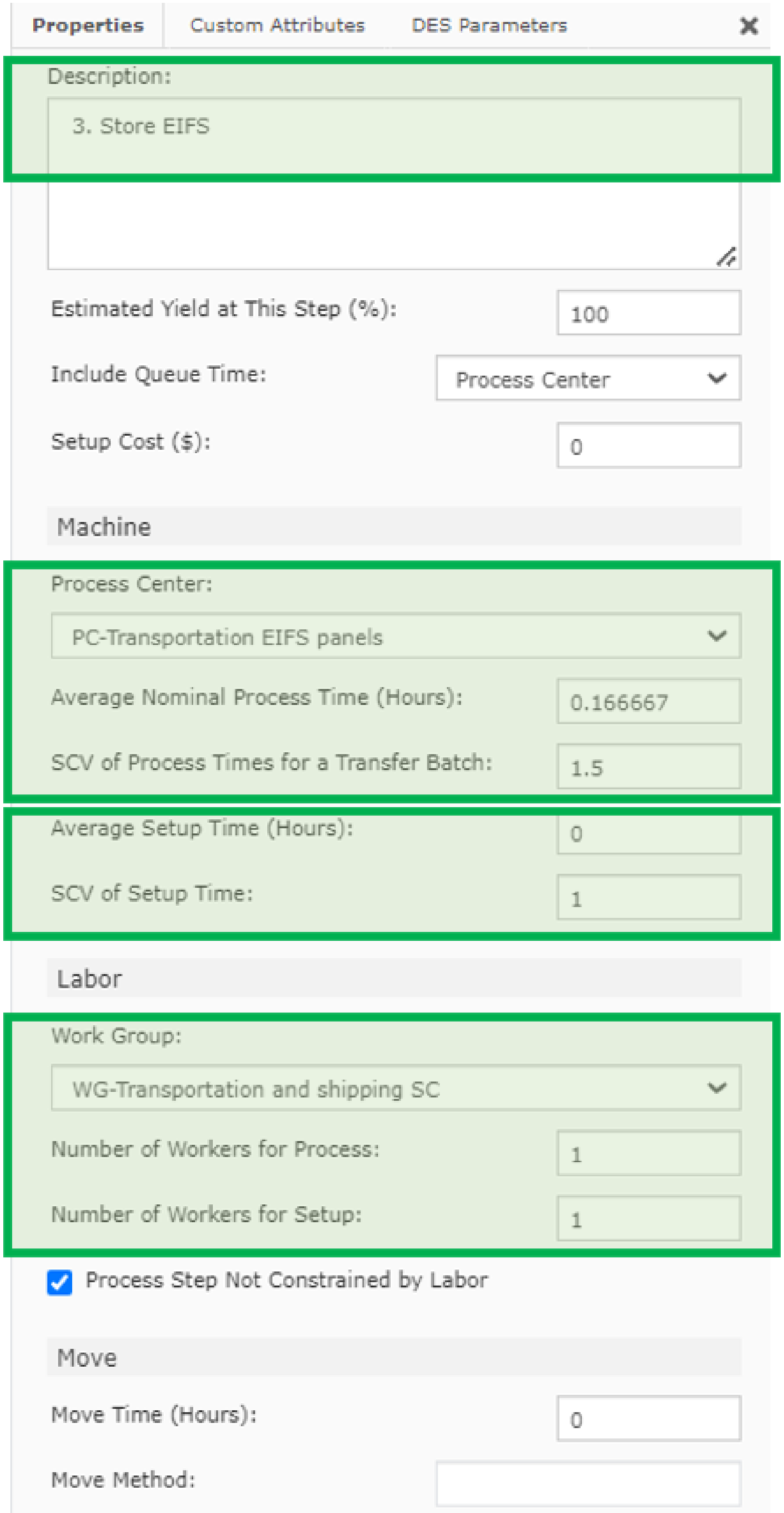

Item Routing
Description:
Windows stored on site : Storing windows on site
Routing:
Storing windows on site
Item:
Windows stored on site
Fraction of Releases (%):
100
Close

Operations

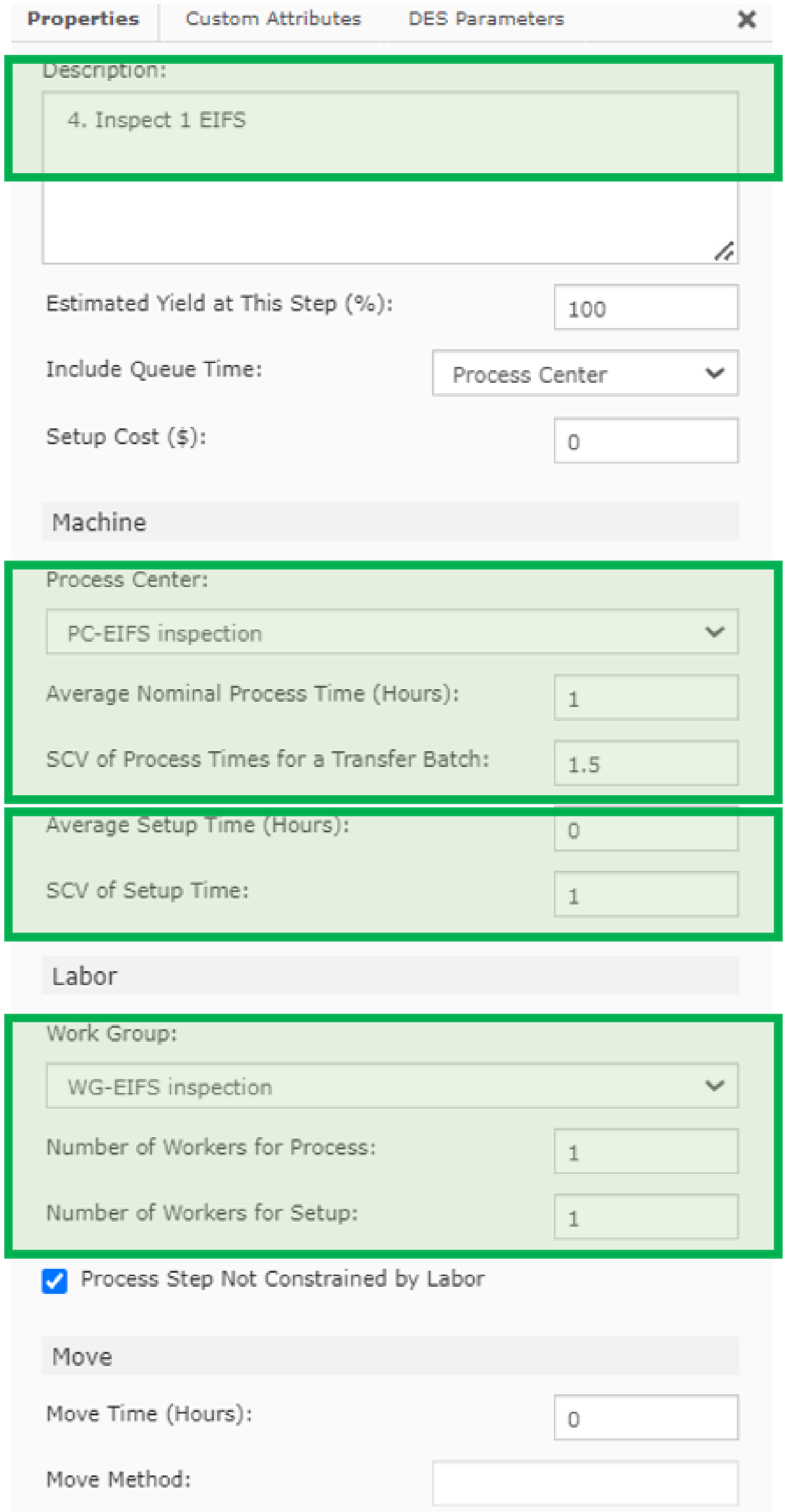


PR/
PT

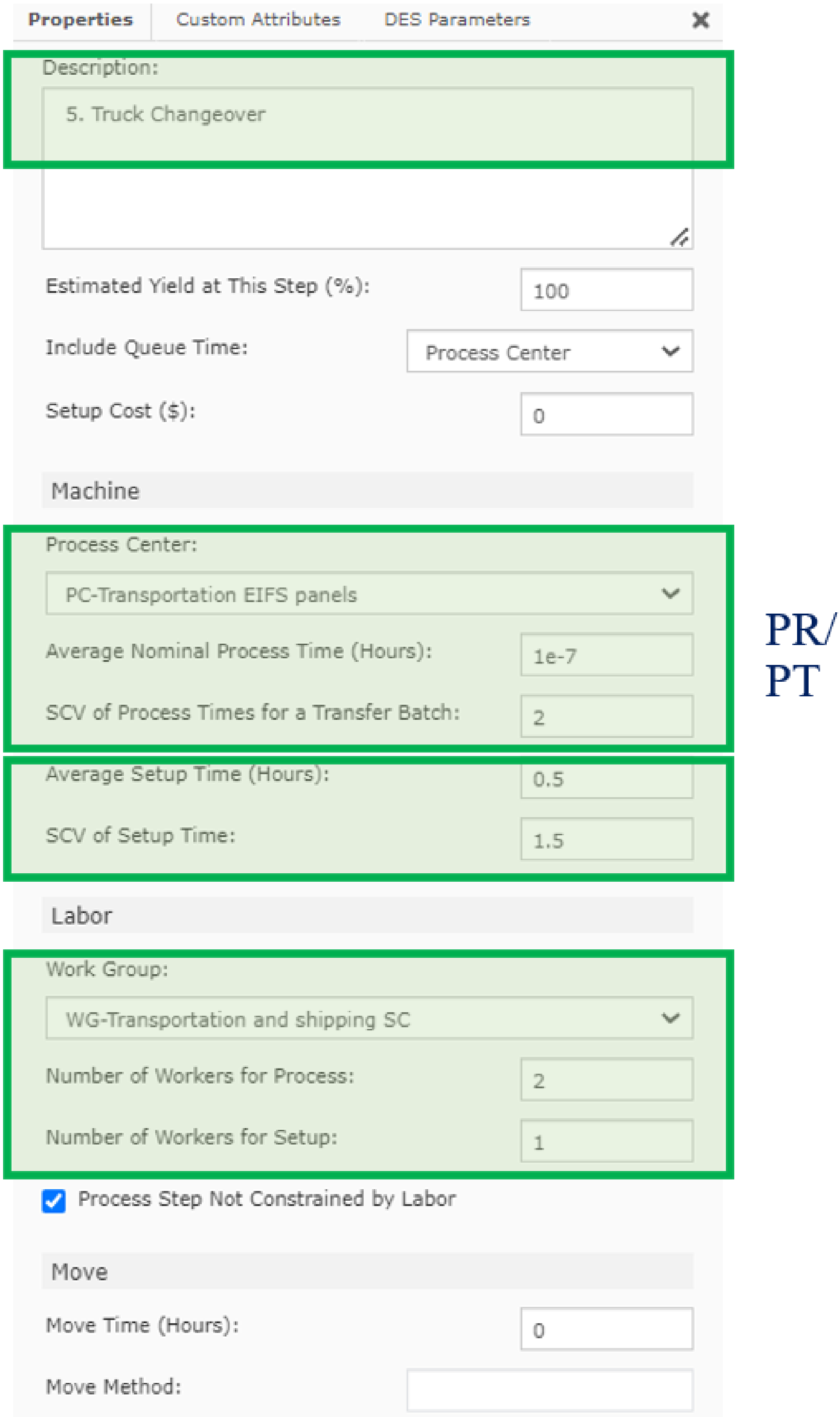

Properties
Custom Attributes
DES Parameters
Description:
2. Transport EIFS
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Transportation EIFS panels
Average Nominal Process Time (Hours):
6
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Transportation and shipping SC
Number of Workers for Process:
1
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:
PR/
PT

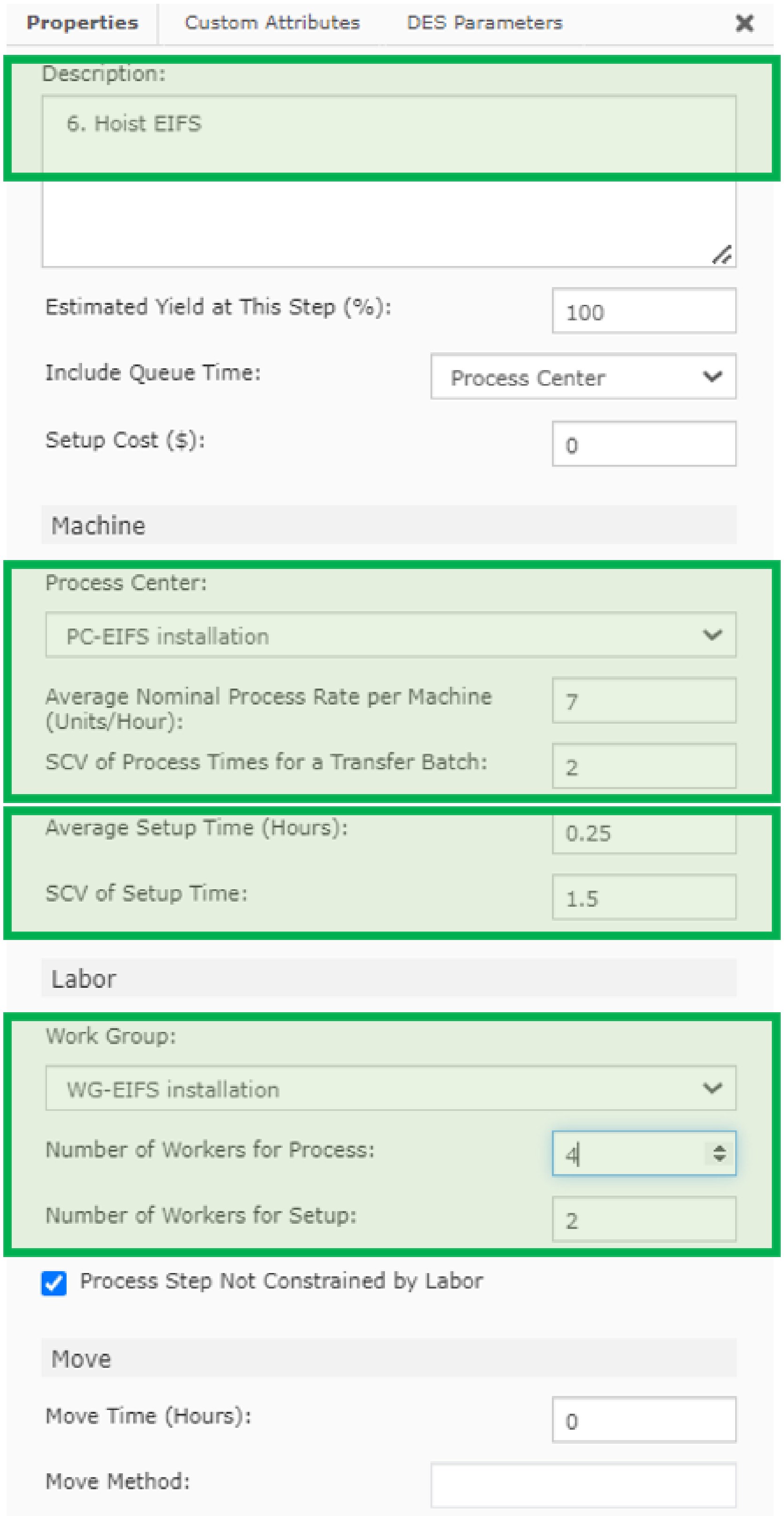

Properties
Custom Attributes
DES Parameters
Description:
3. Store EIFS
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Transportation EIFS panels
Average Nominal Process Time (Hours):
0.166667
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Transportation and shipping SC
Number of Workers for Process:
1
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
4. Inspect 1 EIFS
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-EIFS inspection
Average Nominal Process Time (Hours):
1
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-EIFS inspection
Number of Workers for Process:
1
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

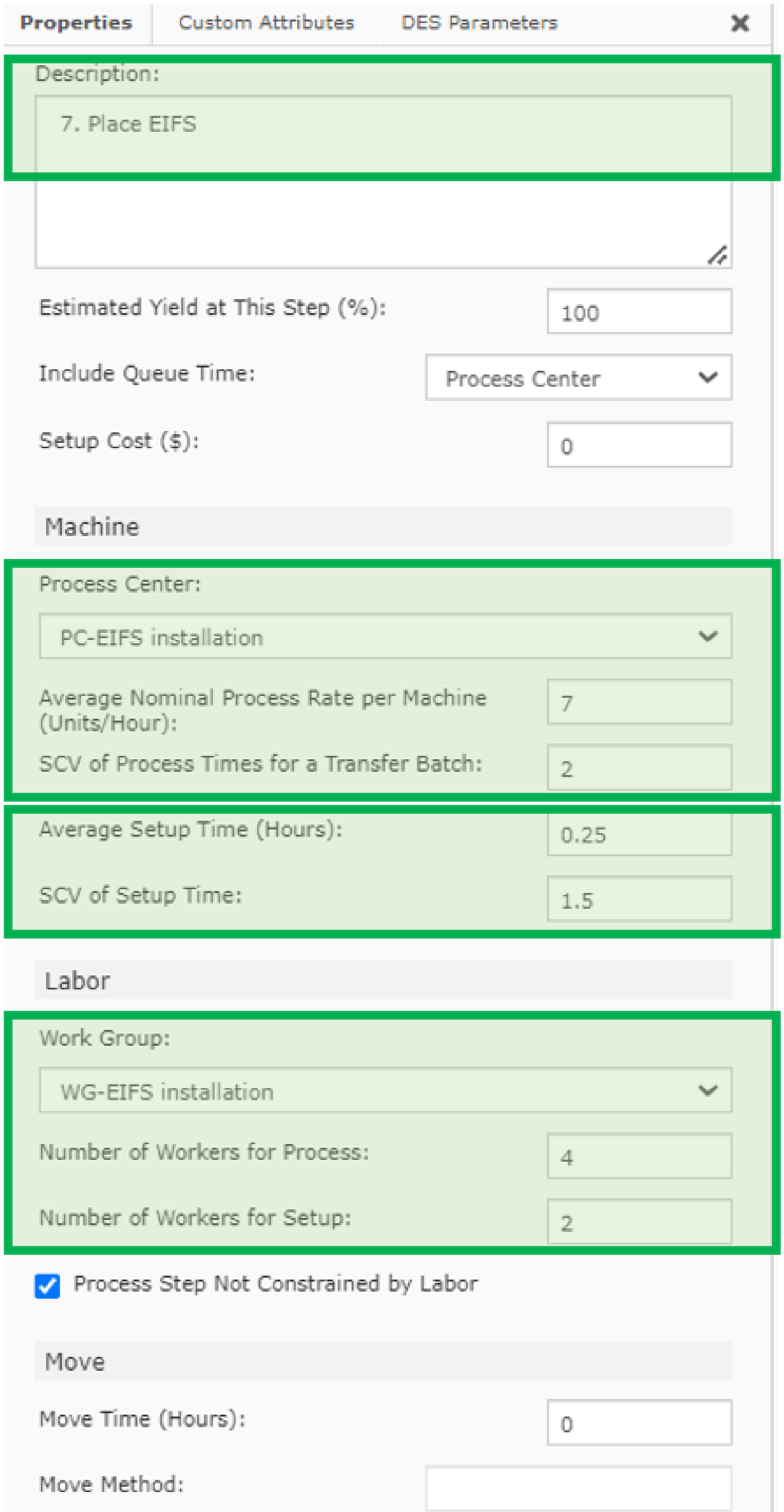
PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
5. Truck Changeover
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Transportation EIFS panels
Average Nominal Process Time (Hours):
1e-7
SCV of Process Times for a Transfer Batch:
2
Average Setup Time (Hours):
0.5
SCV of Setup Time:
1.5
Labor
Work Group:
WG-Transportation and shipping SC
Number of Workers for Process:
2
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:
PR/
PT

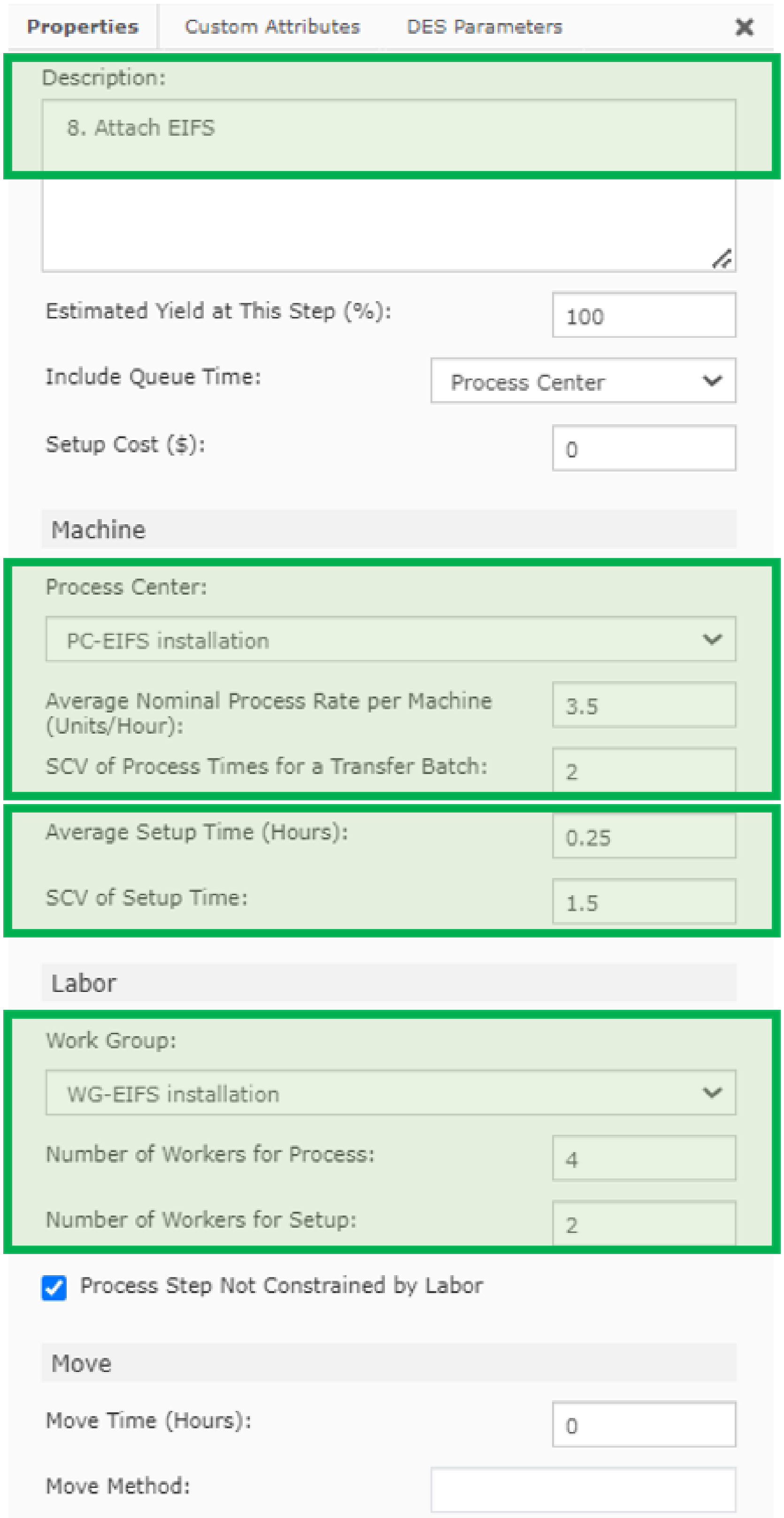


Properties
Custom Attributes
DES Parameters
Description:
6. Hoist EIFS
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-EIFS installation
Average Nominal Process Rate per Machine (Units/Hour):
7
SCV of Process Times for a Transfer Batch:
2
Average Setup Time (Hours):
0.25
SCV of Setup Time:
1.5
Labor
Work Group:
WG-EIFS installation
Number of Workers for Process:
4
Number of Workers for Setup:
2
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

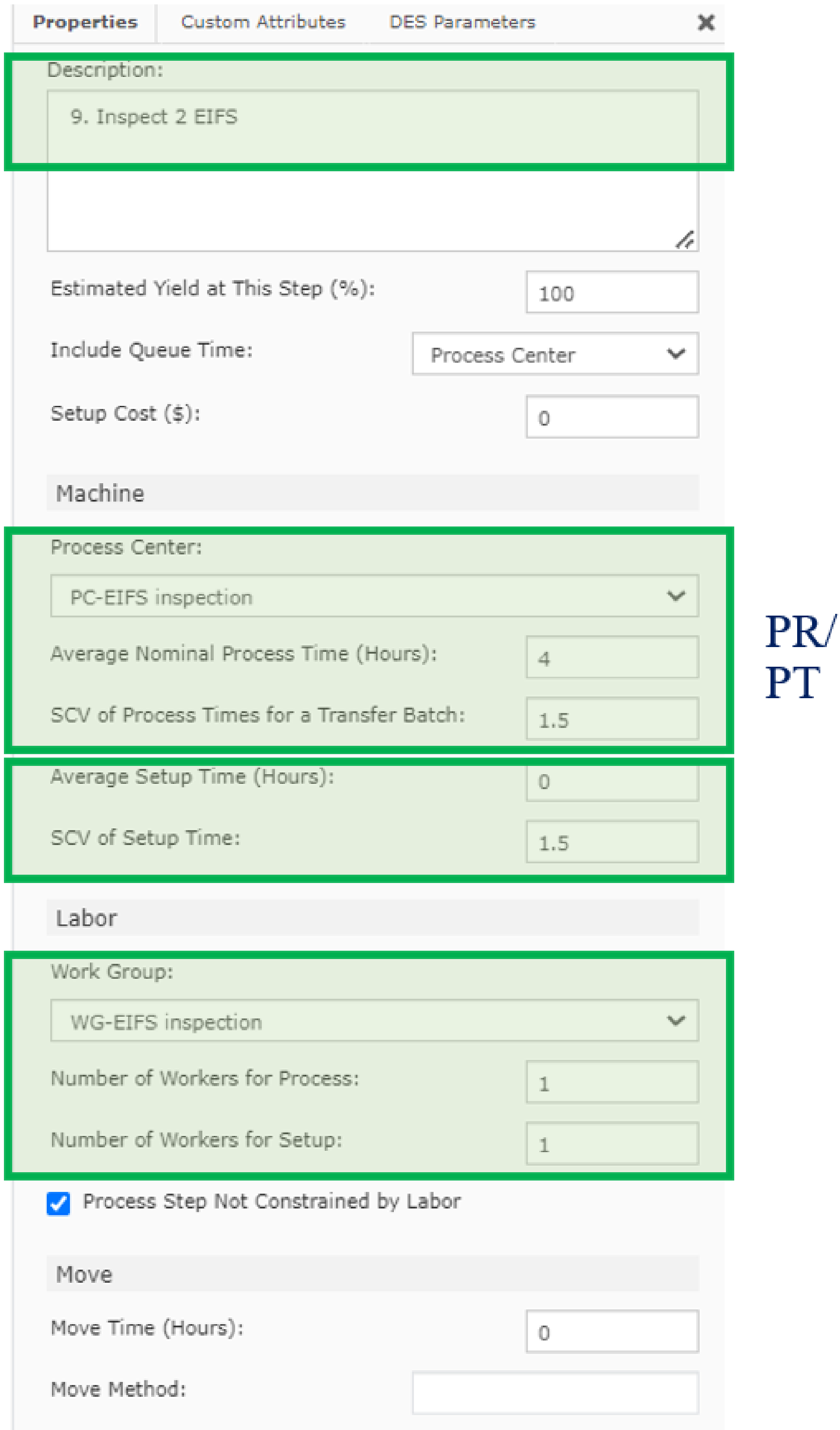
PR/
PT

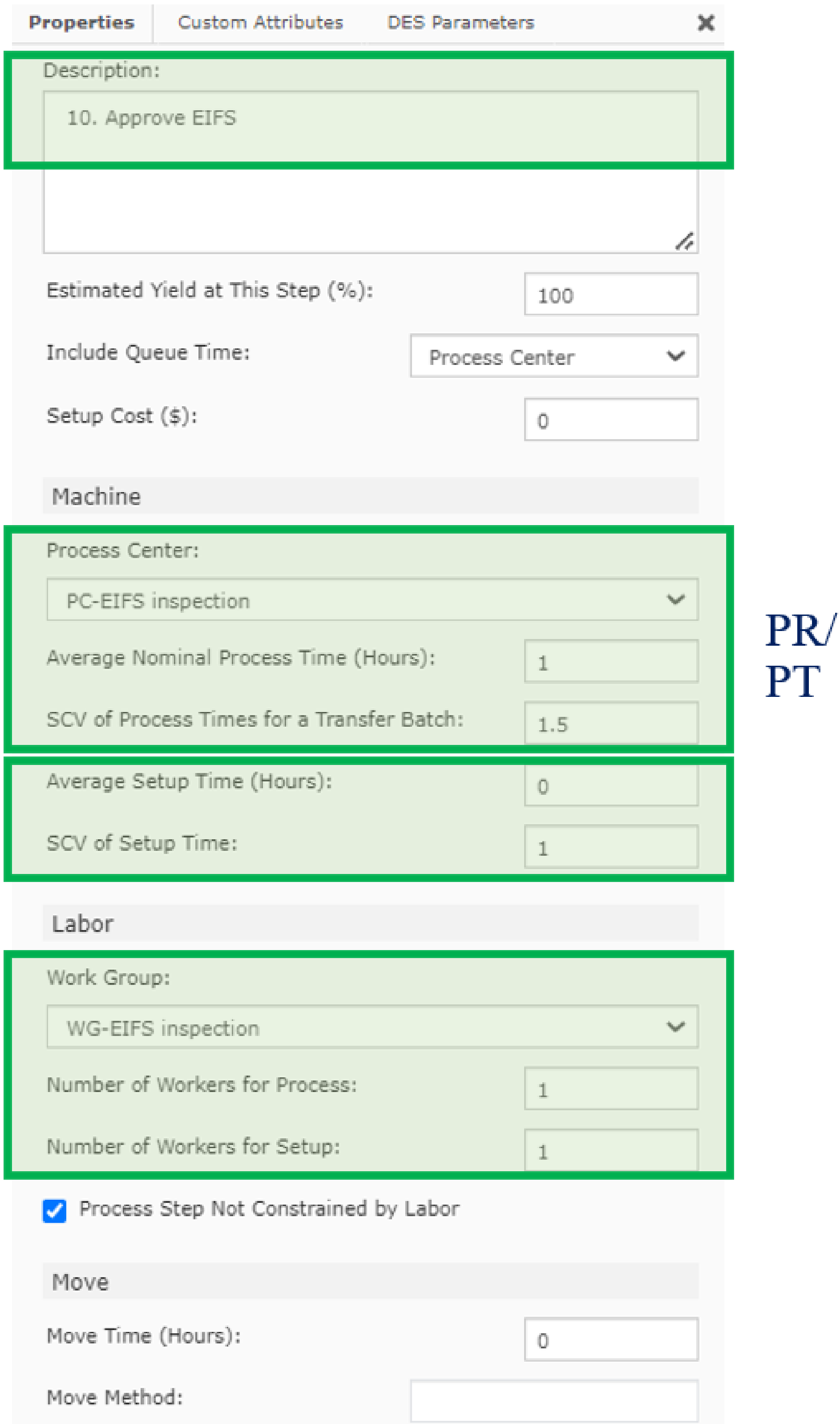

Properties
Custom Attributes
DES Parameters
Description:
7. Place EIFS
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-EIFS installation
Average Nominal Process Rate per Machine (Units/Hour):
7
SCV of Process Times for a Transfer Batch:
2
Average Setup Time (Hours):
0.25
SCV of Setup Time:
1.5
Labor
Work Group:
WG-EIFS installation
Number of Workers for Process:
4
Number of Workers for Setup:
2
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

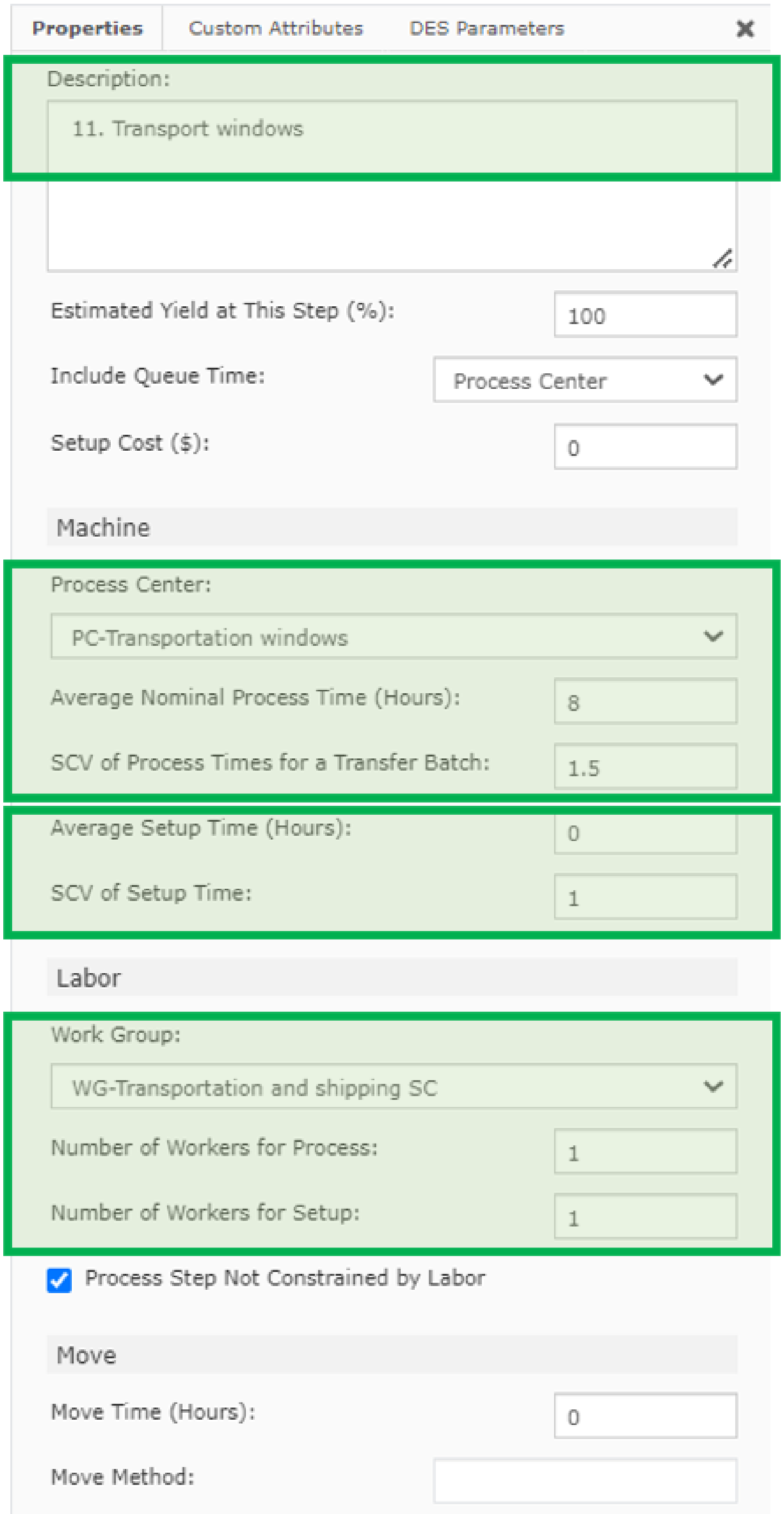
PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
8. Attach EIFS
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-EIFS installation
Average Nominal Process Rate per Machine (Units/Hour):
3.5
SCV of Process Times for a Transfer Batch:
2
Average Setup Time (Hours):
0.25
SCV of Setup Time:
1.5
Labor
Work Group:
WG-EIFS installation
Number of Workers for Process:
4
Number of Workers for Setup:
2
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

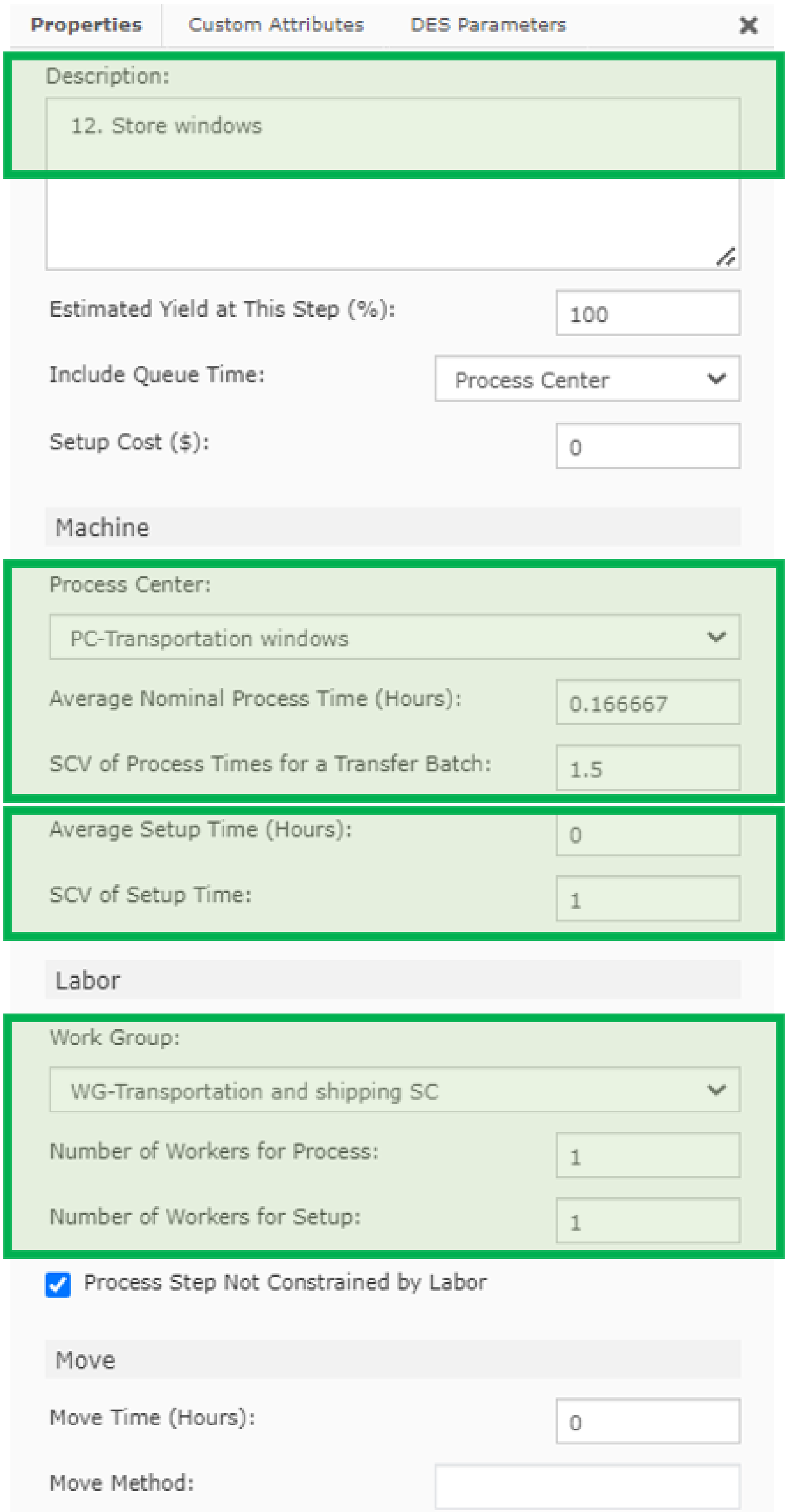
PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
9. Inspect 2 EIFS
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-EIFS inspection
Average Nominal Process Time (Hours):
4
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1.5
Labor
Work Group:
WG-EIFS inspection
Number of Workers for Process:
1
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:
PR/
PT

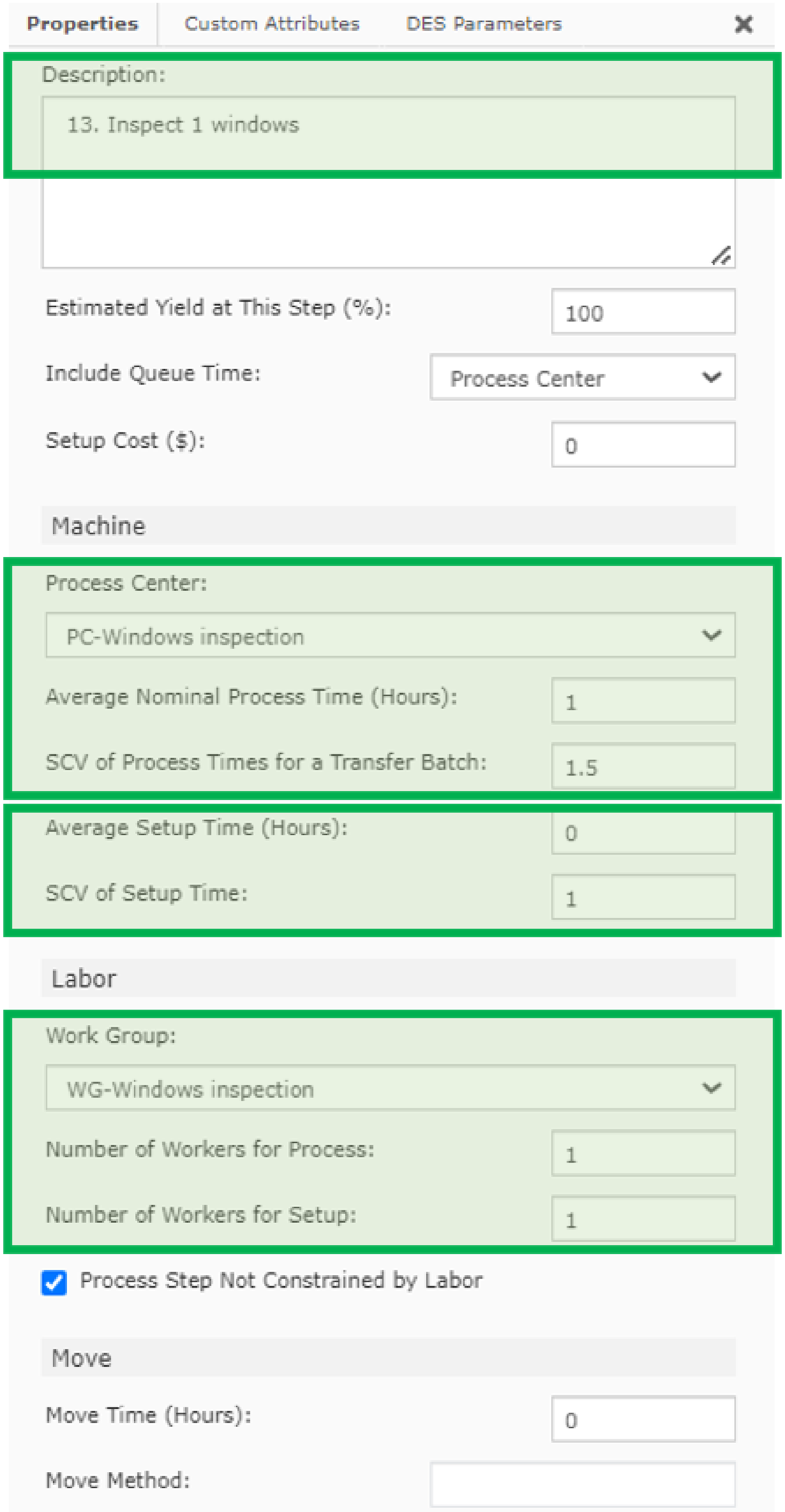

Properties
Custom Attributes
DES Parameters
Description:
10. Approve EIFS
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-EIFS inspection
Average Nominal Process Time (Hours):
1
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-EIFS inspection
Number of Workers for Process:
1
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:
PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
11. Transport windows
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Transportation windows
Average Nominal Process Time (Hours):
8
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Transportation and shipping SC
Number of Workers for Process:
1
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

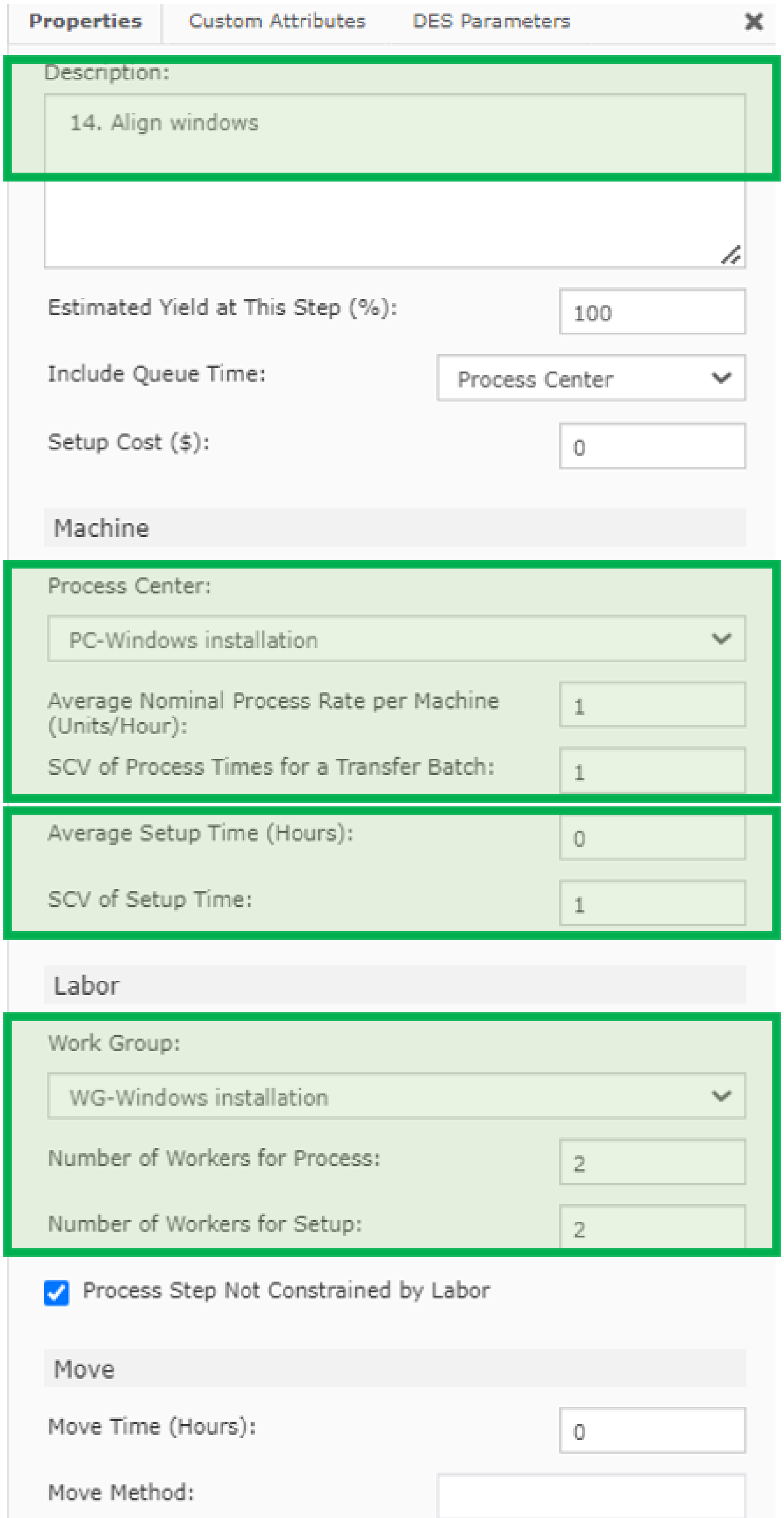
PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
12. Store windows
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Transportation windows
Average Nominal Process Time (Hours):
0.166667
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Transportation and shipping SC
Number of Workers for Process:
1
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

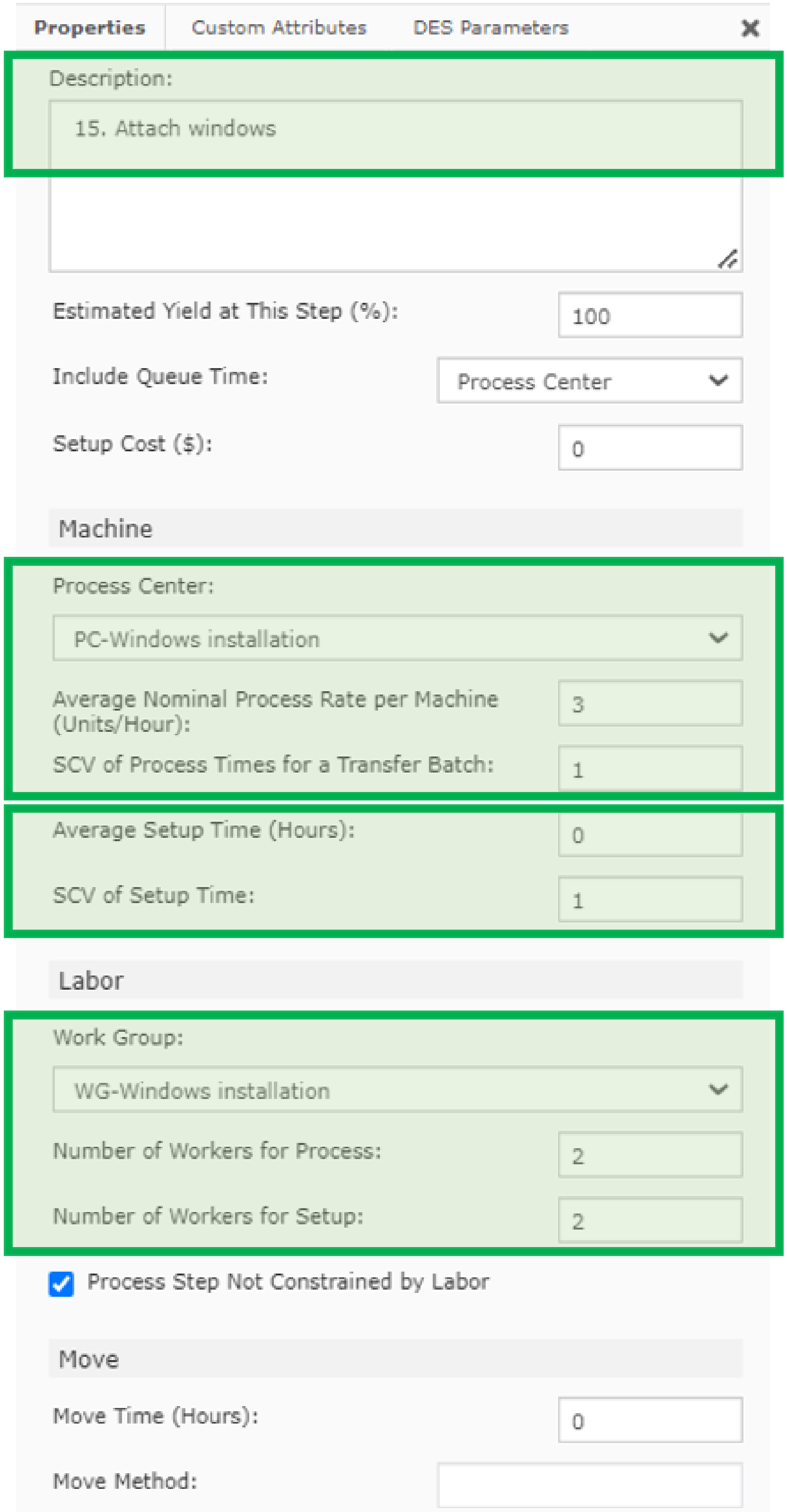
PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
13. Inspect 1 windows
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Windows inspection
Average Nominal Process Time (Hours):
1
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Windows inspection
Number of Workers for Process:
1
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

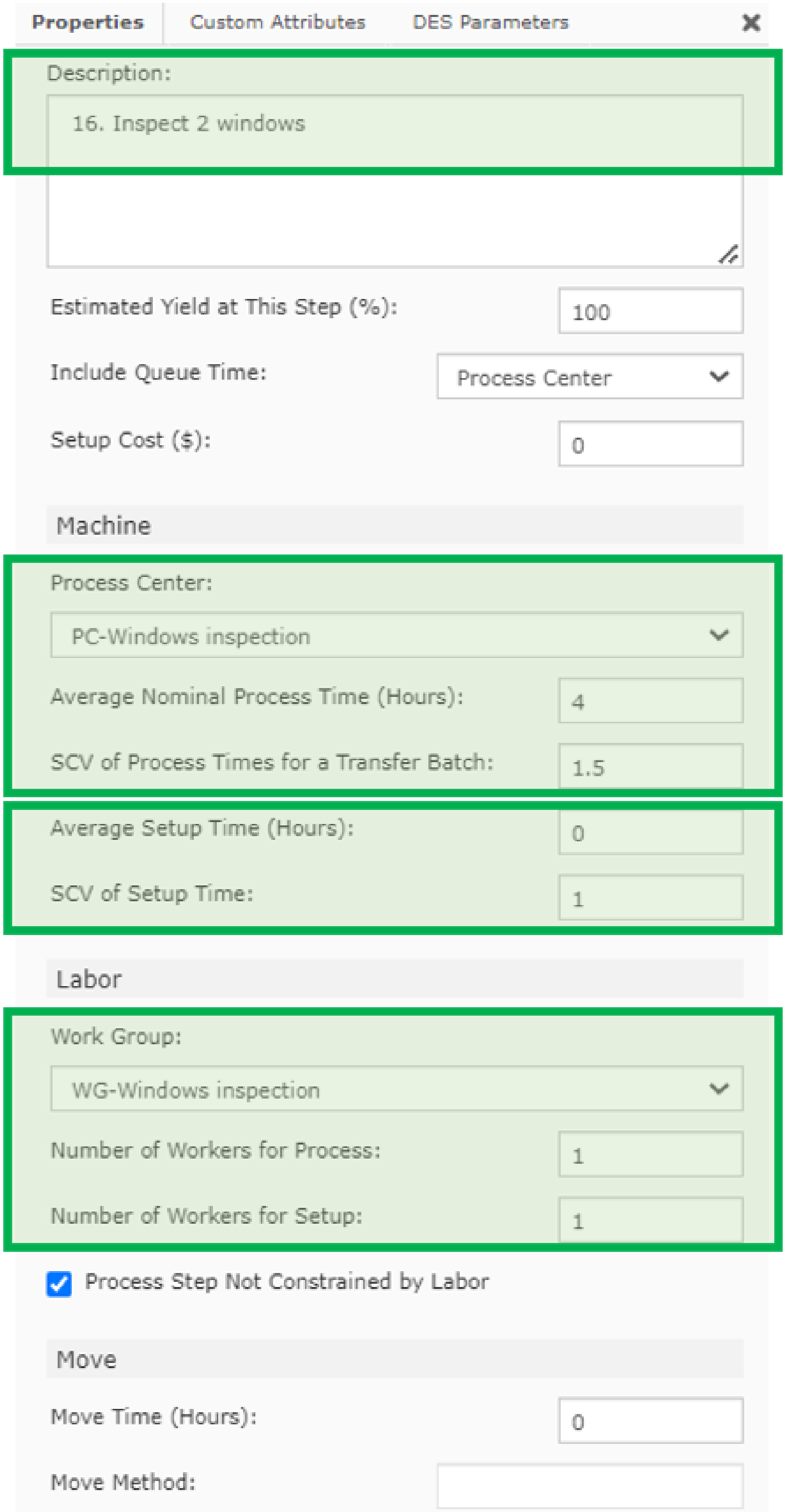
PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
14. Align windows
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Windows installation
Average Nominal Process Rate per Machine (Units/Hour):
1
SCV of Process Times for a Transfer Batch:
1
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Windows installation
Number of Workers for Process:
2
Number of Workers for Setup:
2
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

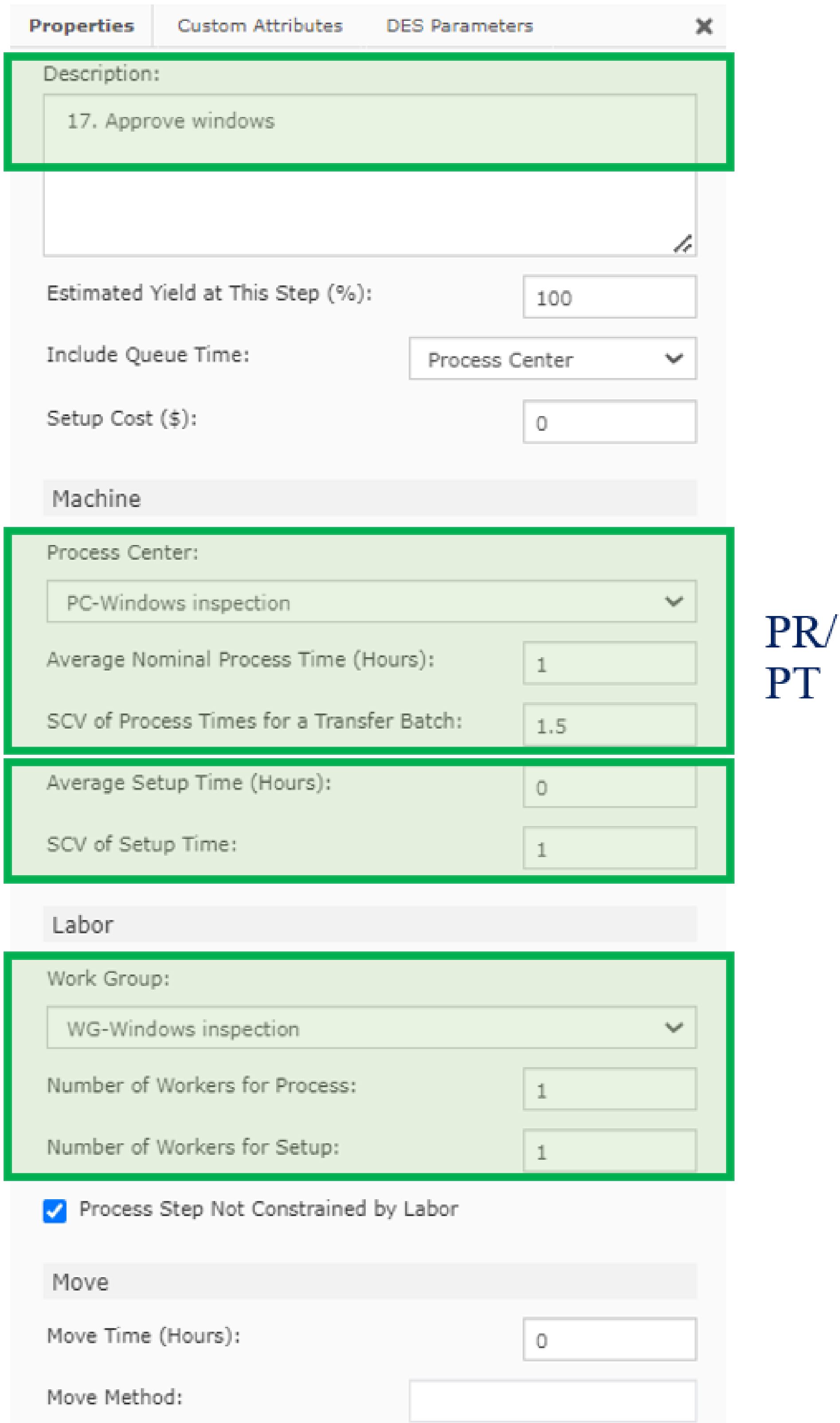
PR/
PT

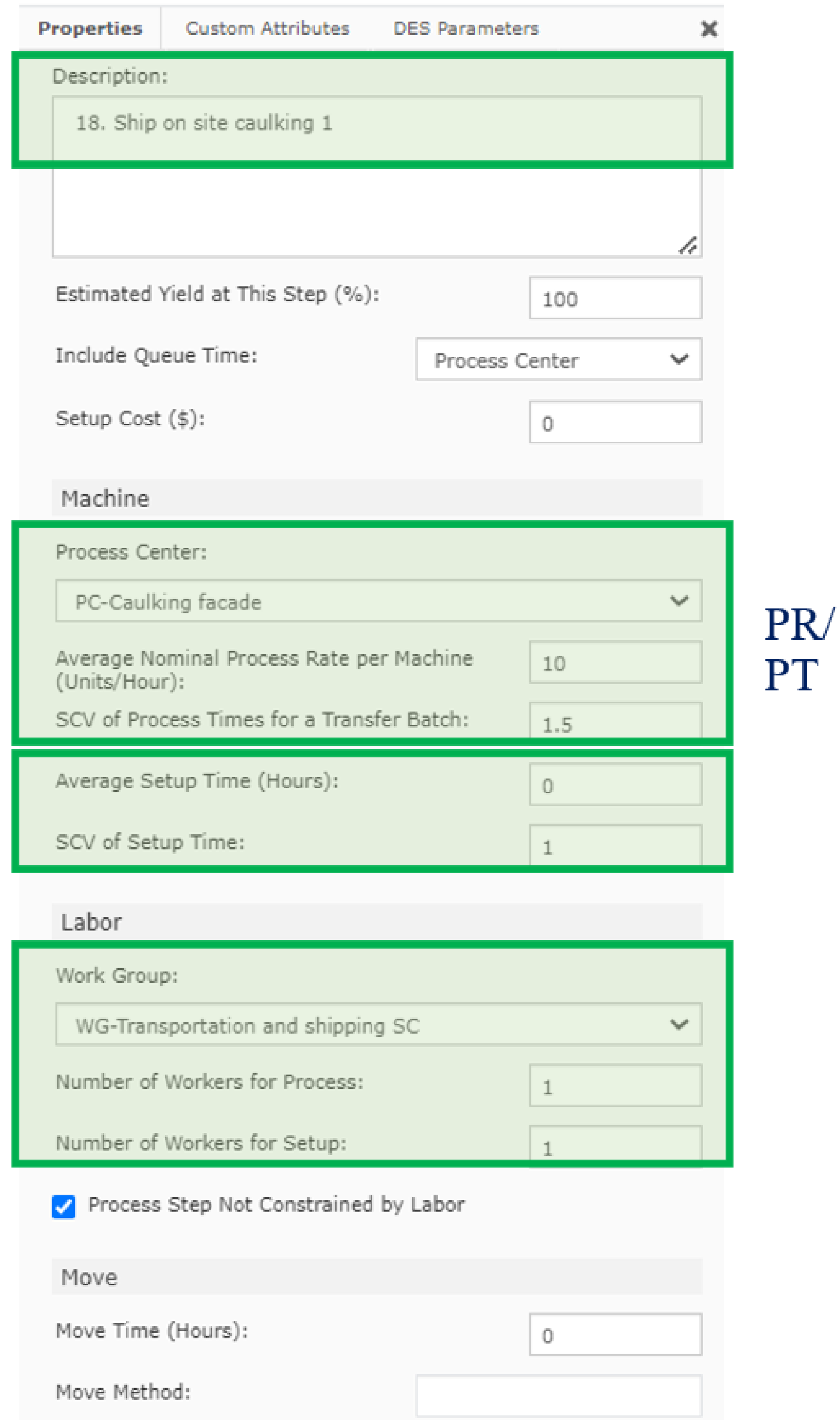

Properties
Custom Attributes
DES Parameters
Description:
15. Attach windows
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Windows installation
Average Nominal Process Rate per Machine (Units/Hour):
3
SCV of Process Times for a Transfer Batch:
1
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Windows installation
Number of Workers for Process:
2
Number of Workers for Setup:
2
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

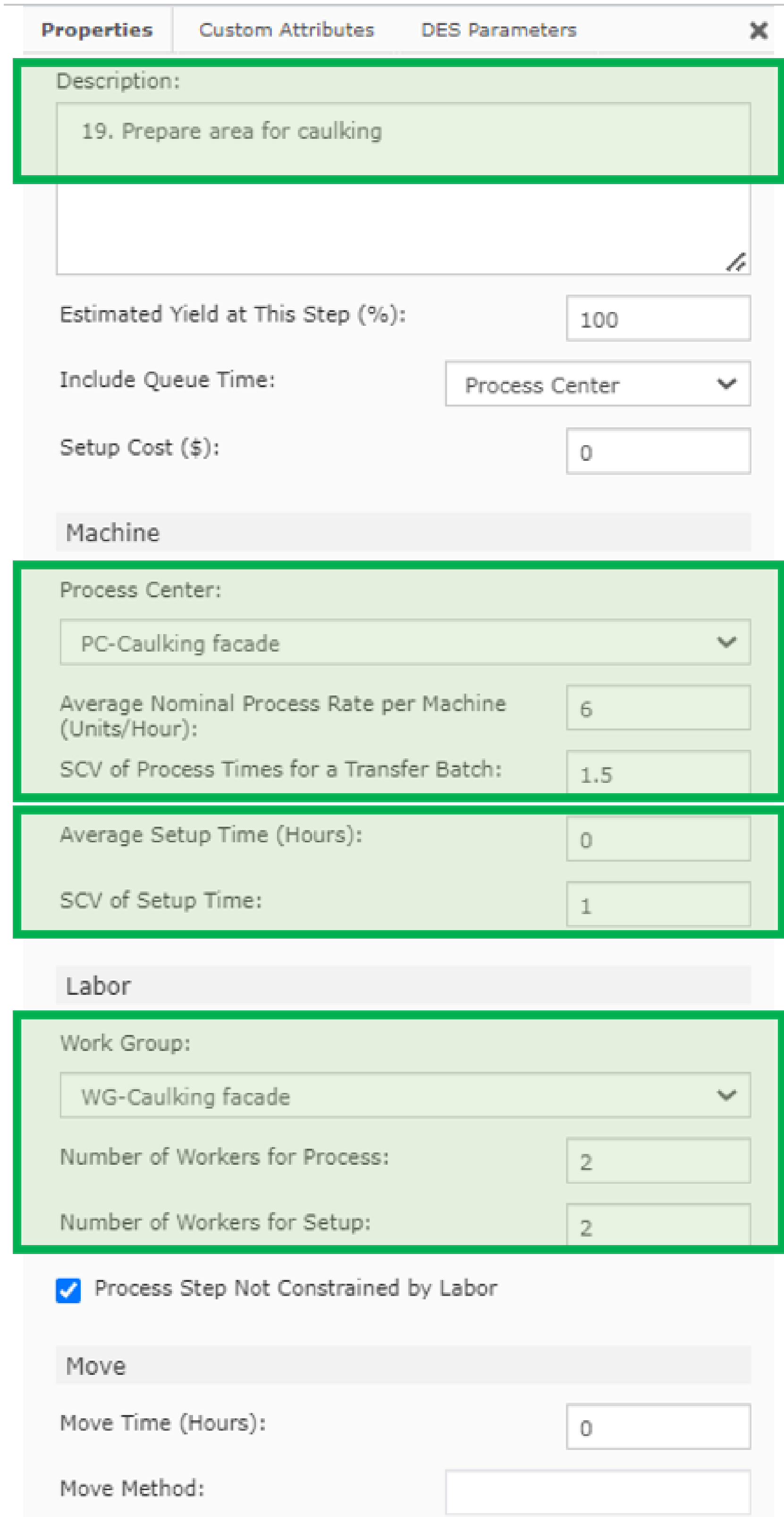
PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
16. Inspect 2 windows
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Windows inspection
Average Nominal Process Time (Hours):
4
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Windows inspection
Number of Workers for Process:
1
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

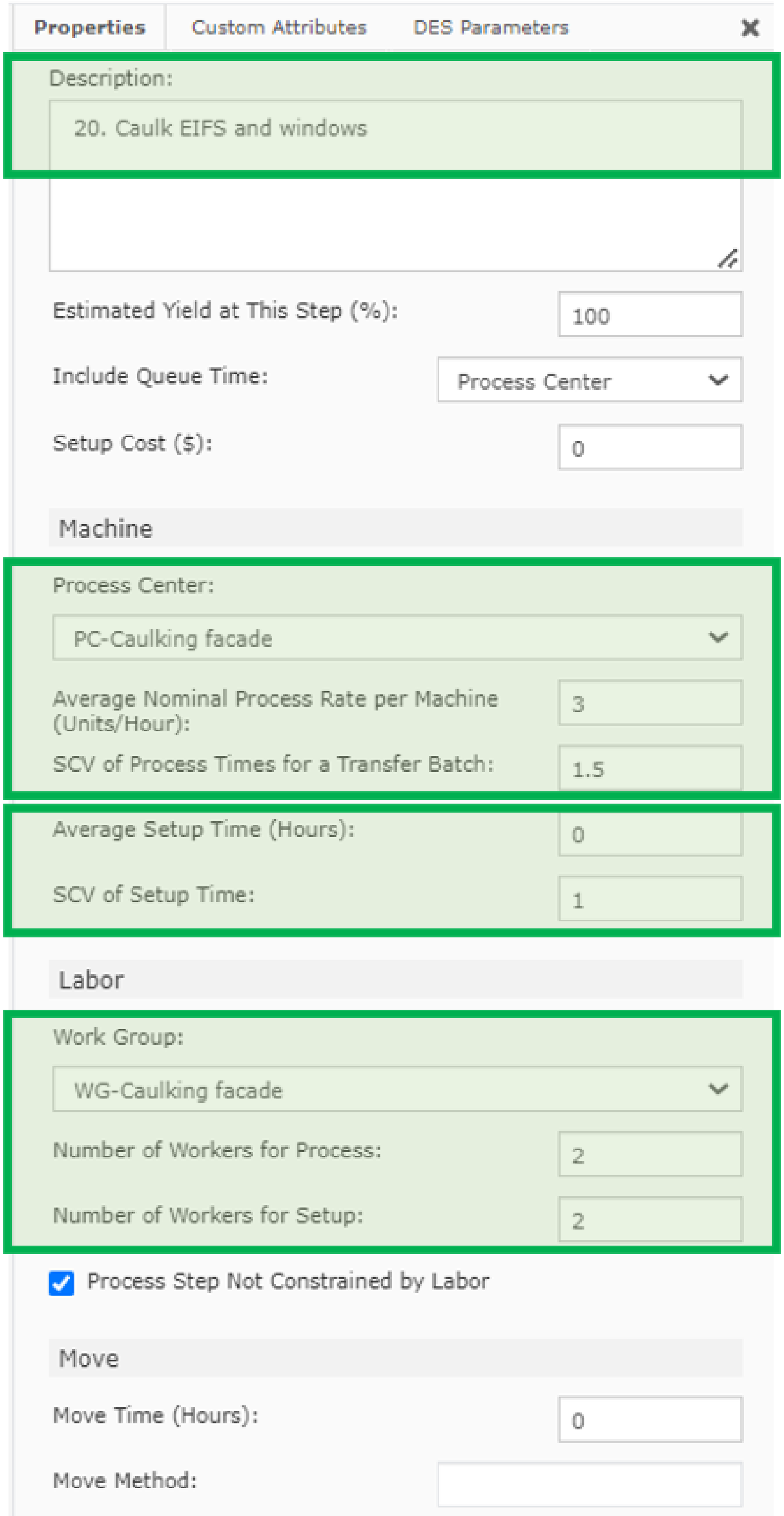
PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
17. Approve windows
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Windows inspection
Average Nominal Process Time (Hours):
1
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Windows inspection
Number of Workers for Process:
1
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:
PR/
PT

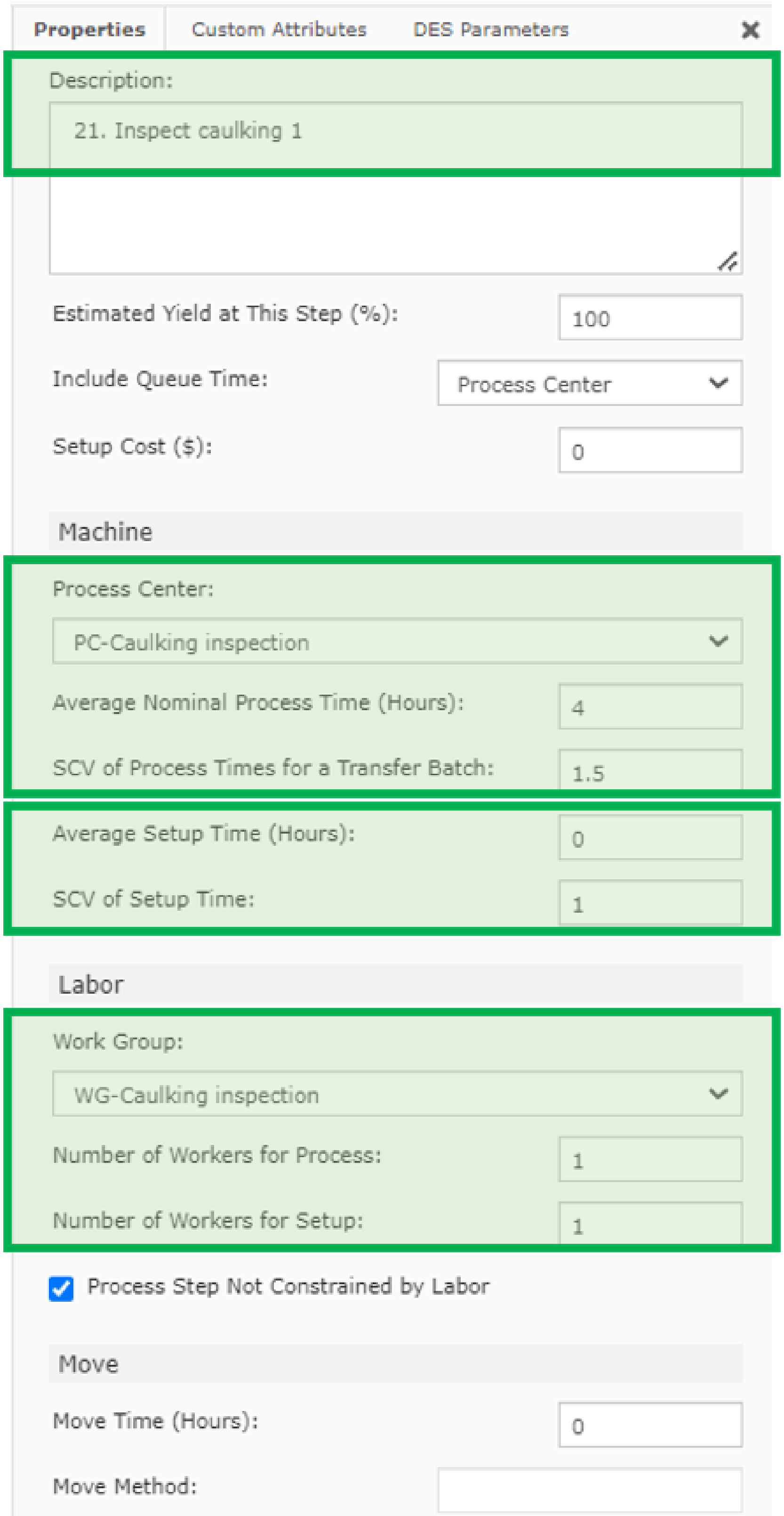

Properties
Custom Attributes
DES Parameters
Description:
18. Ship on site caulking 1
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Caulking facade
Average Nominal Process Rate per Machine (Units/Hour):
10
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Transportation and shipping SC
Number of Workers for Process:
1
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:
PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
19. Prepare area for caulking
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Caulking facade
Average Nominal Process Rate per Machine (Units/Hour):
6
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Caulking facade
Number of Workers for Process:
2
Number of Workers for Setup:
2
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

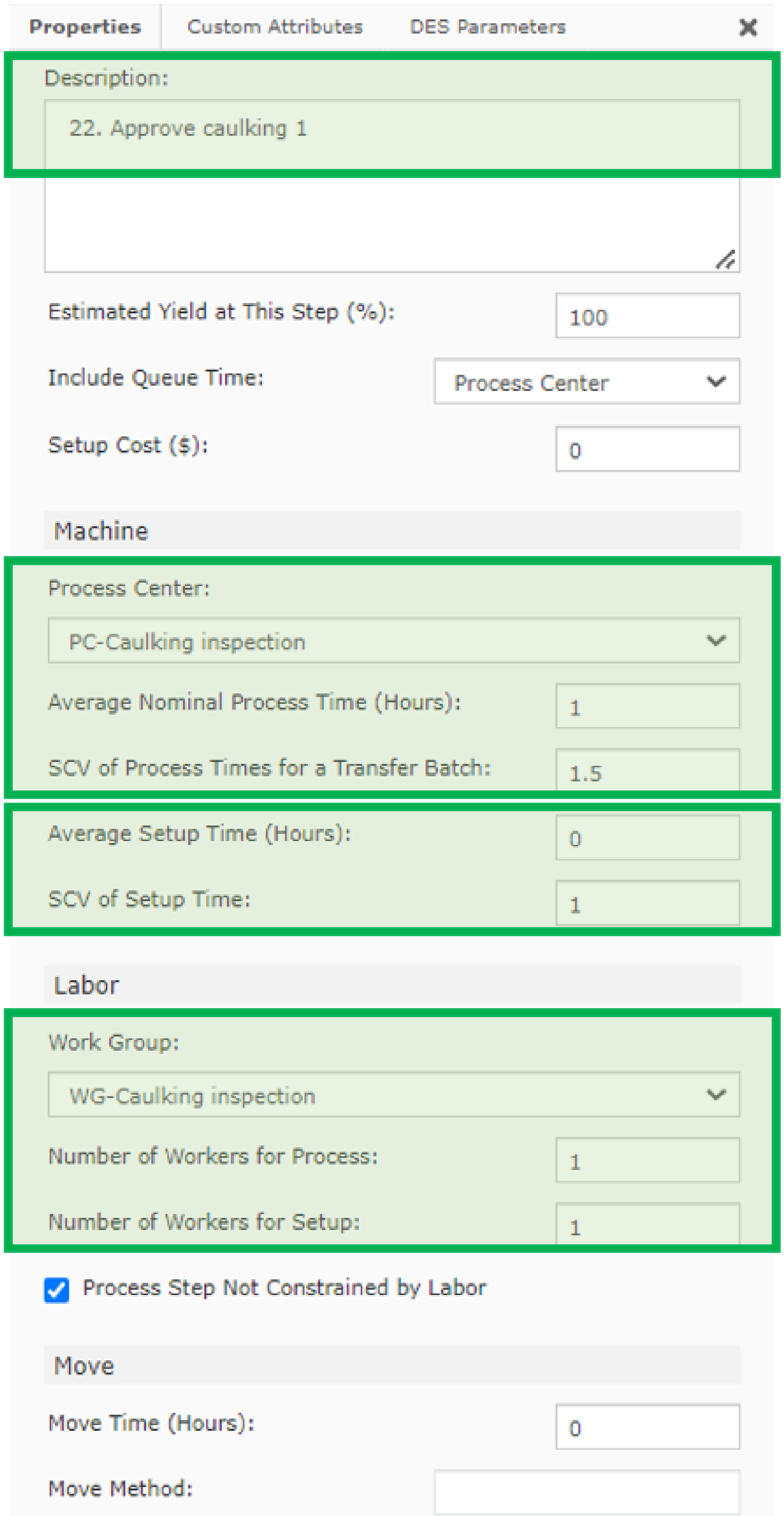
PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
20. Caulk EIFS and windows
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Caulking facade
Average Nominal Process Rate per Machine (Units/Hour):
3
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Caulking facade
Number of Workers for Process:
2
Number of Workers for Setup:
2
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
21. Inspect caulking 1
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Caulking inspection
Average Nominal Process Time (Hours):
4
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Caulking inspection
Number of Workers for Process:
1
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

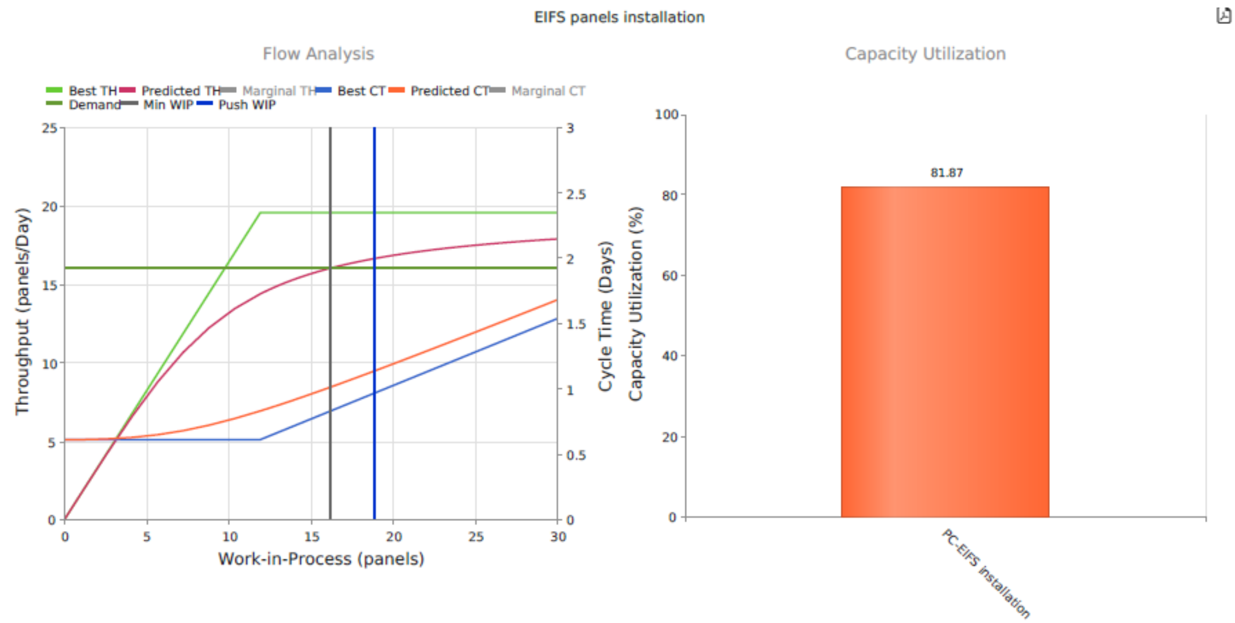
PR/
PT


Properties
Custom Attributes
DES Parameters
Description:
22. Approve caulking 1
Estimated Yield at This Step (%):
100
Include Queue Time:
Process Center
Setup Cost ($):
0
Machine
Process Center:
PC-Caulking inspection
Average Nominal Process Time (Hours):
1
SCV of Process Times for a Transfer Batch:
1.5
Average Setup Time (Hours):
0
SCV of Setup Time:
1
Labor
Work Group:
WG-Caulking inspection
Number of Workers for Process:
1
Number of Workers for Setup:
1
Process Step Not Constrained by Labor
Move
Move Time (Hours):
0
Move Method:

PR/
PT

8.6 APPENDIX F: RESULT SHEETS OF THE 1ST PRODUCTION ANALYTICAL MODEL

Results sheets of the original production system with D=16 EFIS panels.



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
16.00 (panels/Day)	**19.54** (panels/undefined)	**81.87 %**	**0.18** (Days)

MIN WIP	MIN CYCLE TIME
16.15 (panels)	**1.01** (Days) | **8.08** (Hours)

PUSH WIP	PUSH CYCLE TIME
18.85 (panels)	**1.18** (Days) | **9.42** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
16.45 (panels/Day)	**7.11** (Hours)	**18.00** (panels)	**84.19 %**

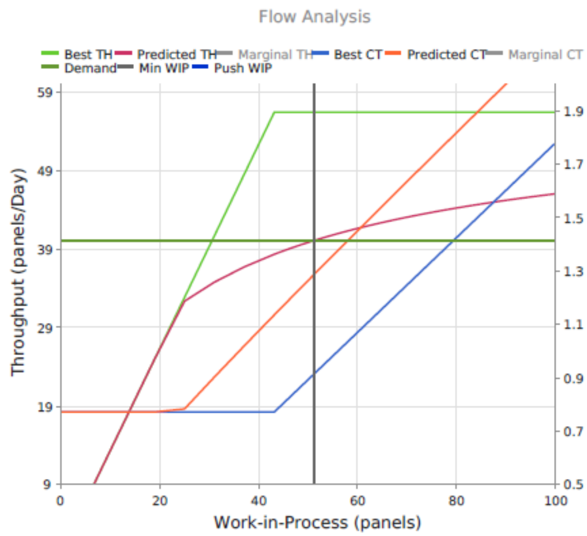
Cycle Time Analysis ▲

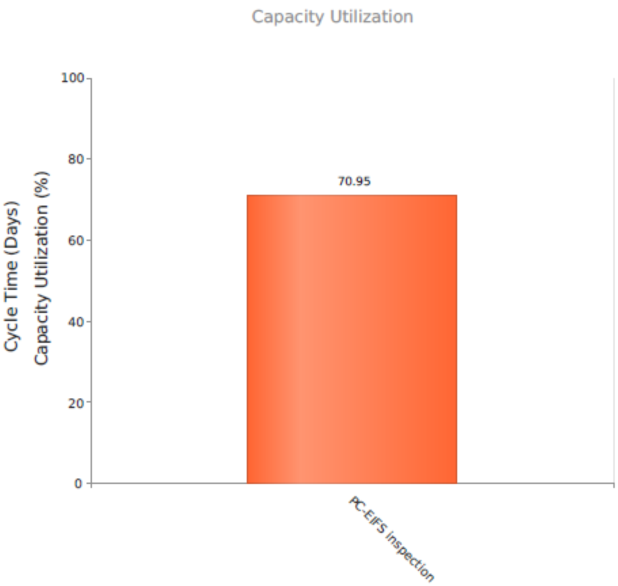
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	16.45	1.09	18.85	16.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	3.69	1.18	3.97	100.00	30.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00	15.22	48.23	36.55	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	81.87	0.39	0.33	1.77	1.23	1.81	17.62
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	16.41

EIFS panels inspection





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
40.00 (panels/Day)	**56.37** (panels/undefined)	**70.95 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
51.35 (panels)	**1.28** (Days) | **10.27** (Hours)

PUSH WIP	PUSH CYCLE TIME
116.88 (panels)	**2.92** (Days) | **23.38** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (panels/Day)	**5.00** (Hours)	**1.00** (panels)	**2.31 %**

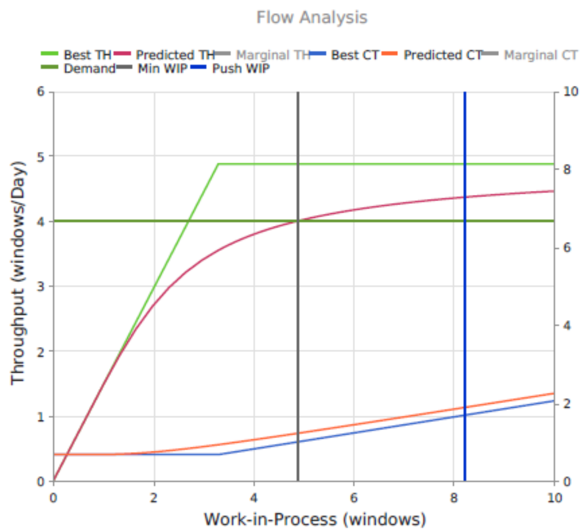
Cycle Time Analysis ▲

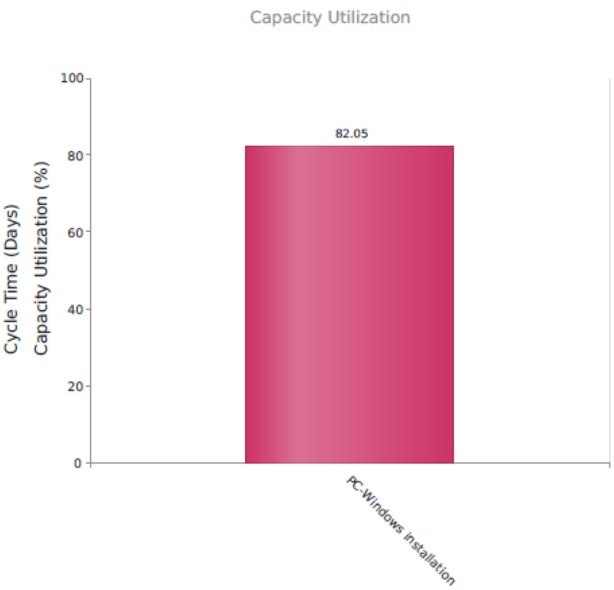
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	116.88	40.00	2.92	18.99	5.00	13.99	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	4.30	2.92	16.33	100.00	30.00	2.92	18.99	5.00	13.99	0.00	0.00	0.00	26.33	73.67	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	70.95	0.48	2.88	1.74	7.00	10.98	136.56

Windows installation





Based on Current Demand

THROUGHPUT
4.00 (windows/Day)

BOTTLENECK RATE
4.87 (windows/undefined)

BOTTLENECK UTILIZATION
82.05 %

RAW PROCESS TIME
0.21 (Days)

MIN WIP
4.90 (windows)

MIN CYCLE TIME
1.23 (Days) | **9.81** (Hours)

PUSH WIP
8.22 (windows)

PUSH CYCLE TIME
2.06 (Days) | **16.45** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.48 (windows/Day)

CYCLE TIME
4.40 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
30.39 %

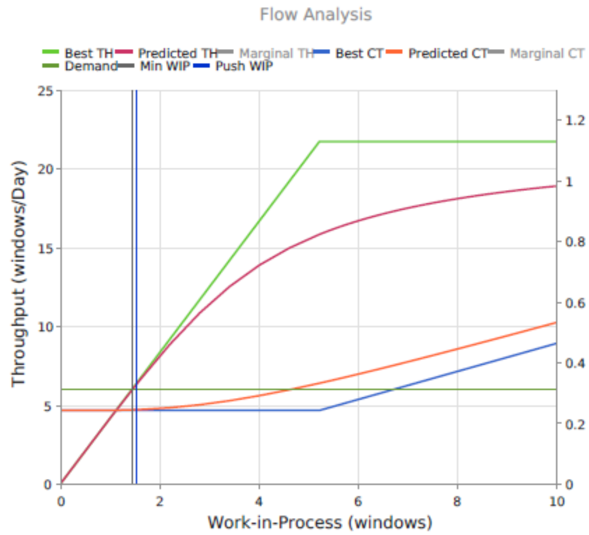
Cycle Time Analysis ▲

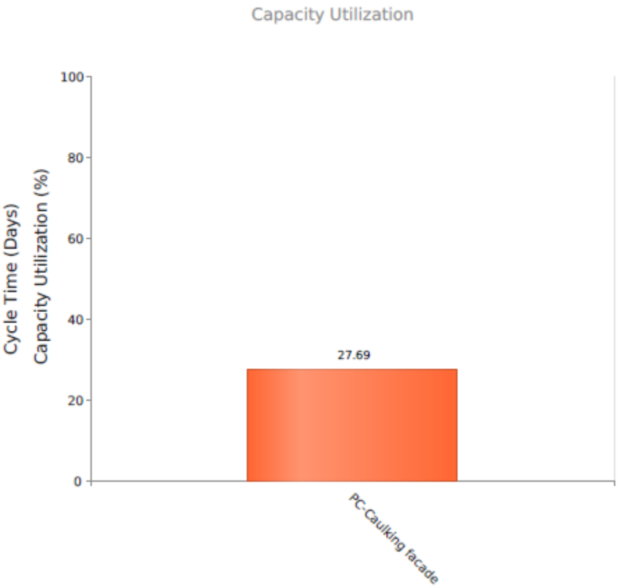
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	8.22	4.00	2.06	13.36	1.33	8.96	3.07	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40	3.05	2.06	9.28	100.00	30.00	2.06	13.36	1.33	8.96	3.07	0.00	0.00	9.98	67.08	22.95	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	82.05	0.18	0.50	3.33	4.48	6.12	8.22

Development of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
6.00 (windows/Day)	**21.67** (windows/undefined)	**27.69 %**	**0.08** (Days)

MIN WIP	MIN CYCLE TIME
1.46 (windows)	**0.24** (Days) | **1.94** (Hours)

PUSH WIP	PUSH CYCLE TIME
1.52 (windows)	**0.25** (Days) | **2.03** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
4.15 (windows/Day)	**1.57** (Hours)	**1.00** (windows)	**19.15 %**

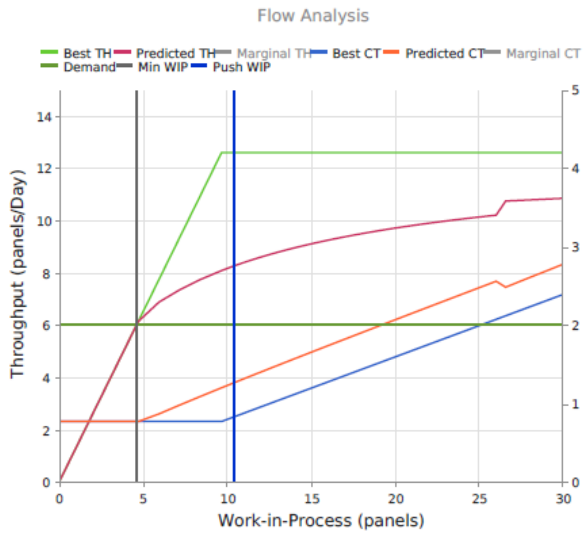
Cycle Time Analysis ▲

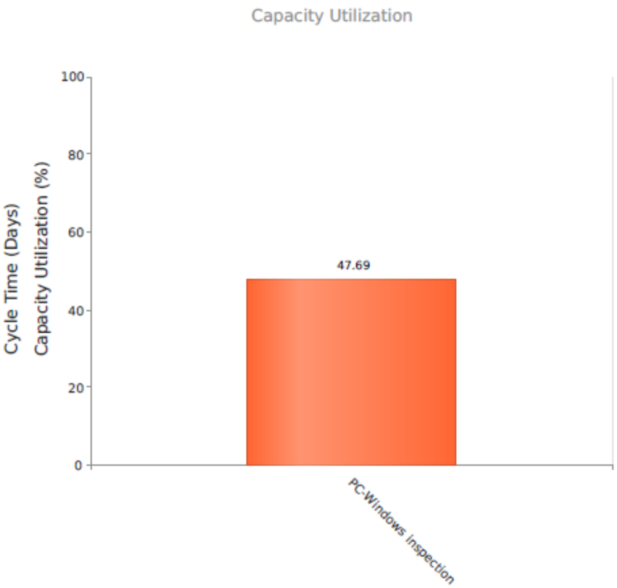
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	1.52	6.00	0.25	1.65	0.50	0.08	1.07	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.35	0.25	1.42	100.00	30.00	0.25	1.65	0.50	0.08	1.07	0.00	0.00	30.30	5.05	64.65	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	27.69	0.64	2.61	0.43	0.04	0.23	1.65

Windows inspection





Based on Current Demand

THROUGHPUT
6.00 (panels/Day)

BOTTLENECK RATE
12.58 (panels/undefined)

BOTTLENECK UTILIZATION
47.69 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
4.62 (panels)

MIN CYCLE TIME
0.77 (Days) | **6.15** (Hours)

PUSH WIP
10.46 (panels)

PUSH CYCLE TIME
1.74 (Days) | **13.94** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT
1.30 (panels/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (panels)

BOTTLENECK UTILIZATION
10.33 %

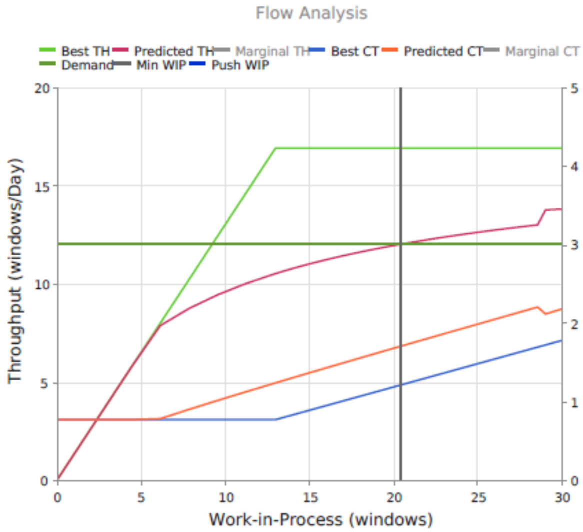
Cycle Time Analysis ▴

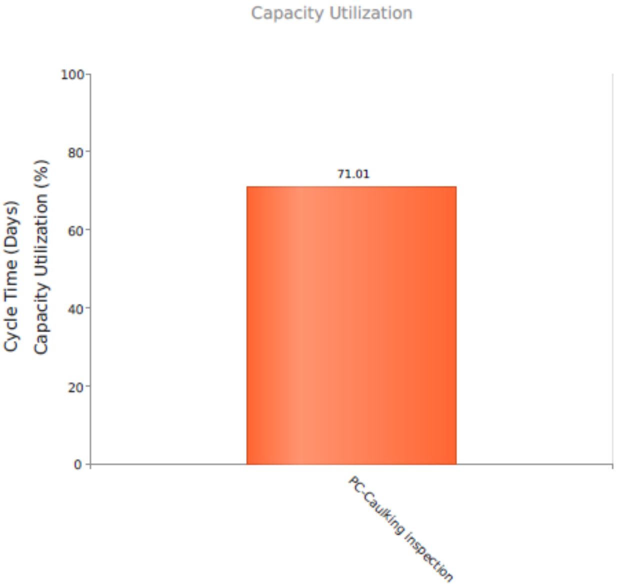
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	10.46	6.00	1.74	11.33	5.00	6.33	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	4.75	1.74	10.77	100.00	30.00	1.74	11.33	5.00	6.33	0.00	0.00	0.00	44.13	55.87	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	47.69	0.82	2.79	1.94	3.16	6.73	14.30

Inspection of caulking 1





Based on Current Demand

THROUGHPUT **12.00** (windows/Day)
BOTTLENECK RATE **16.90** (windows/undefined)
BOTTLENECK UTILIZATION **71.01 %**
RAW PROCESS TIME **0.77** (Days)

MIN WIP **20.43** (windows)
MIN CYCLE TIME **1.70** (Days) | **13.62** (Hours)

PUSH WIP **41.75** (windows)
PUSH CYCLE TIME **3.48** (Days) | **27.83** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT **1.30** (windows/Day)
CYCLE TIME **5.00** (Hours)
WIP LEVEL **1.00** (windows)
BOTTLENECK UTILIZATION **7.69 %**

Cycle Time Analysis ▲

	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	41.75	12.00	3.48	22.62	5.00	17.62	0.00	0.00	0.00

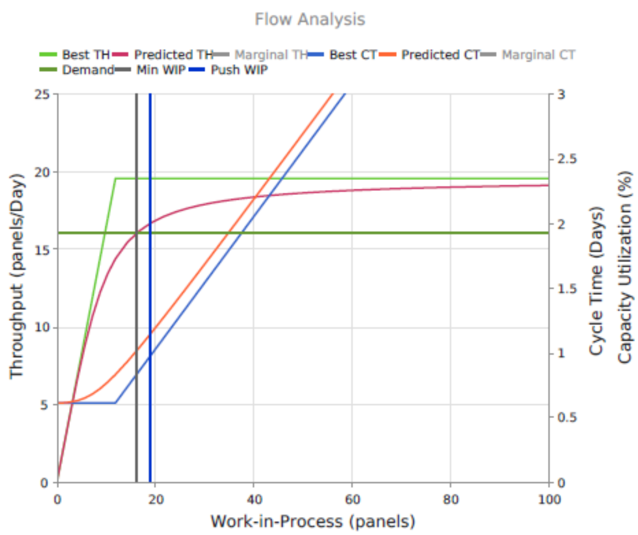
	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	4.39	3.48	19.84	100.00	30.00	3.48	22.62	5.00	17.62	0.00	0.00	0.00	22.11	77.89	0.00	0.00	0.00

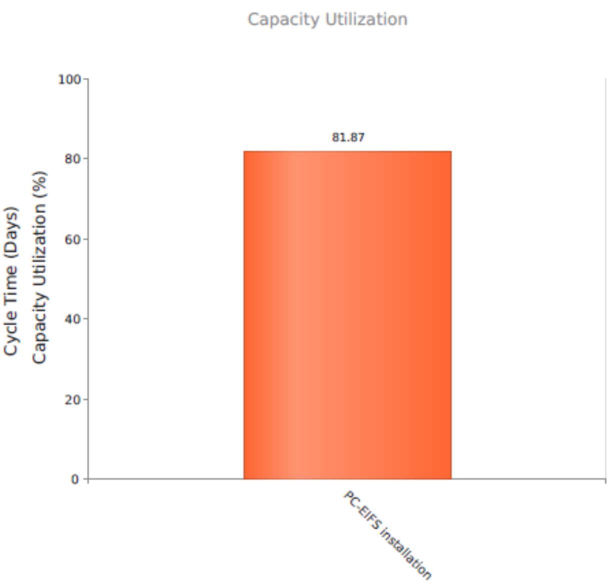
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	71.01	0.54	2.40	2.50	8.81	13.57	41.75

8.7 Appendix G: Result sheets of CONWIP scenarios of the 1st model

Results sheets of the CONWIP scenarios of the original production system model.

EIFS panels installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
16.00 (panels/Day)	**19.54** (panels/undefined)	**81.87 %**	**0.18** (Days)

MIN WIP	MIN CYCLE TIME
16.15 (panels)	**1.01** (Days) | **8.08** (Hours)

PUSH WIP	PUSH CYCLE TIME
18.85 (panels)	**1.18** (Days) | **9.42** (Hours)

Based on CONWIP Level of 16 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
15.96 (panels/Day)	**6.52** (Hours)	**16.00** (panels)	**81.68 %**

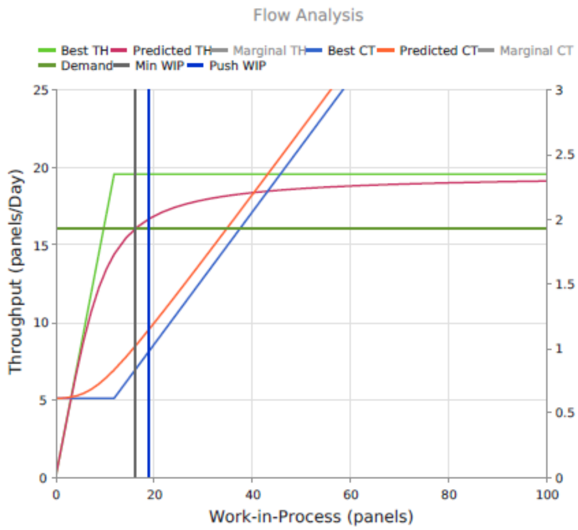
Cycle Time Analysis ▲

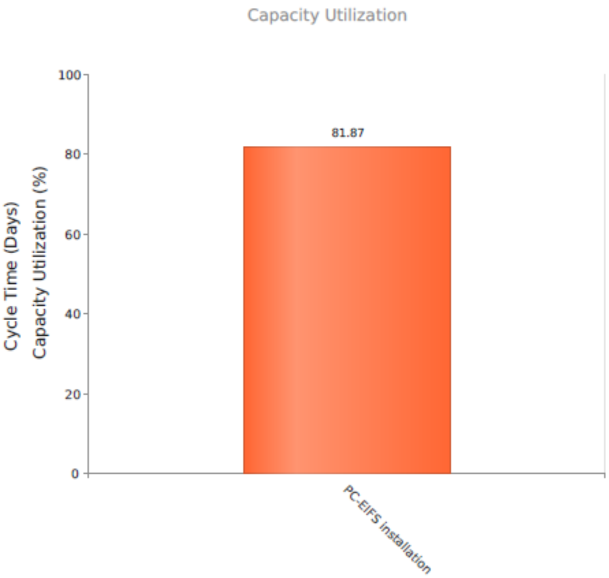
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	16.00	15.96	1.00	18.85	16.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	3.38	1.18	3.97	100.00	30.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00	15.22	48.23	36.55	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	81.87	0.39	0.33	1.77	1.23	1.81	17.62
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	16.41

EIFS panels installation





Based on Current Demand

THROUGHPUT **16.00** (panels/Day)

BOTTLENECK RATE **19.54** (panels/undefined)

BOTTLENECK UTILIZATION **81.87 %**

RAW PROCESS TIME **0.18** (Days)

MIN WIP **16.15** (panels)

MIN CYCLE TIME **1.01** (Days) | **8.08** (Hours)

PUSH WIP **18.85** (panels)

PUSH CYCLE TIME **1.18** (Days) | **9.42** (Hours)

Based on CONWIP Level of 17 (panels)

THROUGHPUT **16.22** (panels/Day)

CYCLE TIME **6.81** (Hours)

WIP LEVEL **17.00** (panels)

BOTTLENECK UTILIZATION **83.01 %**

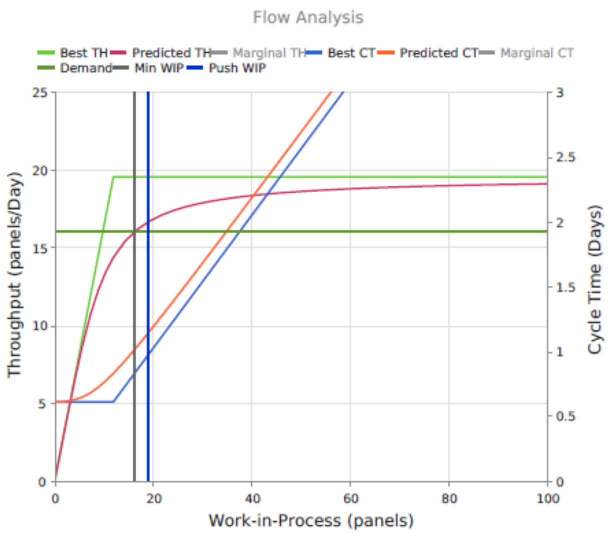
Cycle Time Analysis ▲

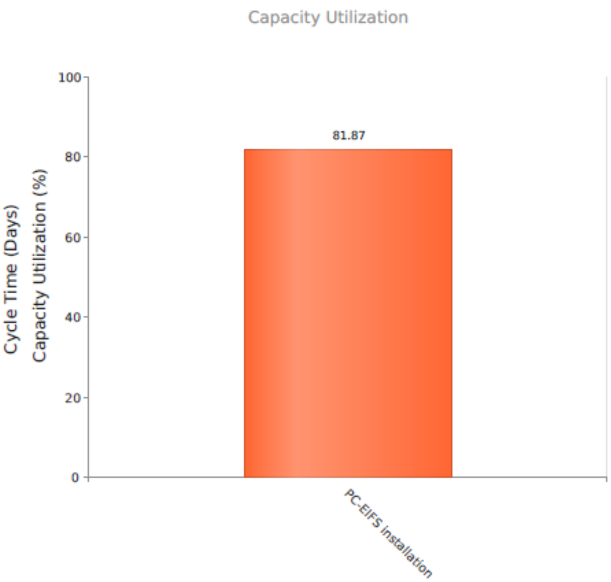
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	17.00	16.22	1.05	18.85	16.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	3.54	1.18	3.97	100.00	30.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00	15.22	48.23	36.55	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	81.87	0.39	0.33	1.77	1.23	1.81	17.62
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	16.41

EIFS panels installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
16.00 (panels/Day)	**19.54** (panels/undefined)	**81.87 %**	**0.18** (Days)

MIN WIP	MIN CYCLE TIME
16.15 (panels)	**1.01** (Days) | **8.08** (Hours)

PUSH WIP	PUSH CYCLE TIME
18.85 (panels)	**1.18** (Days) | **9.42** (Hours)

Based on CONWIP Level of 19 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
16.65 (panels/Day)	**7.42** (Hours)	**19.00** (panels)	**85.21 %**

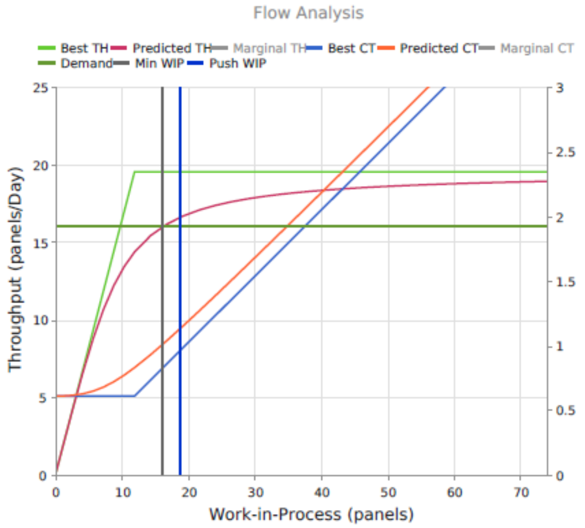
Cycle Time Analysis ▲

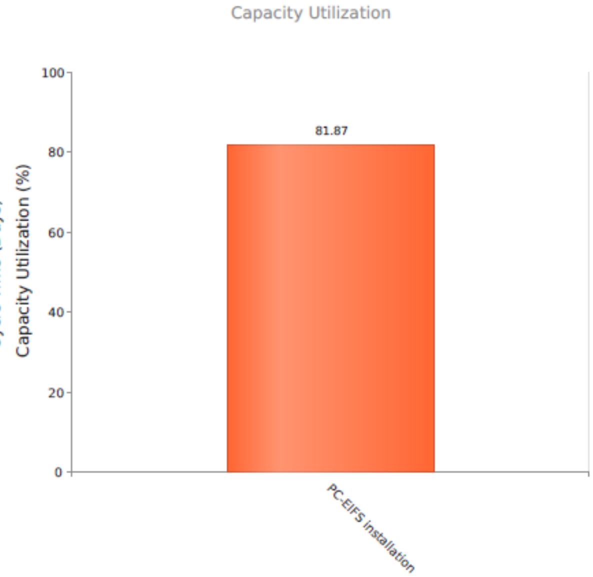
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	19.00	16.65	1.14	18.85	16.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	3.85	1.18	3.97	100.00	30.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00	15.22	48.23	36.55	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	81.87	0.39	0.33	1.77	1.23	1.81	17.62
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	16.41

EIFS panels installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
16.00 (panels/Day)	**19.54** (panels/undefined)	**81.87 %**	**0.18** (Days)

MIN WIP	MIN CYCLE TIME
16.15 (panels)	**1.01** (Days) | **8.08** (Hours)

PUSH WIP	PUSH CYCLE TIME
18.85 (panels)	**1.18** (Days) | **9.42** (Hours)

Based on CONWIP Level of 20 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
16.83 (panels/Day)	**7.73** (Hours)	**20.00** (panels)	**86.13 %**

Cycle Time Analysis ▲

	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	20.00	16.83	1.19	18.85	16.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00

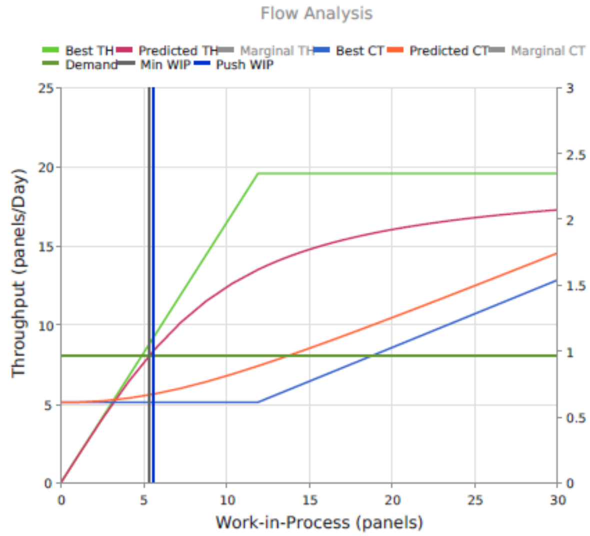
	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	4.01	1.18	3.97	100.00	30.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00	15.22	48.23	36.55	0.00	0.00

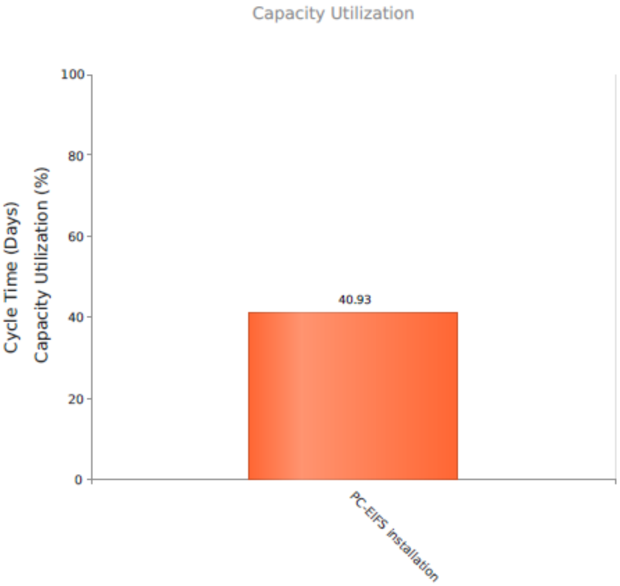
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	81.87	0.39	0.33	1.77	1.23	1.81	17.62
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	16.41

8.8 APPENDIX H: RESULT SHEETS OF THE SENSITIVITY ANALYSIS RUNS

Results sheets of the A2 production system based on D=8 EFIS panels.

EIFS panels installation





Based on Current Demand

THROUGHPUT **8.00** (panels/Day) | BOTTLENECK RATE **19.54** (panels/undefined) | BOTTLENECK UTILIZATION **40.93 %** | RAW PROCESS TIME **0.18** (Days)

MIN WIP **5.32** (panels) | MIN CYCLE TIME **0.67** (Days) | **5.32** (Hours)

PUSH WIP **5.61** (panels) | PUSH CYCLE TIME **0.70** (Days) | **5.61** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT **15.57** (panels/Day) | CYCLE TIME **7.51** (Hours) | WIP LEVEL **18.00** (panels) | BOTTLENECK UTILIZATION **79.68 %**

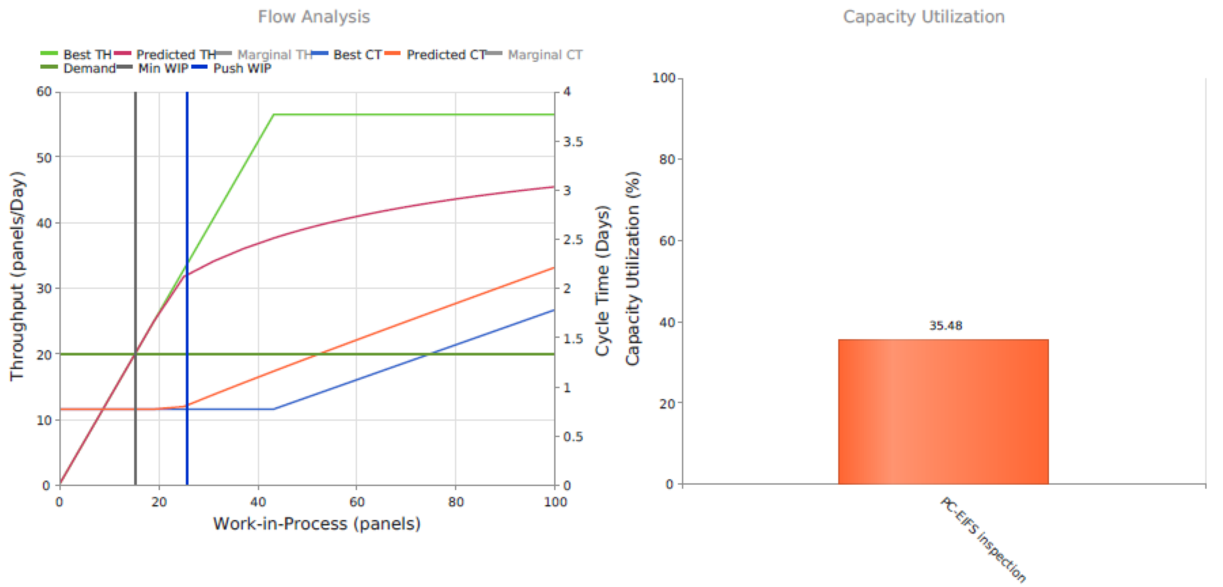
Cycle Time Analysis ▲

	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	15.57	1.16	5.61	8.00	0.70	4.55	1.17	0.59	2.80	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	4.32	0.70	2.62	100.00	30.00	0.70	4.55	1.17	0.59	2.80	0.00	0.00	25.58	12.97	61.45	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	40.93	0.76	0.33	1.77	0.20	0.56	4.99
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	8.21

EIFS panels inspection



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
20.00 (panels/Day)	**56.37** (panels/undefined)	**35.48 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
15.38 (panels)	**0.77** (Days) | **6.15** (Hours)

PUSH WIP	PUSH CYCLE TIME
25.85 (panels)	**1.29** (Days) | **10.34** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (panels/Day)	**5.00** (Hours)	**1.00** (panels)	**2.31 %**

Cycle Time Analysis ▲

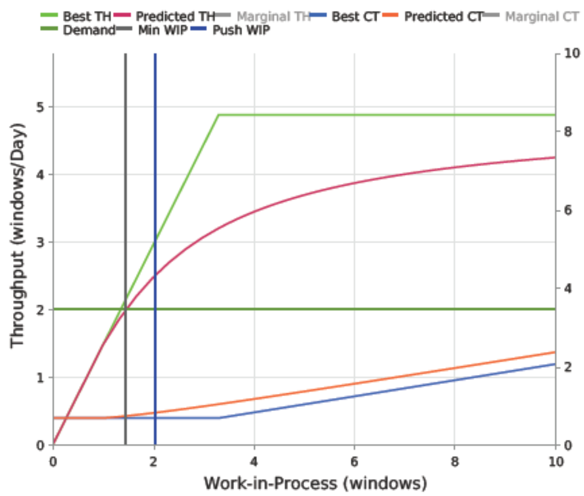
Product Flow	CONWIP			PUSH								
	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	25.85	20.00	1.29	8.40	5.00	3.40	0.00	0.00	0.00

Item	CONWIP		PUSH															
	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	4.89	1.29	8.22	100.00	30.00	1.29	8.40	5.00	3.40	0.00	0.00	0.00	59.51	40.49	0.00	0.00	0.00

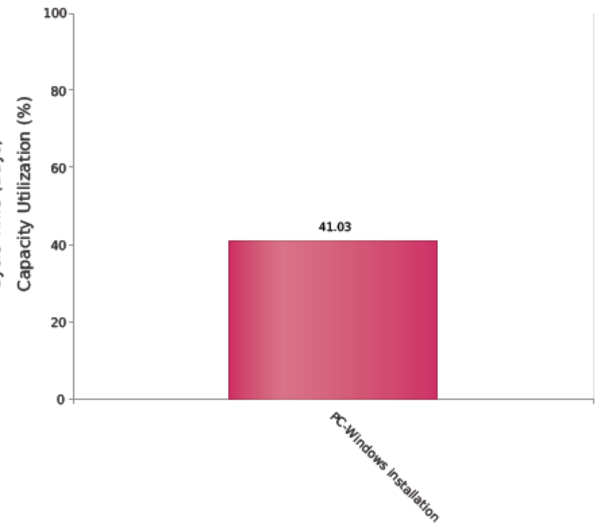
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	35.48	0.75	2.88	1.74	1.70	4.59	29.18

Windows installation

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
2.00 (windows/Day)	**4.87** (windows/undefined)	**41.03 %**	**0.21** (Days)

MIN WIP	MIN CYCLE TIME
1.46 (windows)	**0.73** (Days) | **5.84** (Hours)

PUSH WIP	PUSH CYCLE TIME
2.03 (windows)	**1.02** (Days) | **8.13** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.48 (windows/Day)	**4.40** (Hours)	**1.00** (windows)	**30.39 %**

Cycle Time Analysis ▲

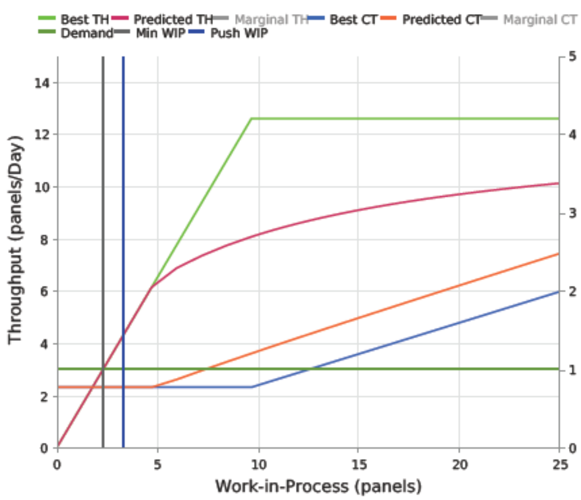
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	2.03	2.00	1.02	6.61	1.33	2.21	3.07	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40	3.14	1.02	4.71	100.00	30.00	1.02	6.61	1.33	2.21	3.07	0.00	0.00	20.19	33.39	46.43	0.00	0.00

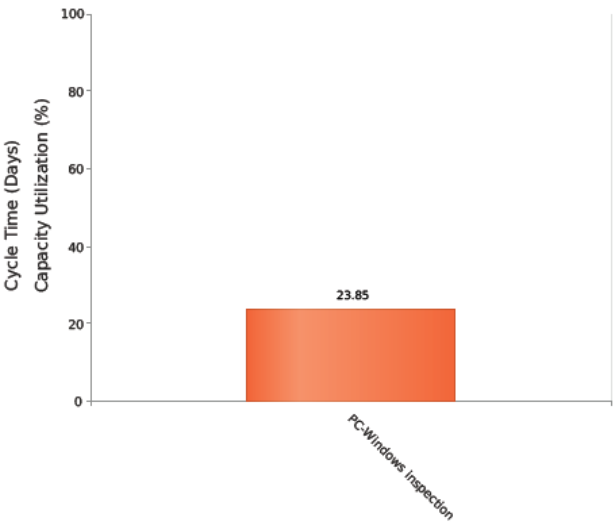
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	41.03	0.60	0.50	3.33	1.10	2.36	2.03

Windows inspection

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
3.00 (panels/Day)	**12.58** (panels/undefined)	**23.85 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
2.31 (panels)	**0.77** (Days) | **6.15** (Hours)

PUSH WIP	PUSH CYCLE TIME
3.31 (panels)	**1.10** (Days) | **8.82** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (panels/Day)	**5.00** (Hours)	**1.00** (panels)	**10.33 %**

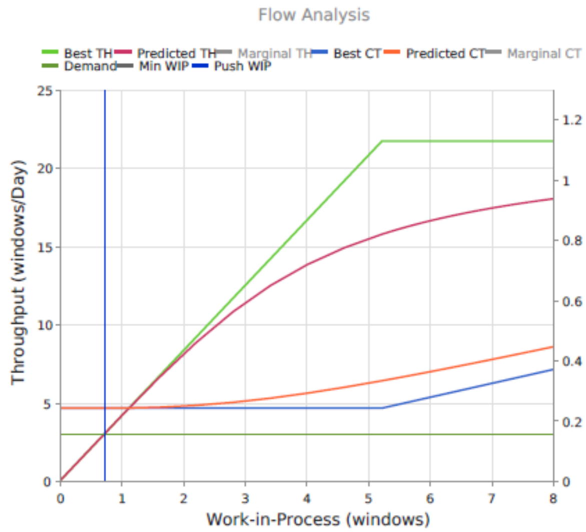
Cycle Time Analysis ▲

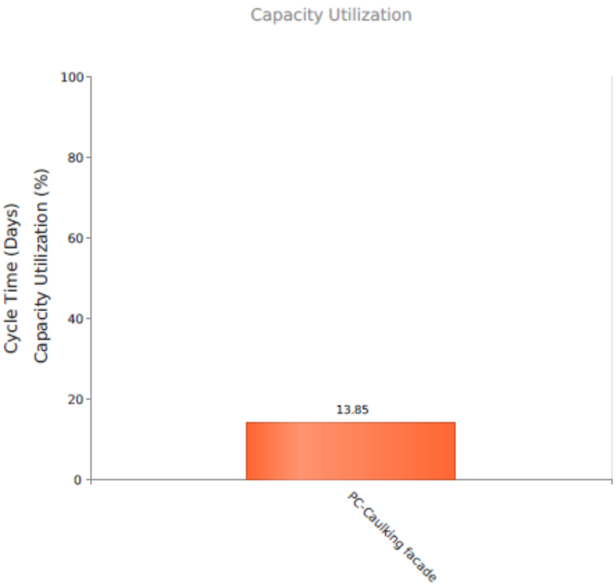
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	3.31	3.00	1.10	7.17	5.00	2.17	0.00	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	5.05	1.10	7.24	100.00	30.00	1.10	7.17	5.00	2.17	0.00	0.00	0.00	69.74	30.26	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	23.85	0.84	2.79	1.94	1.08	3.67	4.27

Development of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
3.00 (windows/Day)	**21.67** (windows/undefined)	**13.85 %**	**0.08** (Days)

MIN WIP	MIN CYCLE TIME
0.72 (windows)	**0.24** (Days) | **1.93** (Hours)

PUSH WIP	PUSH CYCLE TIME
0.73 (windows)	**0.24** (Days) | **1.95** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
4.15 (windows/Day)	**1.57** (Hours)	**1.00** (windows)	**19.15 %**

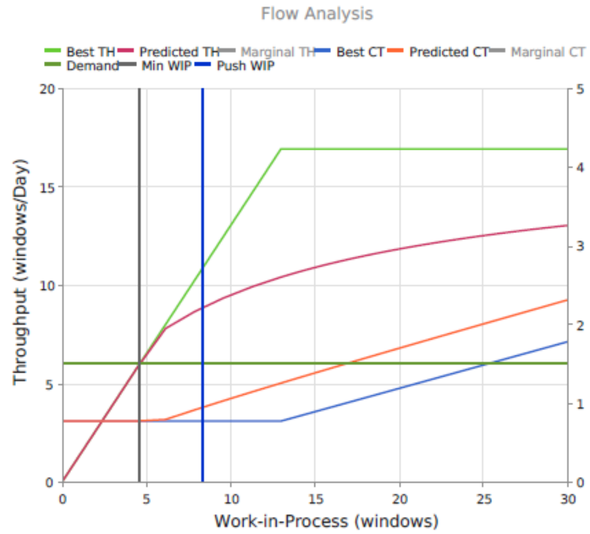
Cycle Time Analysis ▲

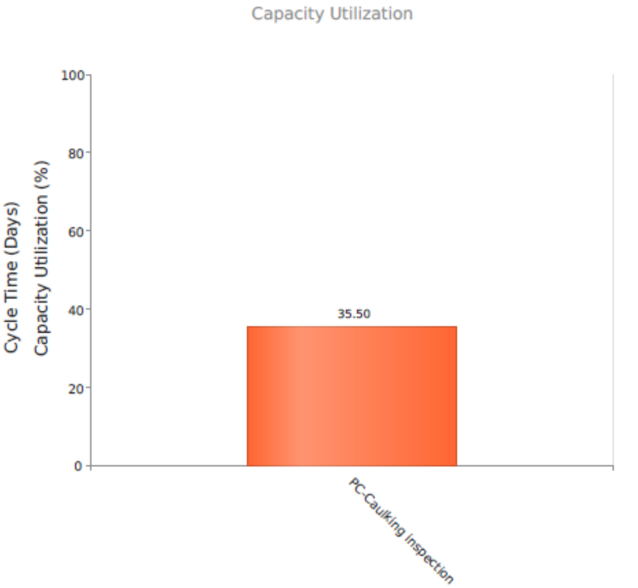
	CONWIP			PUSH							
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	0.73	3.00	0.24	1.59	0.50	0.02	1.07	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.38	0.24	1.39	100.00	30.00	0.24	1.59	0.50	0.02	1.07	0.00	0.00	31.51	1.26	67.23	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	13.85	0.72	2.61	0.43	0.01	0.11	0.78

Inspection of caulking 1





Based on Current Demand

THROUGHPUT
6.00 (windows/Day)

BOTTLENECK RATE
16.90 (windows/undefined)

BOTTLENECK UTILIZATION
35.50 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
4.62 (windows)

MIN CYCLE TIME
0.77 (Days) | **6.15** (Hours)

PUSH WIP
8.33 (windows)

PUSH CYCLE TIME
1.39 (Days) | **11.11** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.30 (windows/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
7.69 %

Cycle Time Analysis ▲

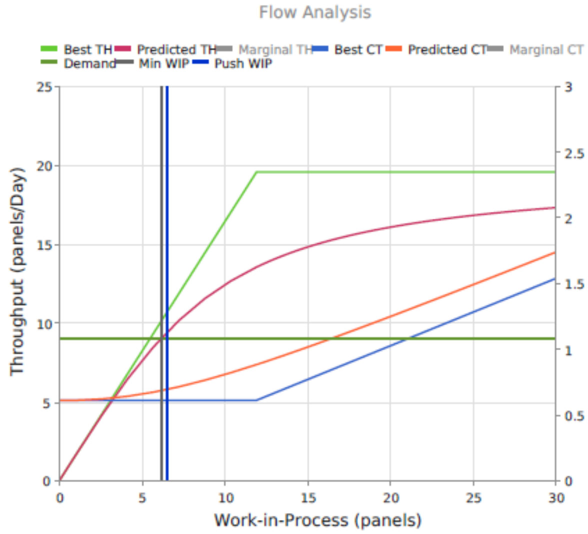
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	8.33	6.00	1.39	9.03	5.00	4.03	0.00	0.00	0.00

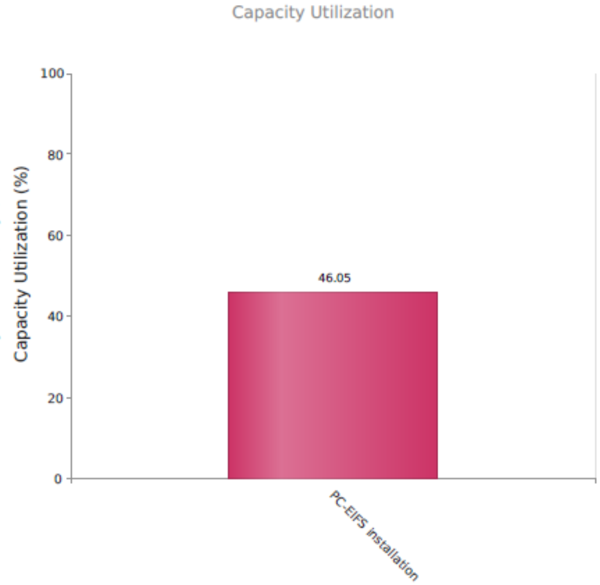
	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	5.11	1.39	9.23	100.00	30.00	1.39	9.03	5.00	4.03	0.00	0.00	0.00	55.40	44.60	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	35.50	0.66	2.40	2.50	2.01	5.46	8.33

Results sheets of the A3 production system based on D=9 EFIS panels.

EIFS panels installation





Based on Current Demand

THROUGHPUT **9.00** (panels/Day)
BOTTLENECK RATE **19.54** (panels/undefined)
BOTTLENECK UTILIZATION **46.05 %**
RAW PROCESS TIME **0.18** (Days)

MIN WIP **6.15** (panels)
MIN CYCLE TIME **0.68** (Days) | **5.47** (Hours)

PUSH WIP **6.54** (panels)
PUSH CYCLE TIME **0.73** (Days) | **5.81** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT **15.63** (panels/Day)
CYCLE TIME **7.49** (Hours)
WIP LEVEL **18.00** (panels)
BOTTLENECK UTILIZATION **79.99 %**

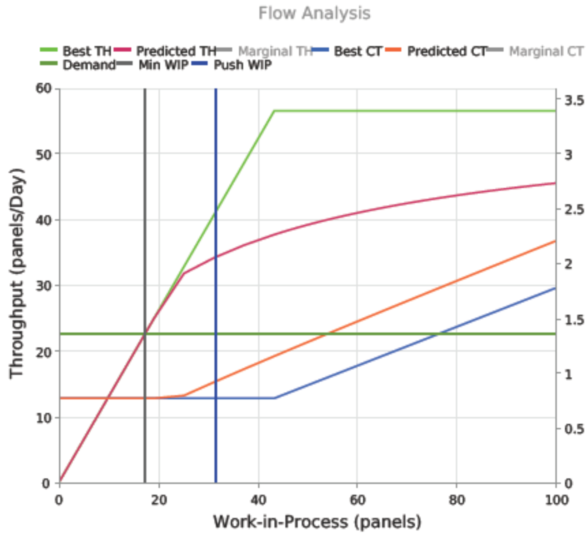
Cycle Time Analysis ▲

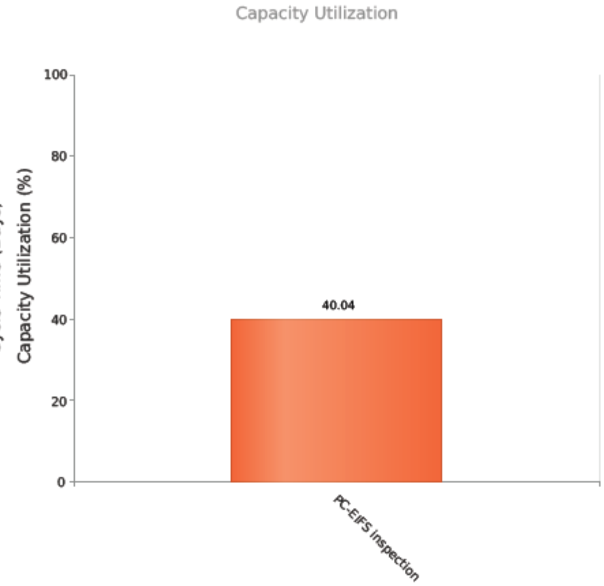
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	15.63	1.15	6.54	9.00	0.73	4.72	1.17	0.76	2.80	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	4.25	0.73	2.68	100.00	30.00	0.73	4.72	1.17	0.76	2.80	0.00	0.00	24.67	16.08	59.26	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	46.05	0.73	0.33	1.77	0.25	0.65	5.85
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	9.23

EIFS panels inspection





Based on Current Demand

THROUGHPUT
22.60 (panels/Day)

BOTTLENECK RATE
56.45 (panels/undefined)

BOTTLENECK UTILIZATION
40.04 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
17.38 (panels)

MIN CYCLE TIME
0.77 (Days) | **6.15** (Hours)

PUSH WIP
31.67 (panels)

PUSH CYCLE TIME
1.40 (Days) | **11.21** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT
1.30 (panels/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (panels)

BOTTLENECK UTILIZATION
2.30 %

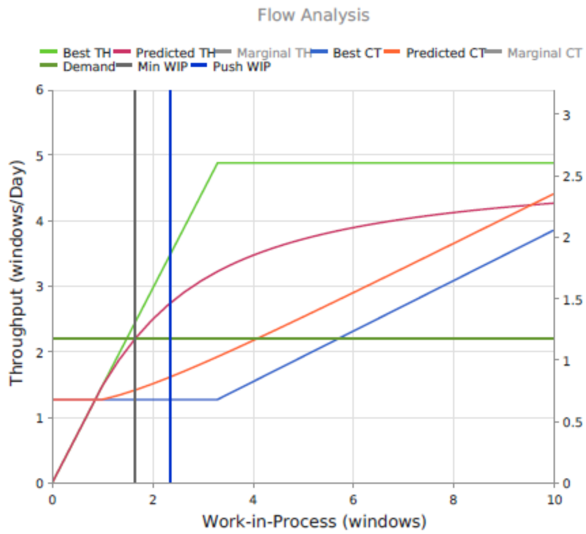
Cycle Time Analysis ▲

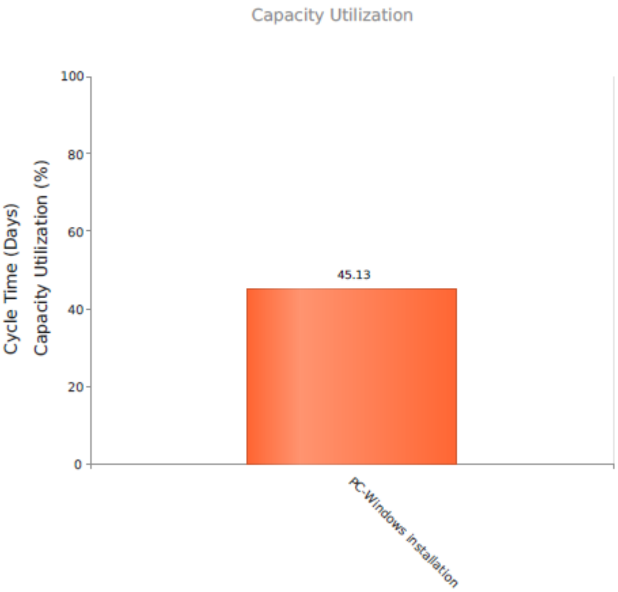
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	31.67	22.60	1.40	9.11	5.00	4.11	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	4.84	1.40	8.82	100.00	30.00	1.40	9.11	5.00	4.11	0.00	0.00	0.00	54.89	45.11	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	40.04	0.72	2.88	1.75	2.05	5.11	35.90

Windows installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
2.20 (windows/Day)	**4.88** (windows/undefined)	**45.13 %**	**0.21** (Days)

MIN WIP	MIN CYCLE TIME
1.66 (windows)	**0.75** (Days) | **6.03** (Hours)

PUSH WIP	PUSH CYCLE TIME
2.34 (windows)	**1.06** (Days) | **8.52** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.48 (windows/Day)	**4.40** (Hours)	**1.00** (windows)	**30.33 %**

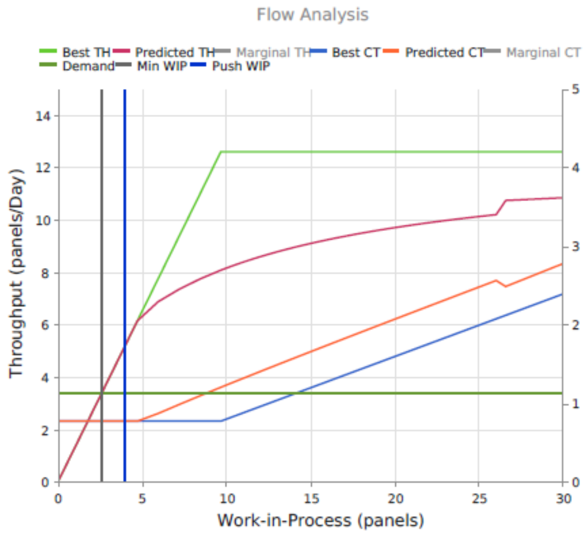
Cycle Time Analysis ▲

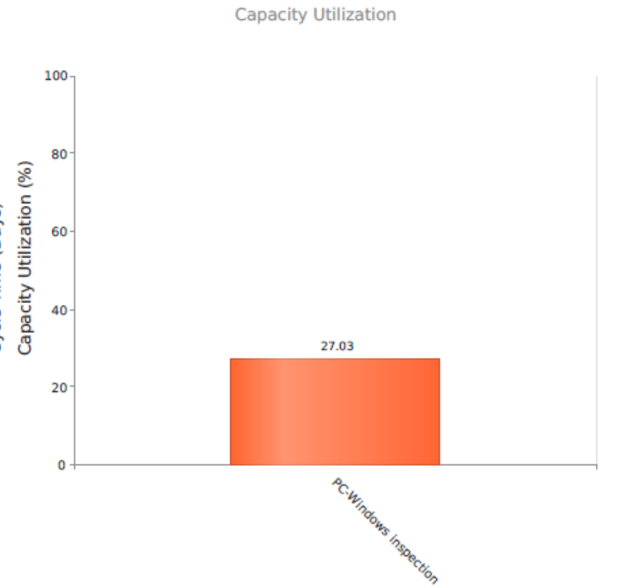
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	2.34	2.20	1.06	6.92	1.33	2.52	3.07	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40	3.12	1.06	4.91	100.00	30.00	1.06	6.92	1.33	2.52	3.07	0.00	0.00	19.27	36.41	44.32	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	45.13	0.56	0.50	3.33	1.26	2.56	2.34

Windows inspection





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
3.40 (panels/Day)	**12.58** (panels/undefined)	**27.03 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
2.62 (panels)	**0.77** (Days) | **6.15** (Hours)

PUSH WIP	PUSH CYCLE TIME
3.96 (panels)	**1.16** (Days) | **9.31** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (panels/Day)	**5.00** (Hours)	**1.00** (panels)	**10.33 %**

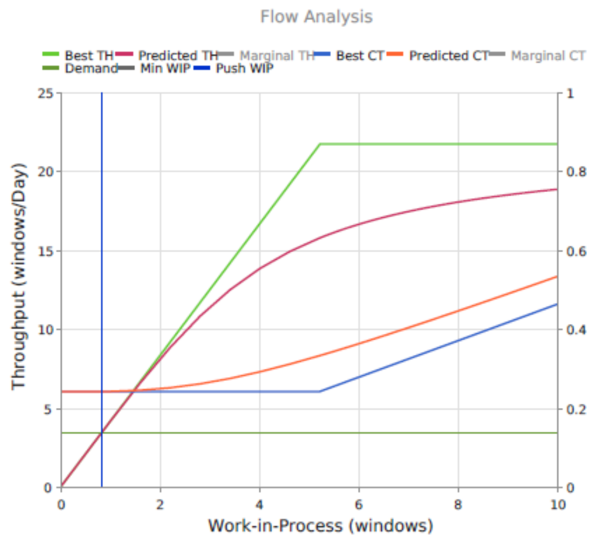
Cycle Time Analysis ▲

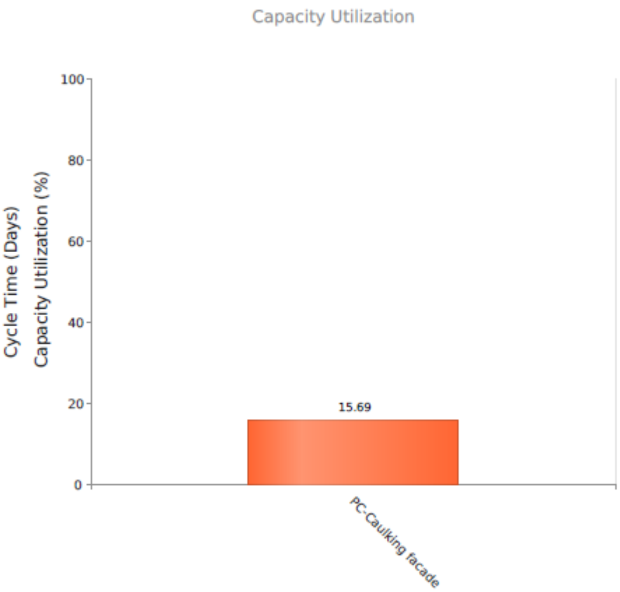
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	3.96	3.40	1.16	7.56	5.00	2.56	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	5.03	1.16	7.60	100.00	30.00	1.16	7.56	5.00	2.56	0.00	0.00	0.00	66.10	33.90	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	27.03	0.84	2.79	1.94	1.28	4.02	5.15

Development of caulking 1





Based on Current Demand

THROUGHPUT
3.40 (windows/Day)

BOTTLENECK RATE
21.67 (windows/undefined)

BOTTLENECK UTILIZATION
15.69 %

RAW PROCESS TIME
0.08 (Days)

MIN WIP
0.82 (windows)

MIN CYCLE TIME
0.24 (Days) | **1.93** (Hours)

PUSH WIP
0.83 (windows)

PUSH CYCLE TIME
0.24 (Days) | **1.96** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
4.15 (windows/Day)

CYCLE TIME
1.57 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
19.15 %

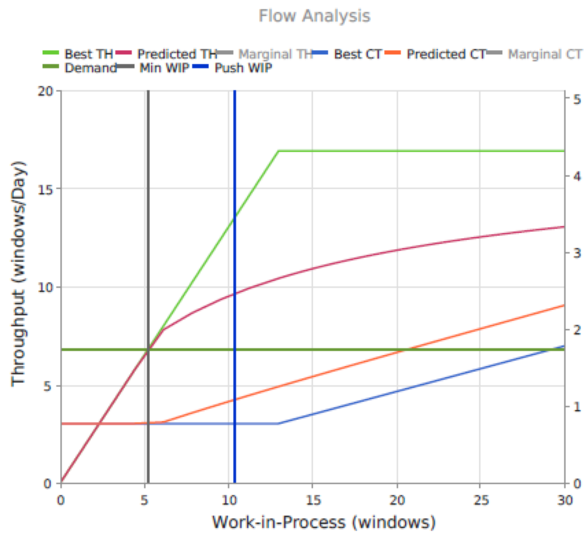
Cycle Time Analysis ▲

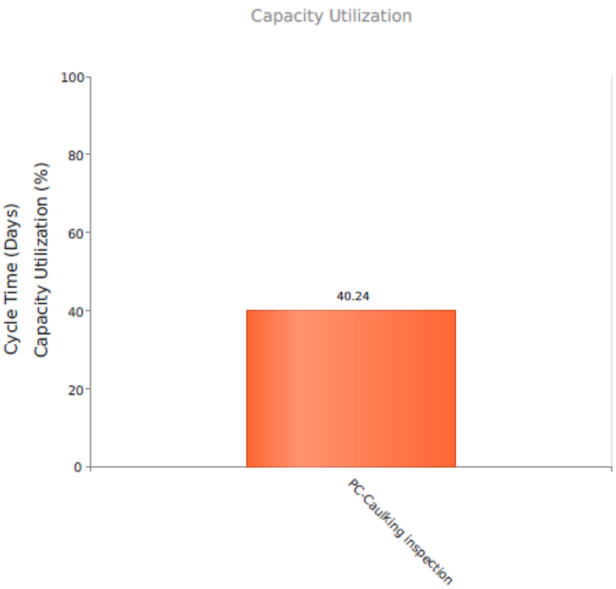
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	0.83	3.40	0.24	1.59	0.50	0.03	1.07	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.37	0.24	1.40	100.00	30.00	0.24	1.59	0.50	0.03	1.07	0.00	0.00	31.40	1.61	66.99	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	15.69	0.71	2.61	0.43	0.01	0.12	0.89

Inspection of caulking 1





Based on Current Demand

THROUGHPUT
6.80 (windows/Day)

BOTTLENECK RATE
16.90 (windows/undefined)

BOTTLENECK UTILIZATION
40.24 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
5.23 (windows)

MIN CYCLE TIME
0.77 (Days) | **6.15** (Hours)

PUSH WIP
10.36 (windows)

PUSH CYCLE TIME
1.52 (Days) | **12.19** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.30 (windows/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
7.69 %

Cycle Time Analysis ▲

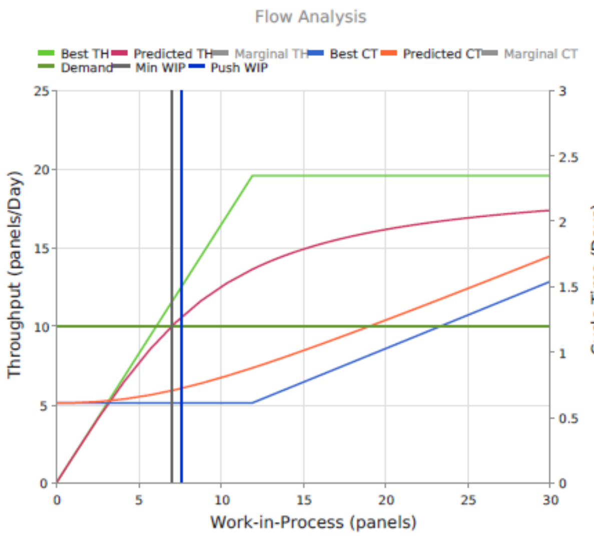
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	10.36	6.80	1.52	9.90	5.00	4.90	0.00	0.00	0.00

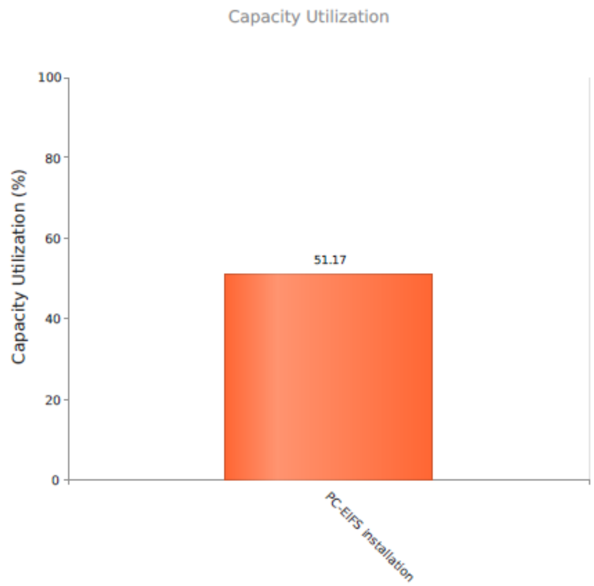
	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	5.06	1.52	10.01	100.00	30.00	1.52	9.90	5.00	4.90	0.00	0.00	0.00	50.49	49.51	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	40.24	0.64	2.40	2.50	2.45	6.11	10.36

Results sheets of the A4 production system based on D=10 EFIS panels.

EIFS panels installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
10.00 (panels/Day)	**19.54** (panels/undefined)	**51.17 %**	**0.18** (Days)

MIN WIP	MIN CYCLE TIME
7.05 (panels)	**0.70** (Days) | **5.64** (Hours)

PUSH WIP	PUSH CYCLE TIME
7.58 (panels)	**0.76** (Days) | **6.06** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
15.70 (panels/Day)	**7.45** (Hours)	**18.00** (panels)	**80.35 %**

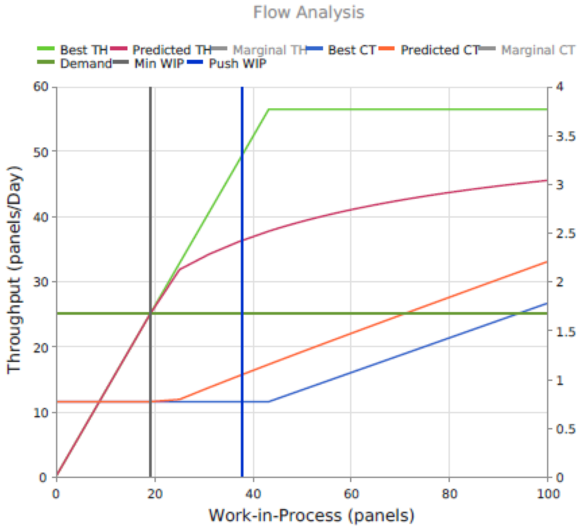
Cycle Time Analysis ▲

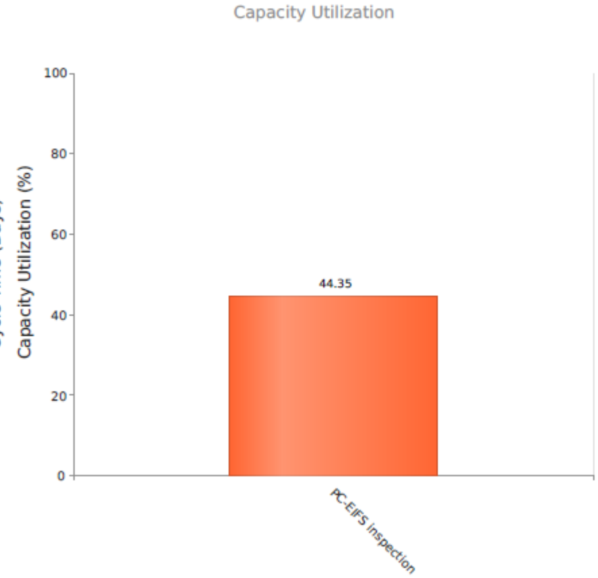
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	15.70	1.15	7.58	10.00	0.76	4.92	1.17	0.96	2.80	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	4.17	0.76	2.76	100.00	30.00	0.76	4.92	1.17	0.96	2.80	0.00	0.00	23.66	19.50	56.84	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	51.17	0.69	0.33	1.77	0.32	0.75	6.81
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	10.26

EIFS panels inspection





Based on Current Demand

THROUGHPUT
25.00 (panels/Day)

BOTTLENECK RATE
56.37 (panels/undefined)

BOTTLENECK UTILIZATION
44.35 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
19.23 (panels)

MIN CYCLE TIME
0.77 (Days) | **6.15** (Hours)

PUSH WIP
37.93 (panels)

PUSH CYCLE TIME
1.52 (Days) | **12.14** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT
1.30 (panels/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (panels)

BOTTLENECK UTILIZATION
2.31 %

Cycle Time Analysis ▲

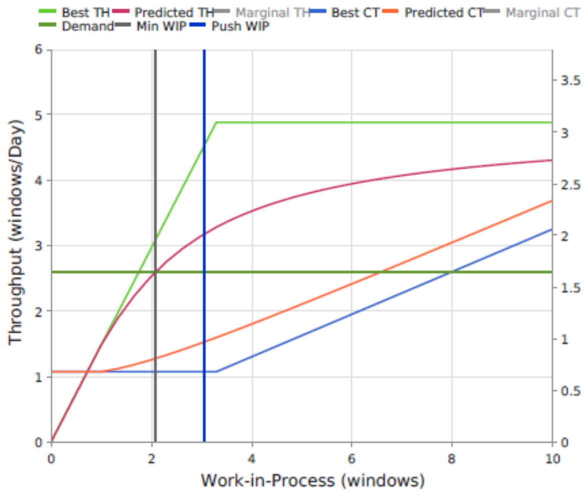
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	37.93	25.00	1.52	9.86	5.00	4.86	0.00	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	4.79	1.52	9.44	100.00	30.00	1.52	9.86	5.00	4.86	0.00	0.00	0.00	50.70	49.30	0.00	0.00	0.00

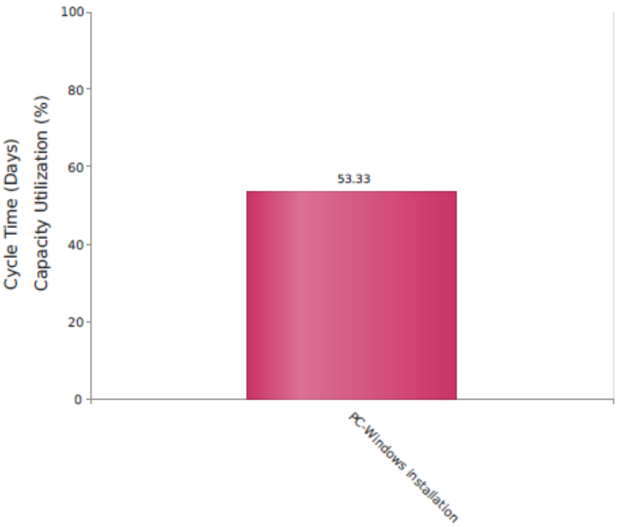
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	44.35	0.70	2.88	1.74	2.43	5.64	43.21

Windows installation

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT **2.60** (windows/Day) | BOTTLENECK RATE **4.88** (windows/undefined) | BOTTLENECK UTILIZATION **53.33 %** | RAW PROCESS TIME **0.21** (Days)

MIN WIP **2.10** (windows) | MIN CYCLE TIME **0.81** (Days) | **6.45** (Hours)

PUSH WIP **3.05** (windows) | PUSH CYCLE TIME **1.17** (Days) | **9.38** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT **1.48** (windows/Day) | CYCLE TIME **4.40** (Hours) | WIP LEVEL **1.00** (windows) | BOTTLENECK UTILIZATION **30.33 %**

Cycle Time Analysis ▲

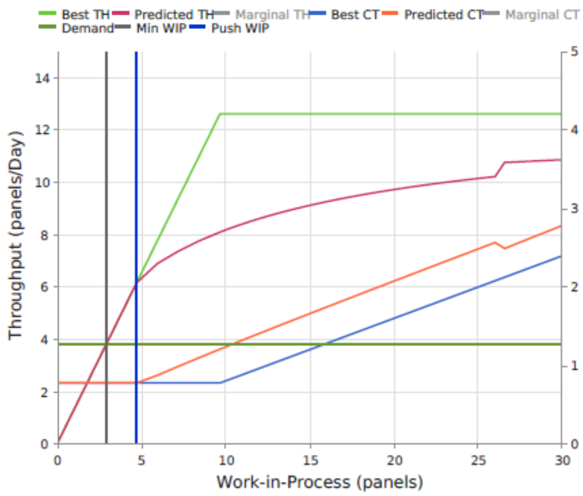
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	3.05	2.60	1.17	7.62	1.33	3.22	3.07	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40	3.10	1.17	5.36	100.00	30.00	1.17	7.62	1.33	3.22	3.07	0.00	0.00	17.49	42.28	40.23	0.00	0.00

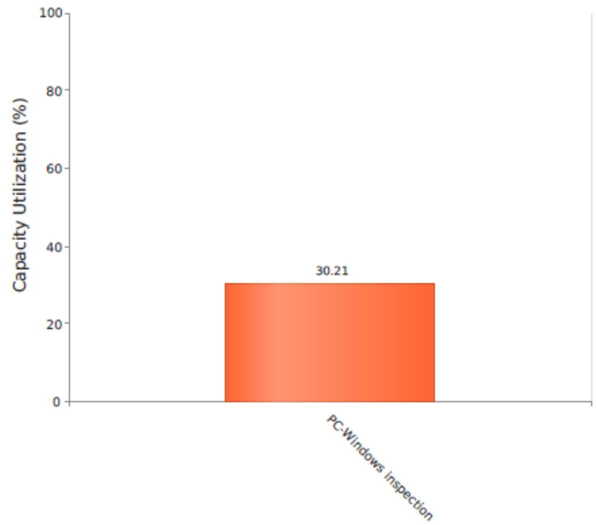
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	53.33	0.49	0.50	3.33	1.61	2.98	3.05

Windows inspection

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
3.80 (panels/Day)	**12.58** (panels/undefined)	**30.21 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
2.92 (panels)	**0.77** (Days) | **6.15** (Hours)

PUSH WIP	PUSH CYCLE TIME
4.67 (panels)	**1.23** (Days) | **9.84** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (panels/Day)	**5.00** (Hours)	**1.00** (panels)	**10.33 %**

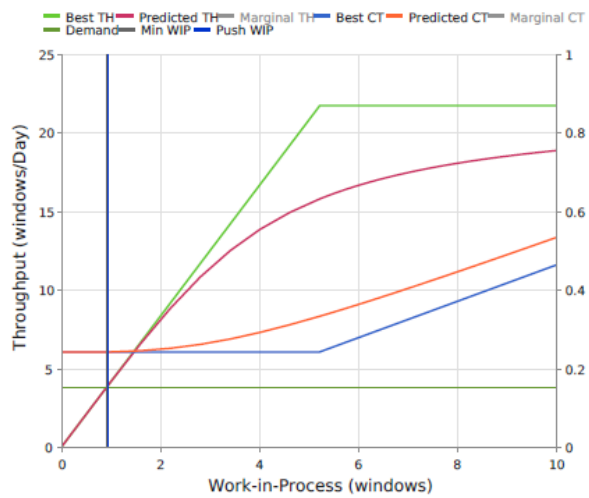
Cycle Time Analysis ▲

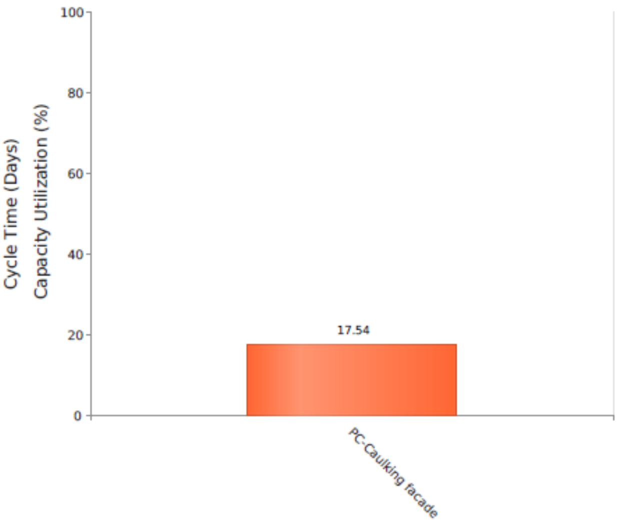
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	4.67	3.80	1.23	8.00	5.00	3.00	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	5.00	1.23	7.99	100.00	30.00	1.23	8.00	5.00	3.00	0.00	0.00	0.00	62.53	37.47	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	30.21	0.83	2.79	1.94	1.50	4.38	6.14

Development of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
3.80 (windows/Day)	**21.67** (windows/undefined)	**17.54 %**	**0.08** (Days)

MIN WIP	MIN CYCLE TIME
0.92 (windows)	**0.24** (Days) | **1.93** (Hours)

PUSH WIP	PUSH CYCLE TIME
0.93 (windows)	**0.25** (Days) | **1.97** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
4.15 (windows/Day)	**1.57** (Hours)	**1.00** (windows)	**19.15 %**

Cycle Time Analysis ▲

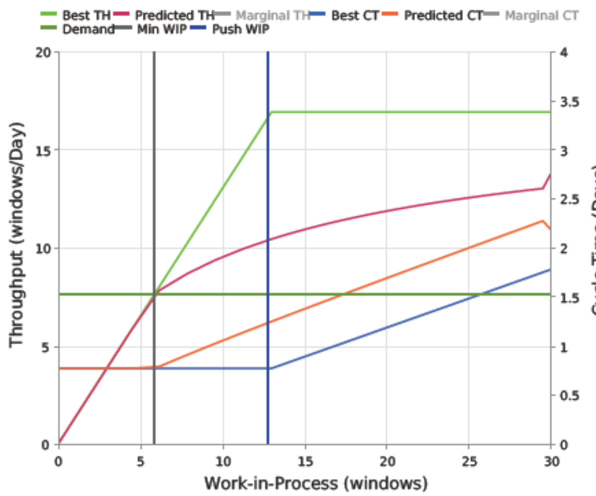
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	0.93	3.80	0.25	1.60	0.50	0.03	1.07	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.37	0.25	1.40	100.00	30.00	0.25	1.60	0.50	0.03	1.07	0.00	0.00	31.27	2.01	66.72	0.00	0.00

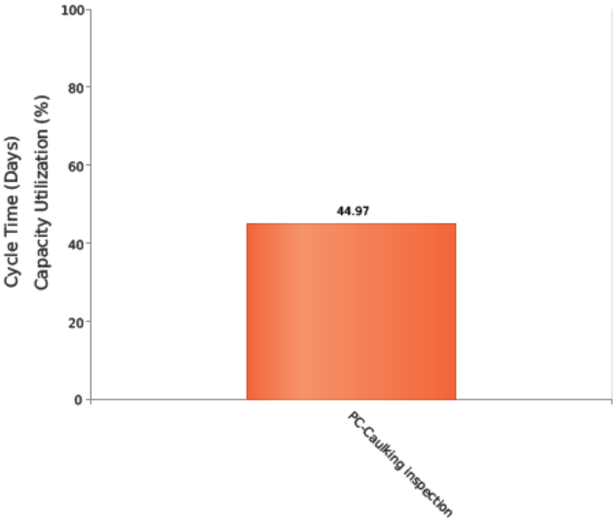
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	17.54	0.70	2.61	0.43	0.02	0.14	1.00

Inspection of caulking 1

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
7.60 (windows/Day)	**16.90** (windows/undefined)	**44.97 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
5.85 (windows)	**0.77** (Days) | **6.15** (Hours)

PUSH WIP	PUSH CYCLE TIME
12.77 (windows)	**1.68** (Days) | **13.45** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (windows/Day)	**5.00** (Hours)	**1.00** (windows)	**7.69 %**

Cycle Time Analysis ▲

	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	12.77	7.60	1.68	10.92	5.00	5.92	0.00	0.00	0.00

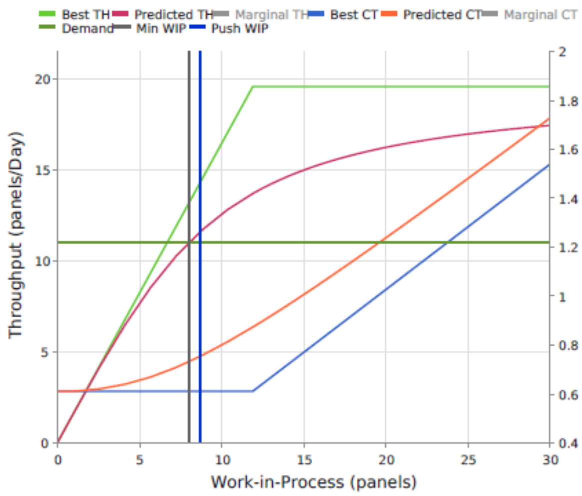
	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	4.98	1.68	10.89	100.00	30.00	1.68	10.92	5.00	5.92	0.00	0.00	0.00	45.77	54.23	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	44.97	0.62	2.40	2.50	2.96	6.82	12.77

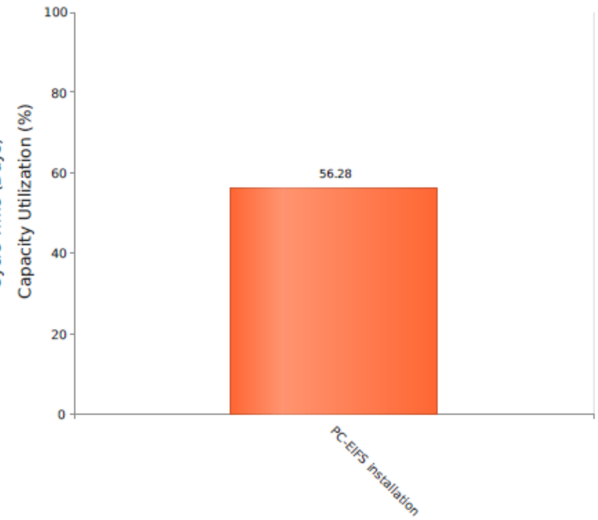
Results sheets of the A5 production system based on D=11 EFIS panels.

EIFS panels installation

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT
11.00 (panels/Day)

BOTTLENECK RATE
19.54 (panels/undefined)

BOTTLENECK UTILIZATION
56.28 %

RAW PROCESS TIME
0.18 (Days)

MIN WIP
8.04 (panels)

MIN CYCLE TIME
0.73 (Days) | **5.85** (Hours)

PUSH WIP
8.74 (panels)

PUSH CYCLE TIME
0.79 (Days) | **6.35** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT
15.78 (panels/Day)

CYCLE TIME
7.41 (Hours)

WIP LEVEL
18.00 (panels)

BOTTLENECK UTILIZATION
80.76 %

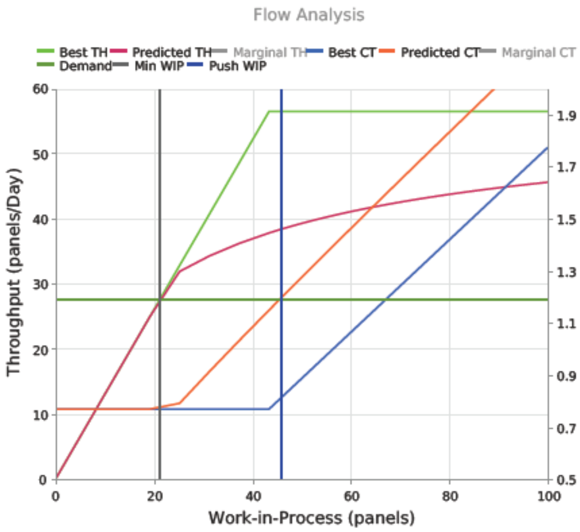
Cycle Time Analysis ▲

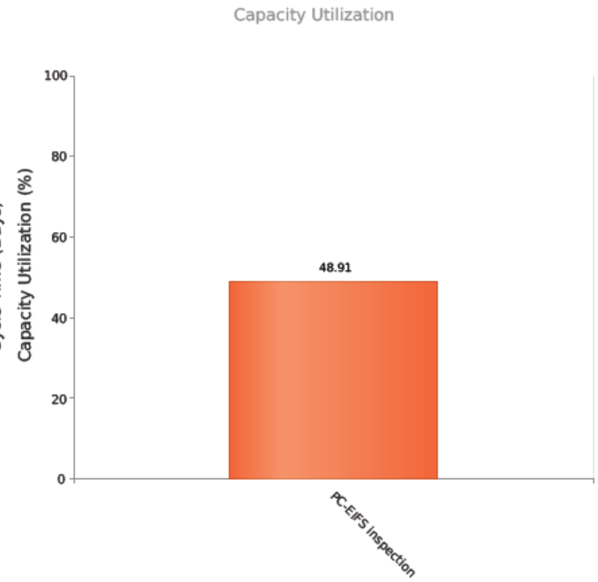
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	15.78	1.14	8.74	11.00	0.79	5.16	1.17	1.20	2.80	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	4.09	0.79	2.85	100.00	30.00	0.79	5.16	1.17	1.20	2.80	0.00	0.00	22.57	23.21	54.22	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	56.28	0.66	0.33	1.77	0.40	0.86	7.89
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	11.28

EIFS panels inspection





Based on Current Demand

THROUGHPUT
27.60 (panels/Day)

BOTTLENECK RATE
56.43 (panels/undefined)

BOTTLENECK UTILIZATION
48.91 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
21.23 (panels)

MIN CYCLE TIME
0.77 (Days) | **6.15** (Hours)

PUSH WIP
45.84 (panels)

PUSH CYCLE TIME
1.66 (Days) | **13.29** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT
1.30 (panels/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (panels)

BOTTLENECK UTILIZATION
2.30 %

Cycle Time Analysis ▲

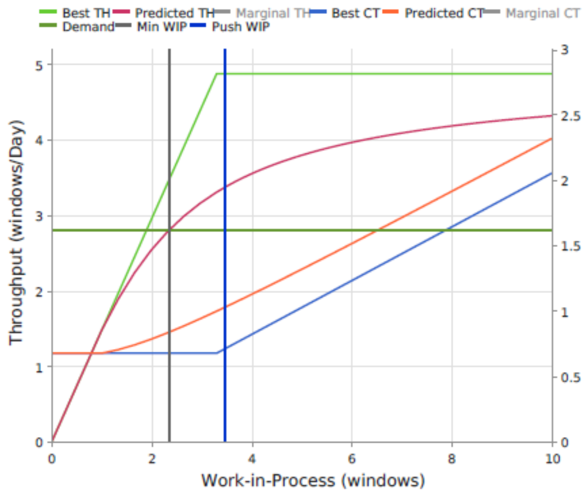
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	45.84	27.60	1.66	10.79	5.00	5.79	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	4.72	1.66	10.19	100.00	30.00	1.66	10.79	5.00	5.79	0.00	0.00	0.00	46.32	53.68	0.00	0.00	0.00

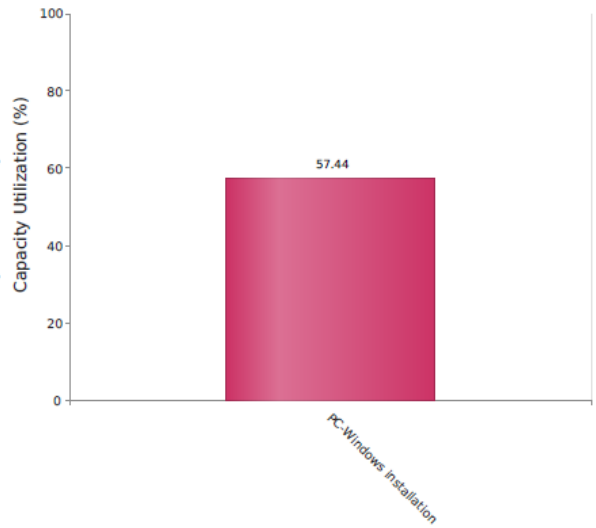
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	48.91	0.67	2.88	1.75	2.90	6.26	52.43

Windows installation

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT **2.80** (windows/Day)

BOTTLENECK RATE **4.87** (windows/undefined)

BOTTLENECK UTILIZATION **57.44 %**

RAW PROCESS TIME **0.21** (Days)

MIN WIP **2.34** (windows)

MIN CYCLE TIME **0.84** (Days) | **6.69** (Hours)

PUSH WIP **3.46** (windows)

PUSH CYCLE TIME **1.23** (Days) | **9.88** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT **1.48** (windows/Day)

CYCLE TIME **4.40** (Hours)

WIP LEVEL **1.00** (windows)

BOTTLENECK UTILIZATION **30.39 %**

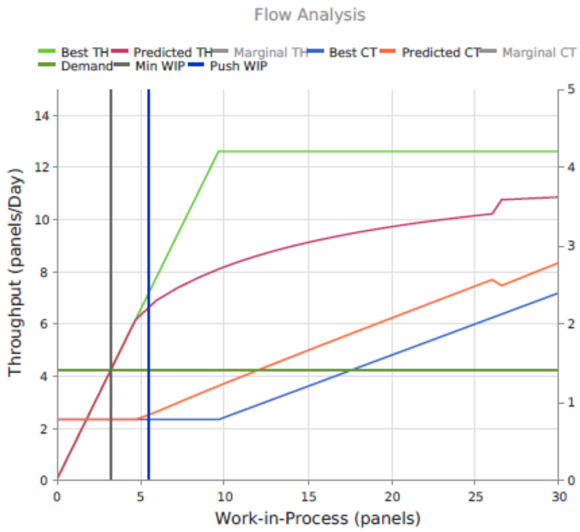
Cycle Time Analysis ▲

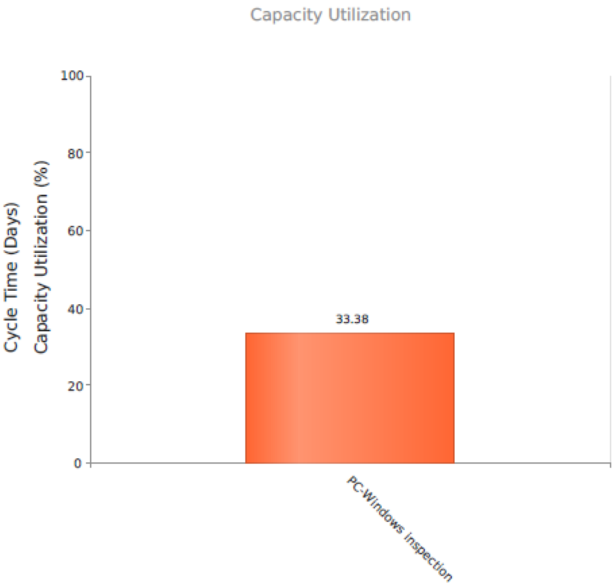
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	3.46	2.80	1.23	8.03	1.33	3.63	3.07	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40	3.08	1.23	5.63	100.00	30.00	1.23	8.03	1.33	3.63	3.07	0.00	0.00	16.61	45.18	38.21	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	57.44	0.45	0.50	3.33	1.81	3.21	3.46

Windows inspection





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
4.20 (panels/Day)	**12.58** (panels/undefined)	**33.38 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
3.23 (panels)	**0.77** (Days) | **6.15** (Hours)

PUSH WIP	PUSH CYCLE TIME
5.47 (panels)	**1.30** (Days) | **10.42** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (panels/Day)	**5.00** (Hours)	**1.00** (panels)	**10.33 %**

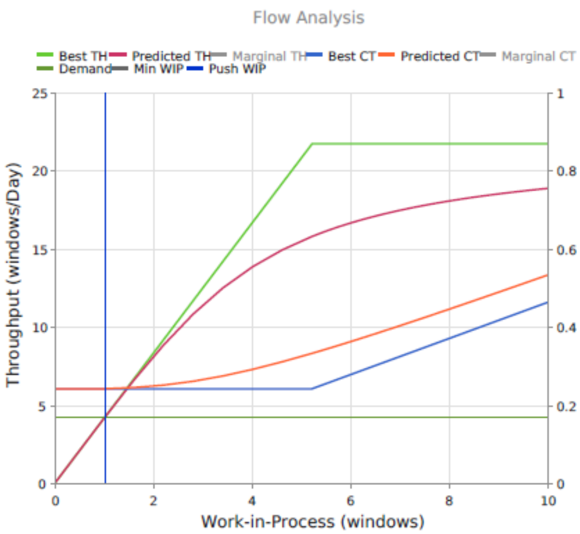
Cycle Time Analysis ▲

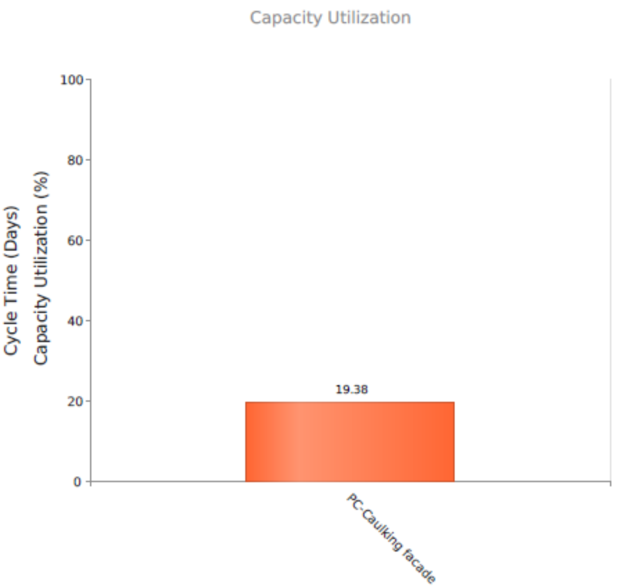
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	5.47	4.20	1.30	8.47	5.00	3.47	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	4.96	1.30	8.41	100.00	30.00	1.30	8.47	5.00	3.47	0.00	0.00	0.00	59.04	40.96	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	33.38	0.83	2.79	1.94	1.73	4.75	7.24

Development of caulking 1





Based on Current Demand

THROUGHPUT
4.20 (windows/Day)

BOTTLENECK RATE
21.67 (windows/undefined)

BOTTLENECK UTILIZATION
19.38 %

RAW PROCESS TIME
0.08 (Days)

MIN WIP
1.01 (windows)

MIN CYCLE TIME
0.24 (Days) | **1.93** (Hours)

PUSH WIP
1.04 (windows)

PUSH CYCLE TIME
0.25 (Days) | **1.98** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
4.15 (windows/Day)

CYCLE TIME
1.57 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
19.15 %

Cycle Time Analysis ▲

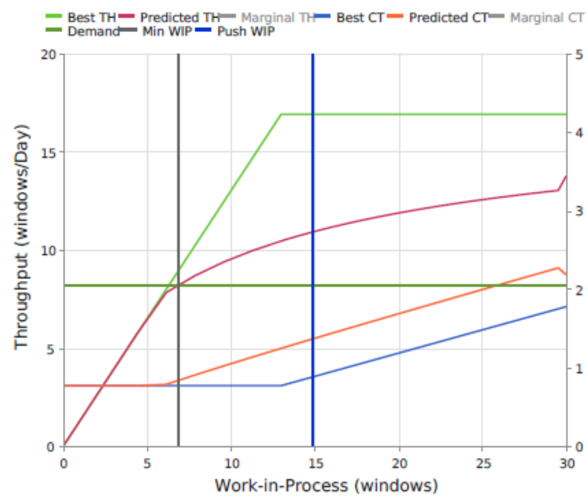
Product Flow	CONWIP WIP (Units)	CONWIP Throughput (Units/Day)	CONWIP Cycle Time (Days)	PUSH WIP (Predicted) (Units)	PUSH Throughput (Units/Day)	PUSH Cycle Time (Days)	PUSH Cycle Time = (Hours)	PUSH Raw Process Time + (Hours)	PUSH Queue Time + (Hours)	PUSH Batch Time + (Hours)	PUSH Move Time + (Hours)	PUSH Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	1.04	4.20	0.25	1.61	0.50	0.04	1.07	0.00	0.00

Item	CONWIP Cycle Time (Hours)	CONWIP Cycle Time SD (Hours)	PUSH Cycle Time (Days)	PUSH Cycle Time SD (Hours)	PUSH On Time Delivery (%)	PUSH Planned Lead Time (Days)	PUSH Replenish. Time (Days)	PUSH Cycle Time = (Hours)	PUSH Raw Process Time + (Hours)	PUSH Queue Time + (Hours)	PUSH Batch Time + (Hours)	PUSH Move Time + (Hours)	PUSH Shift Diff. Time (Hours)	PUSH Raw Process Time (%)	PUSH Queue Time (%)	PUSH Batch Time (%)	PUSH Move Time (%)	PUSH Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.37	0.25	1.40	100.00	30.00	0.25	1.61	0.50	0.04	1.07	0.00	0.00	31.13	2.45	66.42	0.00	0.00

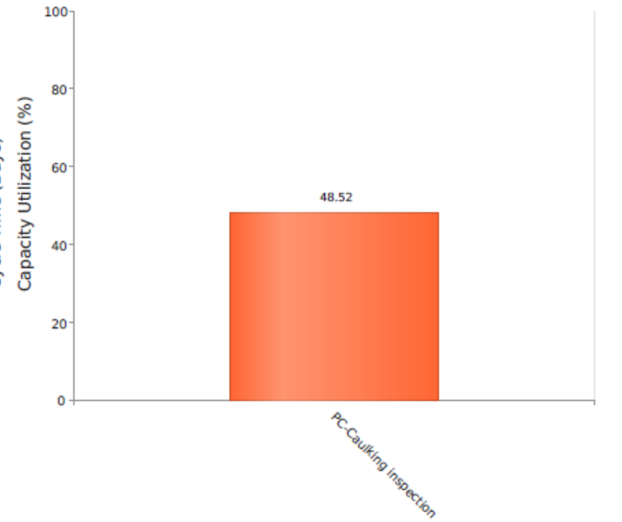
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	19.38	0.69	2.61	0.43	0.02	0.15	1.11

Inspection of caulking 1

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT **8.20** (windows/Day)

BOTTLENECK RATE **16.90** (windows/undefined)

BOTTLENECK UTILIZATION **48.52 %**

RAW PROCESS TIME **0.77** (Days)

MIN WIP **6.86** (windows)

MIN CYCLE TIME **0.84** (Days) | **6.69** (Hours)

PUSH WIP **14.90** (windows)

PUSH CYCLE TIME **1.82** (Days) | **14.54** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT **1.30** (windows/Day)

CYCLE TIME **5.00** (Hours)

WIP LEVEL **1.00** (windows)

BOTTLENECK UTILIZATION **7.69 %**

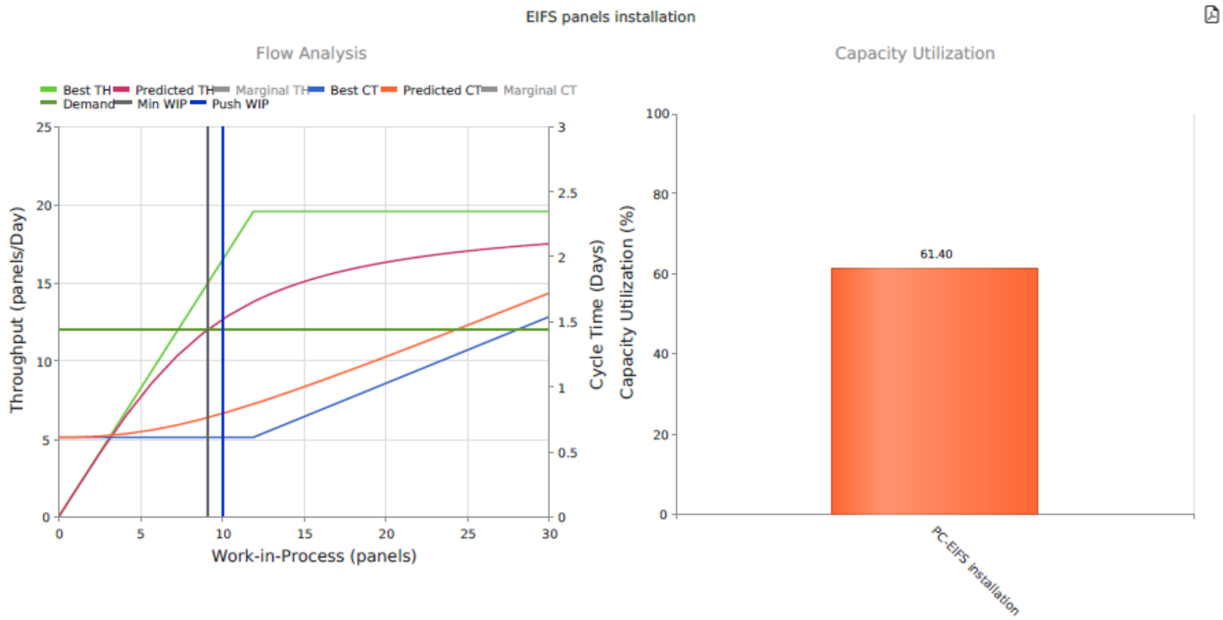
Cycle Time Analysis ▲

	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	14.90	8.20	1.82	11.81	5.00	6.81	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	4.92	1.82	11.62	100.00	30.00	1.82	11.81	5.00	6.81	0.00	0.00	0.00	42.33	57.67	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	48.52	0.60	2.40	2.50	3.41	7.40	14.90

Results sheets of the A6 production system based on D=12 EFIS panels.



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
12.00 (panels/Day)	**19.54** (panels/undefined)	**61.40 %**	**0.18** (Days)

MIN WIP	MIN CYCLE TIME
9.15 (panels)	**0.76** (Days) | **6.10** (Hours)

PUSH WIP	PUSH CYCLE TIME
10.06 (panels)	**0.84** (Days) | **6.71** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
15.88 (panels/Day)	**7.37** (Hours)	**18.00** (panels)	**81.27 %**

Cycle Time Analysis ▲

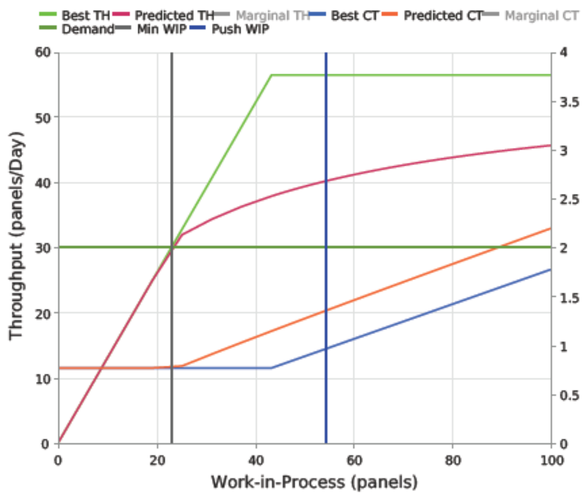
	CONWIP			PUSH							
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	15.88	1.13	10.06	12.00	0.84	5.45	1.17	1.48	2.80	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	4.01	0.84	2.97	100.00	30.00	0.84	5.45	1.17	1.48	2.80	0.00	0.00	21.39	27.23	51.38	0.00	0.00

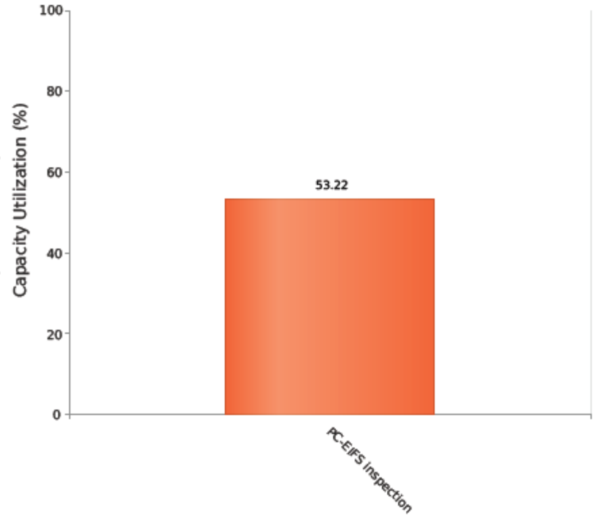
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	61.40	0.61	0.33	1.77	0.49	0.98	9.13
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	12.31

EIFS panels inspection

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT
30.00 (panels/Day)

BOTTLENECK RATE
56.37 (panels/undefined)

BOTTLENECK UTILIZATION
53.22 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
23.08 (panels)

MIN CYCLE TIME
0.77 (Days) | **6.15** (Hours)

PUSH WIP
54.54 (panels)

PUSH CYCLE TIME
1.82 (Days) | **14.54** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT
1.30 (panels/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (panels)

BOTTLENECK UTILIZATION
2.31 %

Cycle Time Analysis ▴

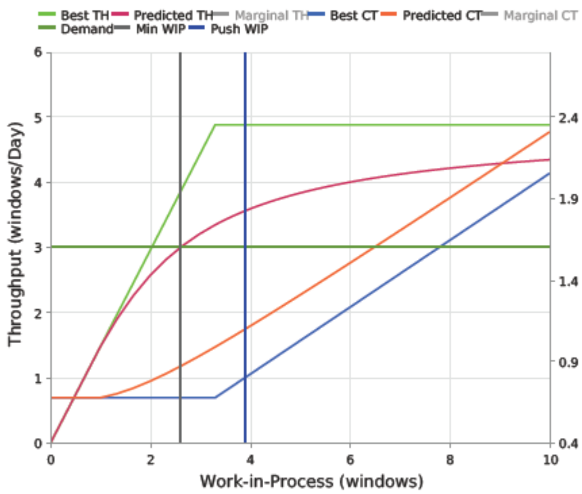
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	54.54	30.00	1.82	11.82	5.00	6.82	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	4.65	1.82	10.99	100.00	30.00	1.82	11.82	5.00	6.82	0.00	0.00	0.00	42.31	57.69	0.00	0.00	0.00

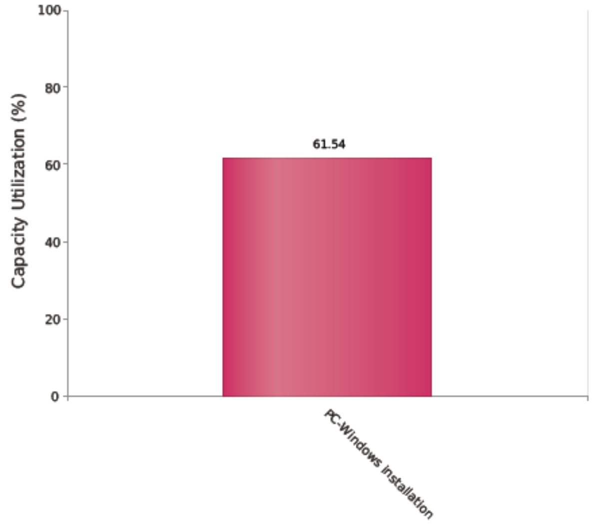
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	53.22	0.63	2.88	1.74	3.41	6.91	62.68

Windows installation

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT
3.00 (windows/Day)

BOTTLENECK RATE
4.88 (windows/undefined)

BOTTLENECK UTILIZATION
61.54 %

RAW PROCESS TIME
0.21 (Days)

MIN WIP
2.61 (windows)

MIN CYCLE TIME
0.87 (Days) | **6.97** (Hours)

PUSH WIP
3.91 (windows)

PUSH CYCLE TIME
1.30 (Days) | **10.44** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.48 (windows/Day)

CYCLE TIME
4.40 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
30.33 %

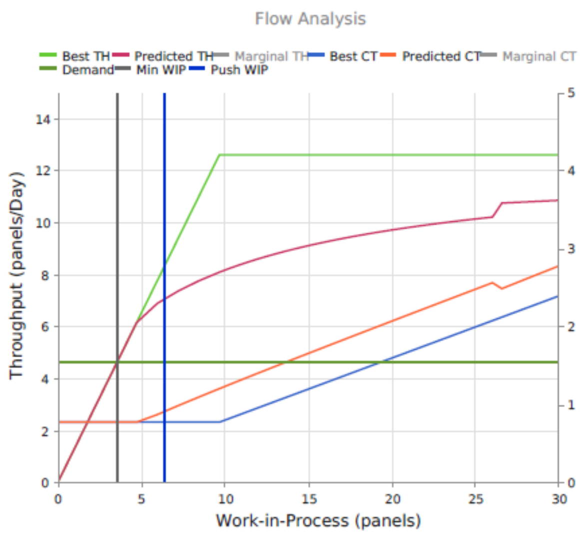
Cycle Time Analysis ▲

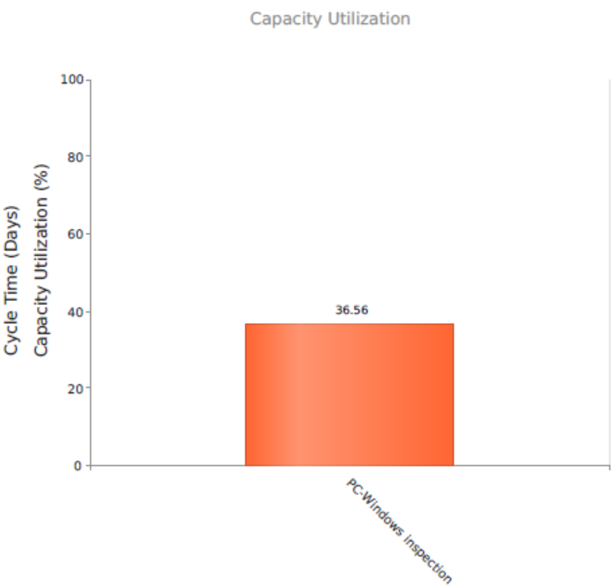
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	3.91	3.00	1.30	8.48	1.33	4.08	3.07	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40	3.07	1.30	5.92	100.00	30.00	1.30	8.48	1.33	4.08	3.07	0.00	0.00	15.72	48.12	36.16	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	61.54	0.40	0.50	3.33	2.04	3.47	3.91

Windows inspection





Based on Current Demand

THROUGHPUT
4.60 (panels/Day)

BOTTLENECK RATE
12.58 (panels/undefined)

BOTTLENECK UTILIZATION
36.56 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
3.54 (panels)

MIN CYCLE TIME
0.77 (Days) | **6.15** (Hours)

PUSH WIP
6.36 (panels)

PUSH CYCLE TIME
1.38 (Days) | **11.06** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT
1.30 (panels/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (panels)

BOTTLENECK UTILIZATION
10.33 %

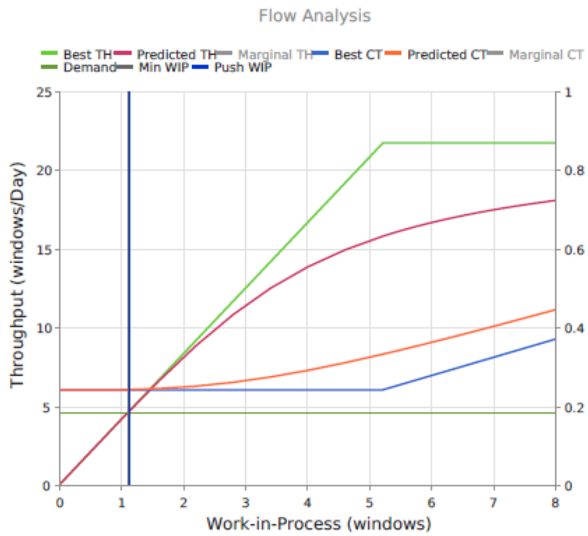
Cycle Time Analysis ▲

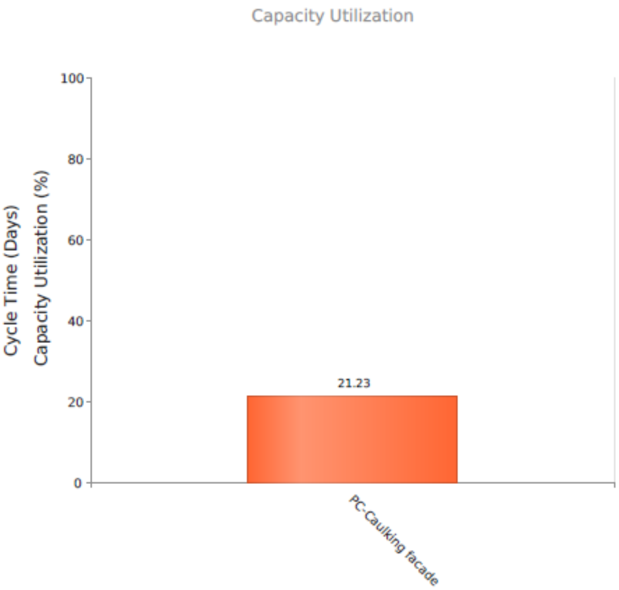
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	6.36	4.60	1.38	8.99	5.00	3.99	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	4.92	1.38	8.85	100.00	30.00	1.38	8.99	5.00	3.99	0.00	0.00	0.00	55.62	44.38	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	36.56	0.82	2.79	1.94	1.99	5.14	8.48

Development of caulking 1





Based on Current Demand

THROUGHPUT
4.60 (windows/Day)

BOTTLENECK RATE
21.67 (windows/undefined)

BOTTLENECK UTILIZATION
21.23 %

RAW PROCESS TIME
0.08 (Days)

MIN WIP
1.11 (windows)

MIN CYCLE TIME
0.24 (Days) | **1.93** (Hours)

PUSH WIP
1.14 (windows)

PUSH CYCLE TIME
0.25 (Days) | **1.99** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
4.15 (windows/Day)

CYCLE TIME
1.57 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
19.15 %

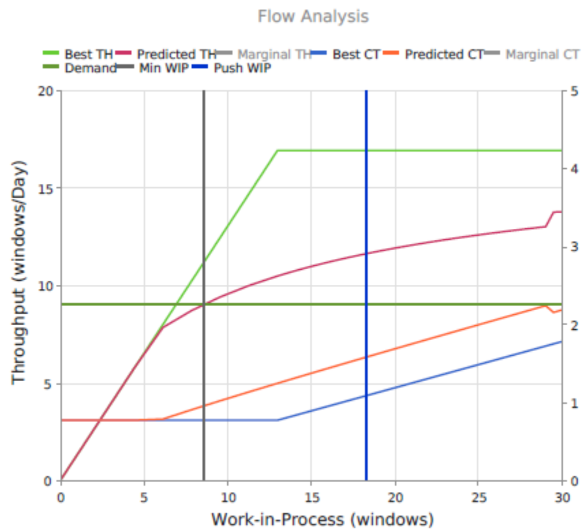
Cycle Time Analysis ▲

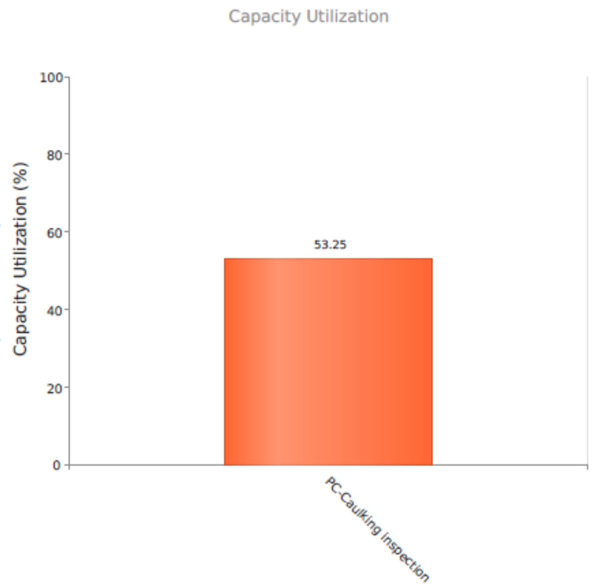
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	1.14	4.60	0.25	1.61	0.50	0.05	1.07	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.37	0.25	1.41	100.00	30.00	0.25	1.61	0.50	0.05	1.07	0.00	0.00	30.98	2.93	66.09	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	21.23	0.68	2.61	0.43	0.02	0.17	1.23

Inspection of caulking 1





Based on Current Demand

THROUGHPUT
9.00 (windows/Day)

BOTTLENECK RATE
16.90 (windows/undefined)

BOTTLENECK UTILIZATION
53.25 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
8.56 (windows)

MIN CYCLE TIME
0.95 (Days) | **7.61** (Hours)

PUSH WIP
18.28 (windows)

PUSH CYCLE TIME
2.03 (Days) | **16.25** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.30 (windows/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
7.69 %

Cycle Time Analysis ▲

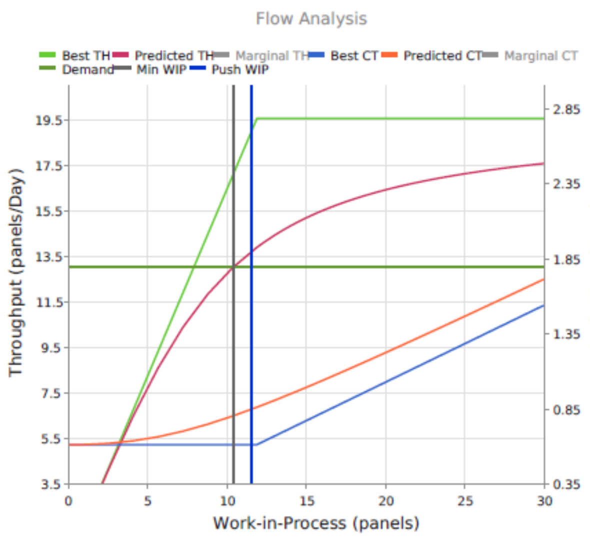
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	18.28	9.00	2.03	13.20	5.00	8.20	0.00	0.00	0.00

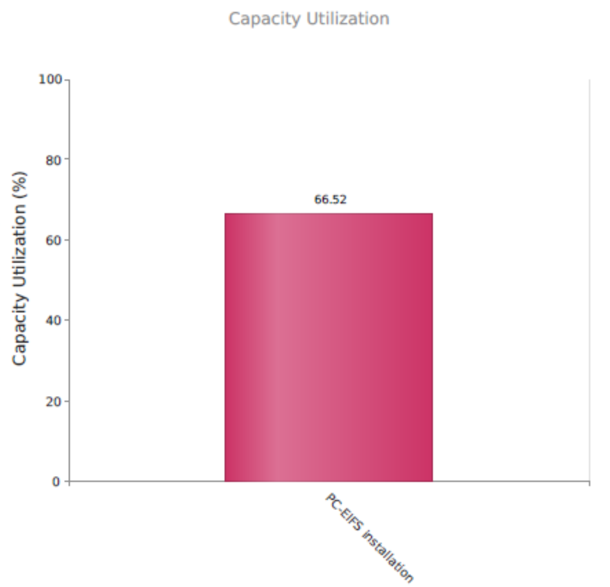
	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	4.83	2.03	12.74	100.00	30.00	2.03	13.20	5.00	8.20	0.00	0.00	0.00	37.88	62.12	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	53.25	0.58	2.40	2.50	4.10	8.27	18.28

Results sheets of the A7 production system based on D=13 EFIS panels.

EIFS panels installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
13.00 (panels/Day)	**19.54** (panels/undefined)	**66.52 %**	**0.18** (Days)

MIN WIP	MIN CYCLE TIME
10.41 (panels)	**0.80** (Days) | **6.41** (Hours)

PUSH WIP	PUSH CYCLE TIME
11.59 (panels)	**0.89** (Days) | **7.13** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
15.99 (panels/Day)	**7.32** (Hours)	**18.00** (panels)	**81.83 %**

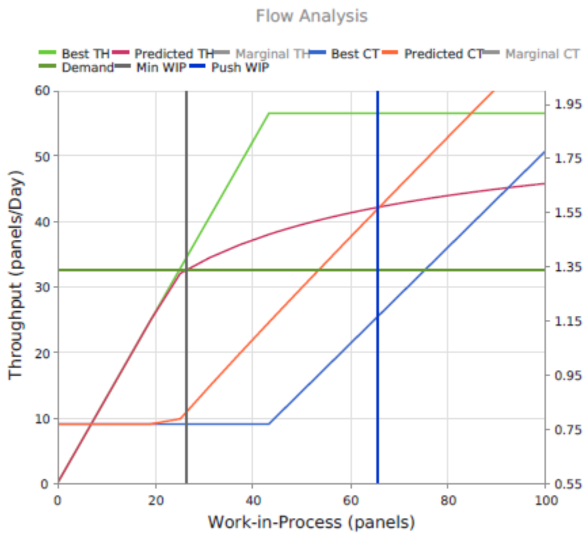
Cycle Time Analysis ▴

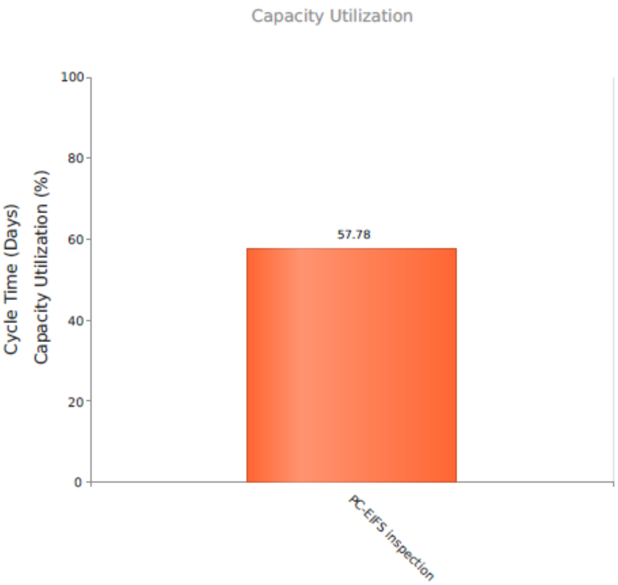
	CONWIP			PUSH							
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	15.99	1.13	11.59	13.00	0.89	5.79	1.17	1.83	2.80	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	3.93	0.89	3.11	100.00	30.00	0.89	5.79	1.17	1.83	2.80	0.00	0.00	20.11	31.59	48.31	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	66.52	0.56	0.33	1.77	0.61	1.12	10.59
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	13.33

EIFS panels inspection





Based on Current Demand

THROUGHPUT
32.60 (panels/Day)

BOTTLENECK RATE
56.42 (panels/undefined)

BOTTLENECK UTILIZATION
57.78 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
26.56 (panels)

MIN CYCLE TIME
0.81 (Days) | **6.52** (Hours)

PUSH WIP
65.80 (panels)

PUSH CYCLE TIME
2.02 (Days) | **16.15** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT
1.30 (panels/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (panels)

BOTTLENECK UTILIZATION
2.30 %

Cycle Time Analysis ▲

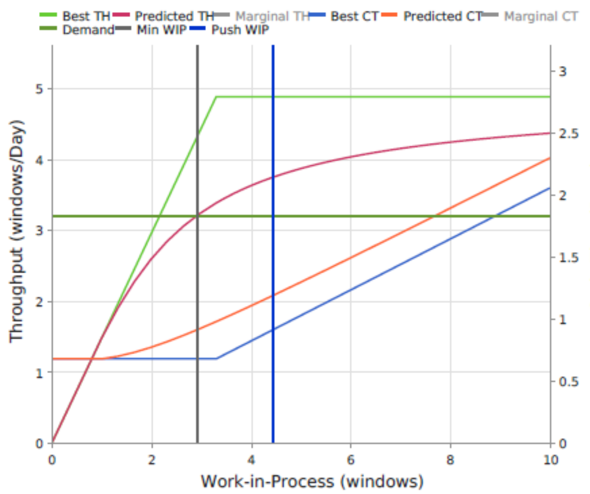
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	65.80	32.60	2.02	13.12	5.00	8.12	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	4.57	2.02	12.00	100.00	30.00	2.02	13.12	5.00	8.12	0.00	0.00	0.00	38.11	61.89	0.00	0.00	0.00

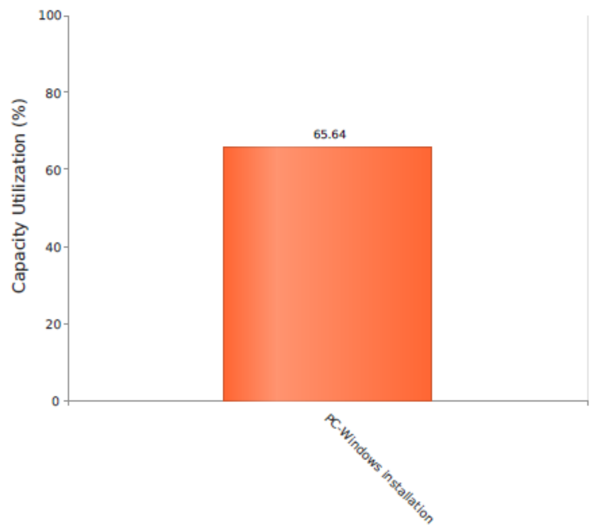
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	57.78	0.60	2.88	1.74	4.06	7.70	75.92

Windows installation

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT
3.20 (windows/Day)

BOTTLENECK RATE
4.88 (windows/undefined)

BOTTLENECK UTILIZATION
65.64 %

RAW PROCESS TIME
0.21 (Days)

MIN WIP
2.91 (windows)

MIN CYCLE TIME
0.91 (Days) | **7.28** (Hours)

PUSH WIP
4.44 (windows)

PUSH CYCLE TIME
1.39 (Days) | **11.09** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.48 (windows/Day)

CYCLE TIME
4.40 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
30.33 %

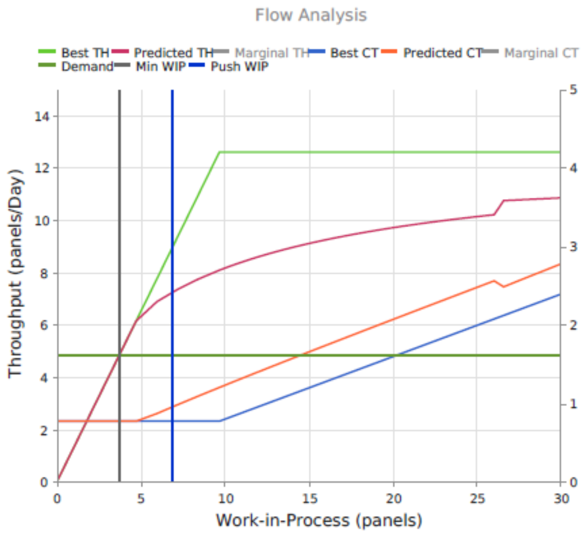
Cycle Time Analysis ▲

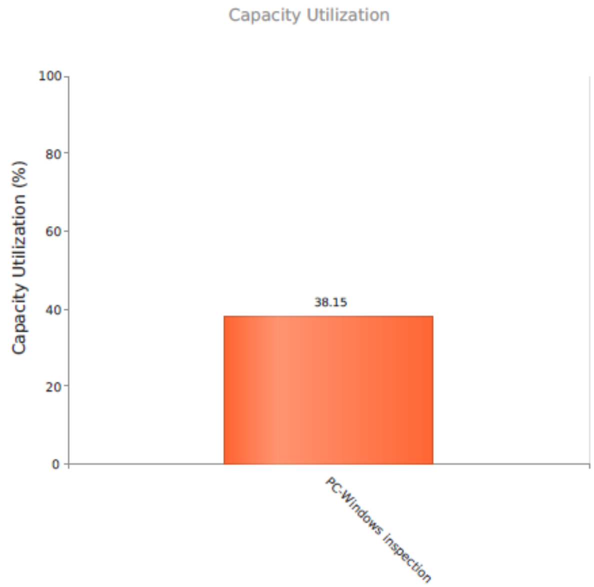
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	4.44	3.20	1.39	9.01	1.33	4.61	3.07	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40	3.06	1.39	6.27	100.00	30.00	1.39	9.01	1.33	4.61	3.07	0.00	0.00	14.80	51.16	34.04	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	65.64	0.36	0.50	3.33	2.30	3.76	4.44

Windows inspection





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
4.80 (panels/Day)	**12.58** (panels/undefined)	**38.15 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
3.69 (panels)	**0.77** (Days) | **6.15** (Hours)

PUSH WIP	PUSH CYCLE TIME
6.85 (panels)	**1.43** (Days) | **11.41** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (panels/Day)	**5.00** (Hours)	**1.00** (panels)	**10.33 %**

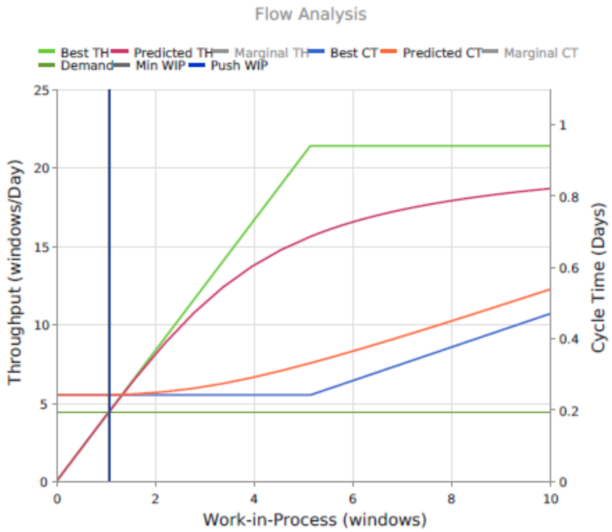
Cycle Time Analysis ▲

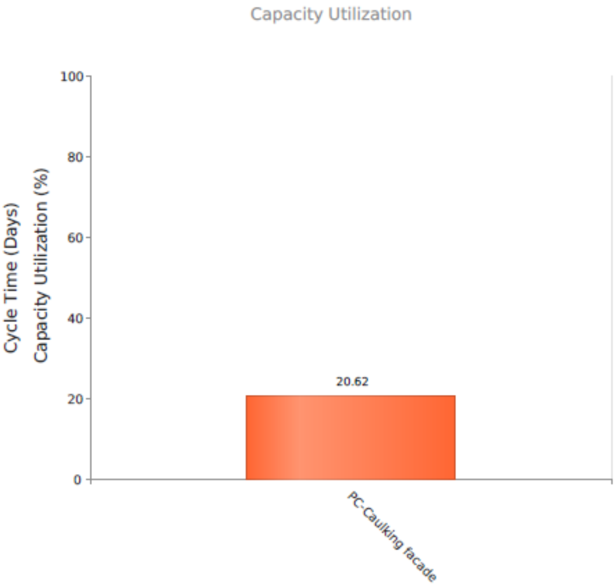
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	6.85	4.80	1.43	9.27	5.00	4.27	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	4.90	1.43	9.09	100.00	30.00	1.43	9.27	5.00	4.27	0.00	0.00	0.00	53.93	46.07	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	38.15	0.82	2.79	1.94	2.14	5.35	9.16

Development of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
4.40 (windows/Day)	**21.34** (windows/undefined)	**20.62 %**	**0.08** (Days)

MIN WIP	MIN CYCLE TIME
1.06 (windows)	**0.24** (Days) | **1.93** (Hours)

PUSH WIP	PUSH CYCLE TIME
1.09 (windows)	**0.25** (Days) | **1.98** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
4.15 (windows/Day)	**1.57** (Hours)	**1.00** (windows)	**19.45 %**

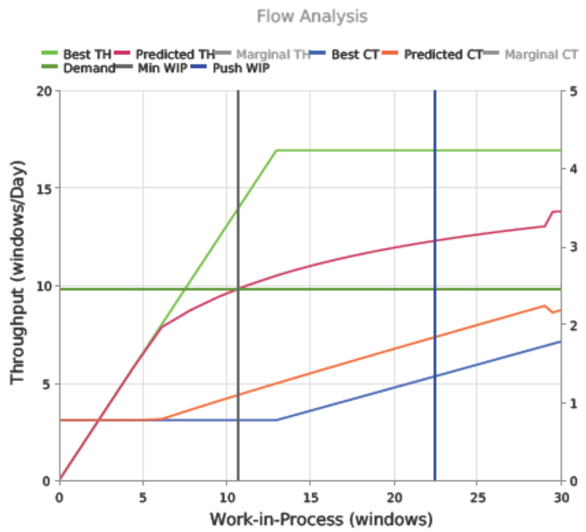
Cycle Time Analysis ▲

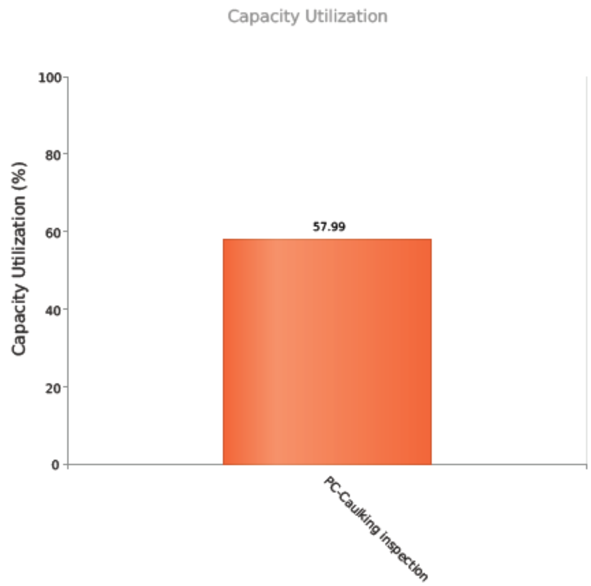
	CONWIP			PUSH							
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	1.09	4.40	0.25	1.61	0.50	0.04	1.07	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.37	0.25	1.40	100.00	30.00	0.25	1.61	0.50	0.04	1.07	0.00	0.00	31.06	2.68	66.26	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	20.62	0.67	2.74	0.41	0.02	0.16	1.18

Inspection of caulking 1





Based on Current Demand

THROUGHPUT
9.80 (windows/Day)

BOTTLENECK RATE
16.90 (windows/undefined)

BOTTLENECK UTILIZATION
57.99 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
10.69 (windows)

MIN CYCLE TIME
1.09 (Days) | **8.72** (Hours)

PUSH WIP
22.48 (windows)

PUSH CYCLE TIME
2.29 (Days) | **18.35** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.30 (windows/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
7.69 %

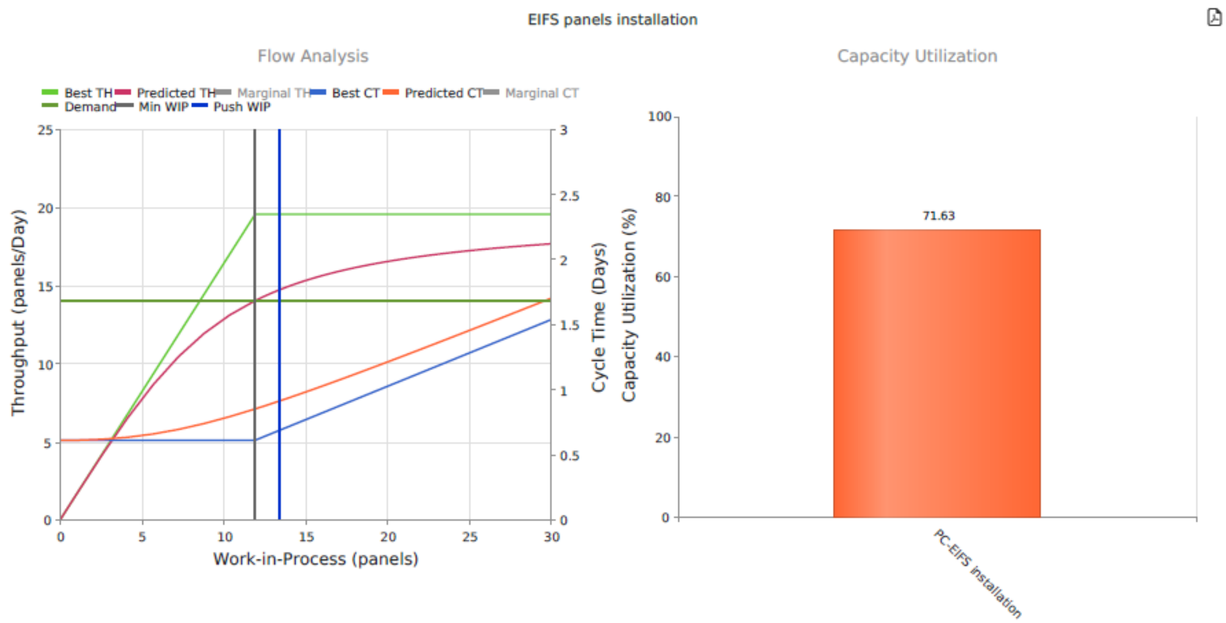
Cycle Time Analysis ▲

	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	22.48	9.80	2.29	14.91	5.00	9.91	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	4.72	2.29	14.08	100.00	30.00	2.29	14.91	5.00	9.91	0.00	0.00	0.00	33.54	66.46	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	57.99	0.56	2.40	2.50	4.95	9.29	22.48

Results sheets of the A8 production system based on D=14 EFIS panels.



Based on Current Demand

THROUGHPUT
14.00 (panels/Day)

BOTTLENECK RATE
19.54 (panels/undefined)

BOTTLENECK UTILIZATION
71.63 %

RAW PROCESS TIME
0.18 (Days)

MIN WIP
11.89 (panels)

MIN CYCLE TIME
0.85 (Days) | **6.79** (Hours)

PUSH WIP
13.42 (panels)

PUSH CYCLE TIME
0.96 (Days) | **7.67** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT
16.12 (panels/Day)

CYCLE TIME
7.26 (Hours)

WIP LEVEL
18.00 (panels)

BOTTLENECK UTILIZATION
82.50 %

Cycle Time Analysis ▲

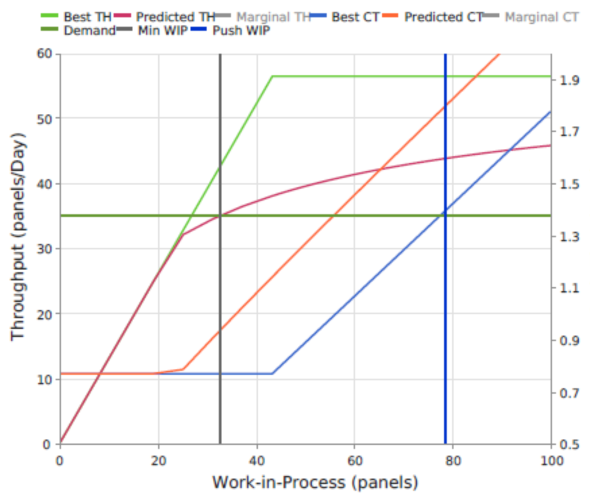
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	16.12	1.12	13.42	14.00	0.96	6.23	1.17	2.26	2.80	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	3.85	0.96	3.31	100.00	30.00	0.96	6.23	1.17	2.26	2.80	0.00	0.00	18.71	36.36	44.94	0.00	0.00

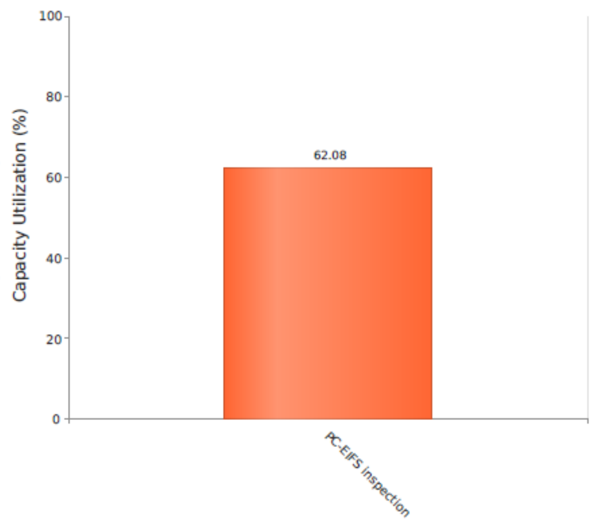
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	71.63	0.51	0.33	1.77	0.75	1.29	12.34
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	14.36

EIFS panels inspection

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT
35.00 (panels/Day)

BOTTLENECK RATE
56.37 (panels/undefined)

BOTTLENECK UTILIZATION
62.08 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
32.72 (panels)

MIN CYCLE TIME
0.93 (Days) | **7.48** (Hours)

PUSH WIP
78.63 (panels)

PUSH CYCLE TIME
2.25 (Days) | **17.97** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT
1.30 (panels/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (panels)

BOTTLENECK UTILIZATION
2.31 %

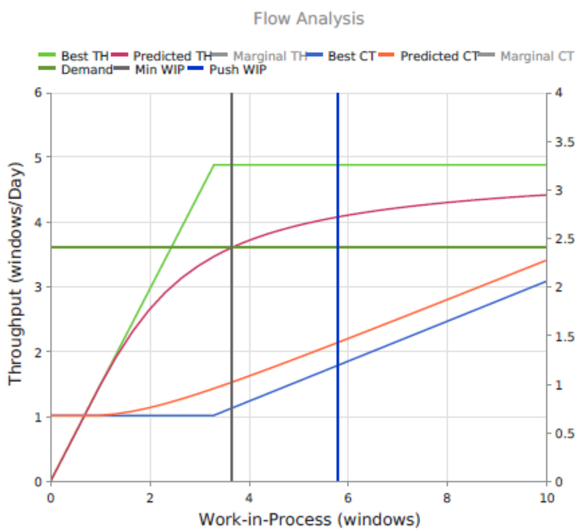
Cycle Time Analysis ▲

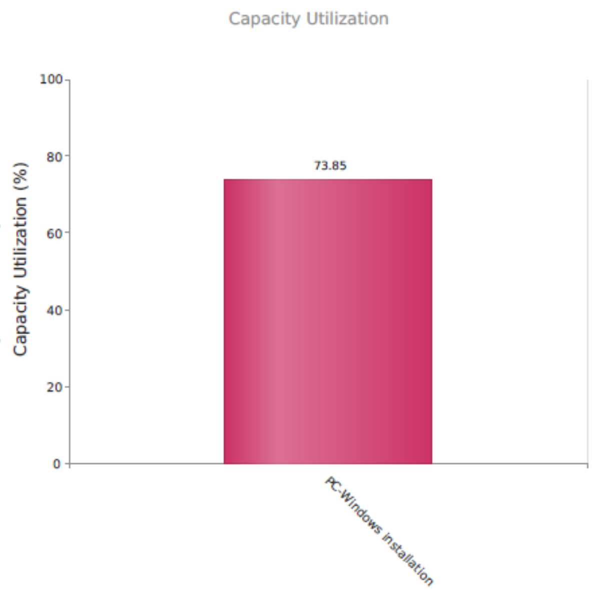
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	78.63	35.00	2.25	14.60	5.00	9.60	0.00	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	4.49	2.25	13.11	100.00	30.00	2.25	14.60	5.00	9.60	0.00	0.00	0.00	34.24	65.76	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	62.08	0.56	2.88	1.74	4.80	8.56	91.13

Windows installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
3.60 (windows/Day)	**4.88** (windows/undefined)	**73.85 %**	**0.21** (Days)

MIN WIP	MIN CYCLE TIME
3.66 (windows)	**1.02** (Days) | **8.14** (Hours)

PUSH WIP	PUSH CYCLE TIME
5.81 (windows)	**1.61** (Days) | **12.90** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.48 (windows/Day)	**4.40** (Hours)	**1.00** (windows)	**30.33 %**

Cycle Time Analysis ▲

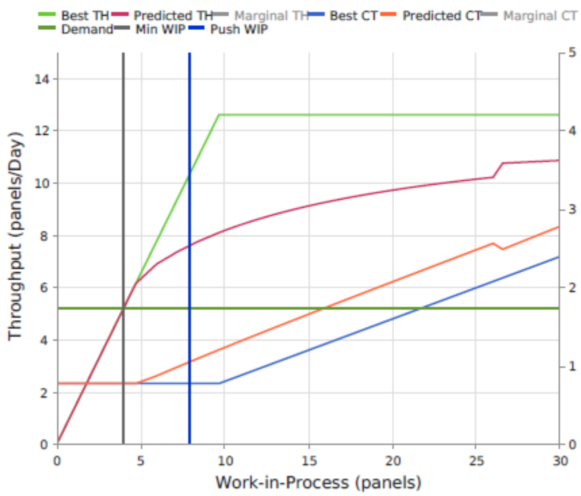
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	5.81	3.60	1.61	10.48	1.33	6.08	3.07	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40	3.05	1.61	7.27	100.00	30.00	1.61	10.48	1.33	6.08	3.07	0.00	0.00	12.72	58.02	29.26	0.00	0.00

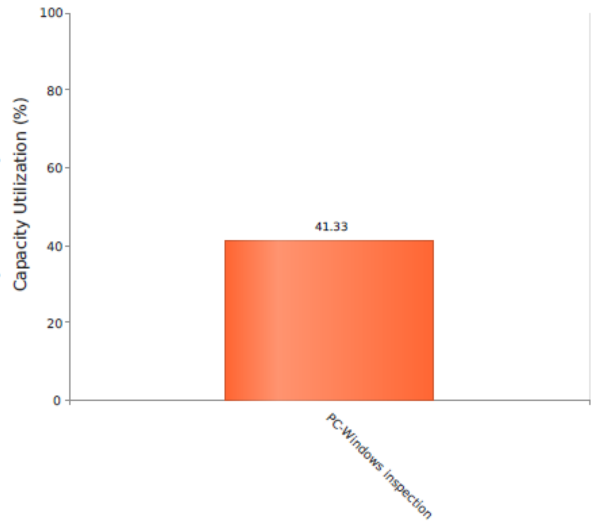
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	73.85	0.26	0.50	3.33	3.04	4.57	5.81

Windows inspection

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT **5.20** (panels/Day)
BOTTLENECK RATE **12.58** (panels/undefined)
BOTTLENECK UTILIZATION **41.33 %**
RAW PROCESS TIME **0.77** (Days)

MIN WIP **4.00** (panels)
MIN CYCLE TIME **0.77** (Days) | **6.15** (Hours)

PUSH WIP **7.90** (panels)
PUSH CYCLE TIME **1.52** (Days) | **12.16** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT **1.30** (panels/Day)
CYCLE TIME **5.00** (Hours)
WIP LEVEL **1.00** (panels)
BOTTLENECK UTILIZATION **10.33 %**

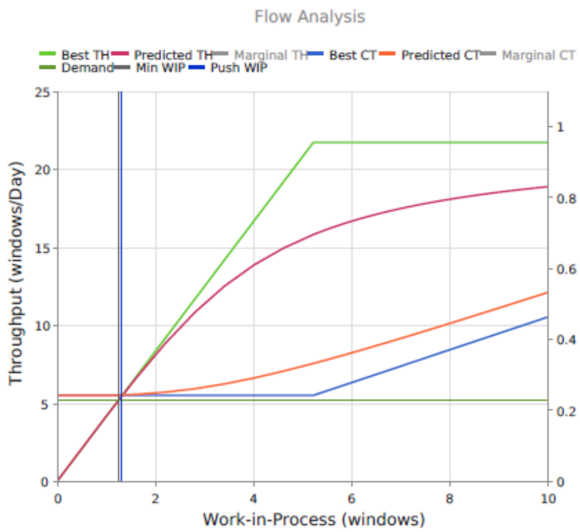
Cycle Time Analysis ▲

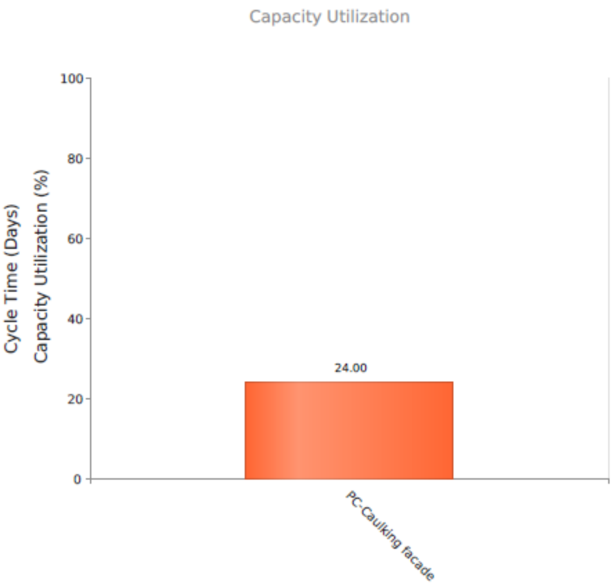
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	7.90	5.20	1.52	9.88	5.00	4.88	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	4.86	1.52	9.60	100.00	30.00	1.52	9.88	5.00	4.88	0.00	0.00	0.00	50.61	49.39	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	41.33	0.82	2.79	1.94	2.44	5.77	10.66

Development of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
5.20 (windows/Day)	**21.67** (windows/undefined)	**24.00 %**	**0.08** (Days)

MIN WIP	MIN CYCLE TIME
1.26 (windows)	**0.24** (Days) | **1.94** (Hours)

PUSH WIP	PUSH CYCLE TIME
1.30 (windows)	**0.25** (Days) | **2.00** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
4.15 (windows/Day)	**1.57** (Hours)	**1.00** (windows)	**19.15 %**

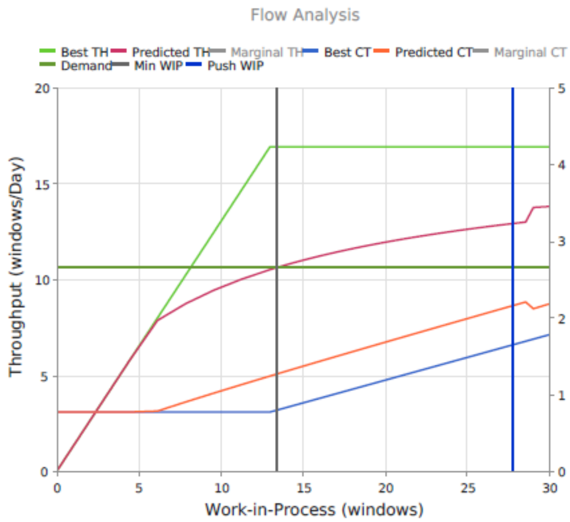
Cycle Time Analysis ▲

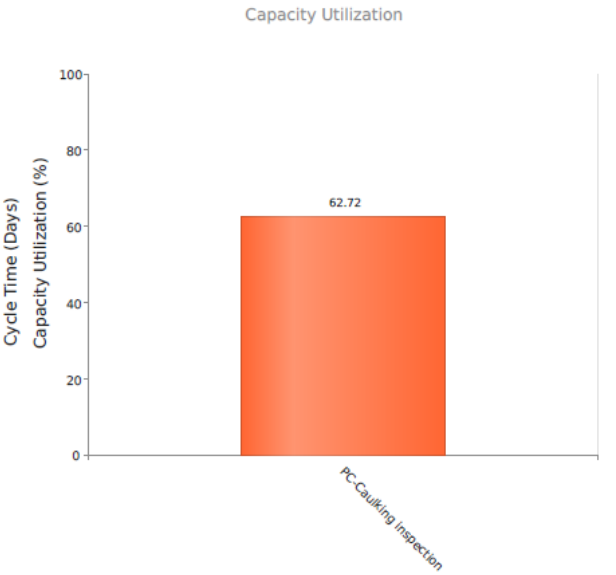
	CONWIP			PUSH							
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	1.30	5.20	0.25	1.63	0.50	0.06	1.07	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.36	0.25	1.41	100.00	30.00	0.25	1.63	0.50	0.06	1.07	0.00	0.00	30.71	3.76	65.52	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	24.00	0.66	2.61	0.43	0.03	0.19	1.41

Inspection of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
10.60 (windows/Day)	**16.90** (windows/undefined)	**62.72 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
13.39 (windows)	**1.26** (Days) | **10.11** (Hours)

PUSH WIP	PUSH CYCLE TIME
27.83 (windows)	**2.63** (Days) | **21.00** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (windows/Day)	**5.00** (Hours)	**1.00** (windows)	**7.69 %**

Cycle Time Analysis ▲

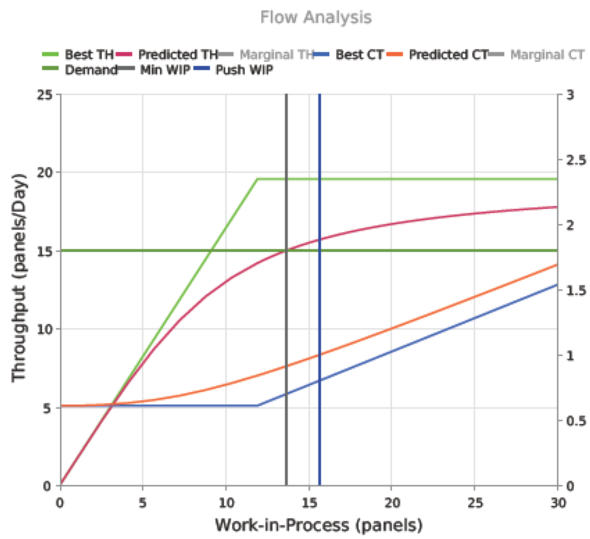
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	27.83	10.60	2.63	17.06	5.00	12.06	0.00	0.00	0.00

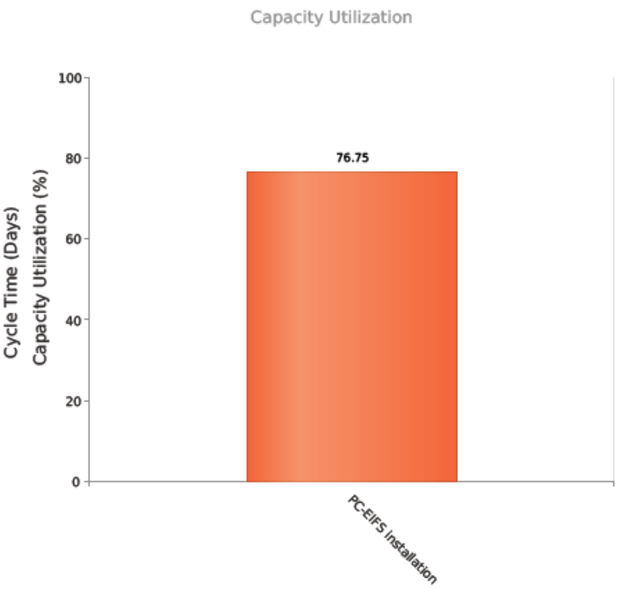
	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	4.61	2.63	15.72	100.00	30.00	2.63	17.06	5.00	12.06	0.00	0.00	0.00	29.30	70.70	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	62.72	0.55	2.40	2.50	6.03	10.53	27.83

Results sheets of the A9 production system with D=15 EFIS panels.

EIFS panels installation





Based on Current Demand

THROUGHPUT
15.00 (panels/Day)

BOTTLENECK RATE
19.54 (panels/undefined)

BOTTLENECK UTILIZATION
76.75 %

RAW PROCESS TIME
0.18 (Days)

MIN WIP
13.71 (panels)

MIN CYCLE TIME
0.91 (Days) | **7.31** (Hours)

PUSH WIP
15.71 (panels)

PUSH CYCLE TIME
1.05 (Days) | **8.38** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT
16.28 (panels/Day)

CYCLE TIME
7.19 (Hours)

WIP LEVEL
18.00 (panels)

BOTTLENECK UTILIZATION
83.32 %

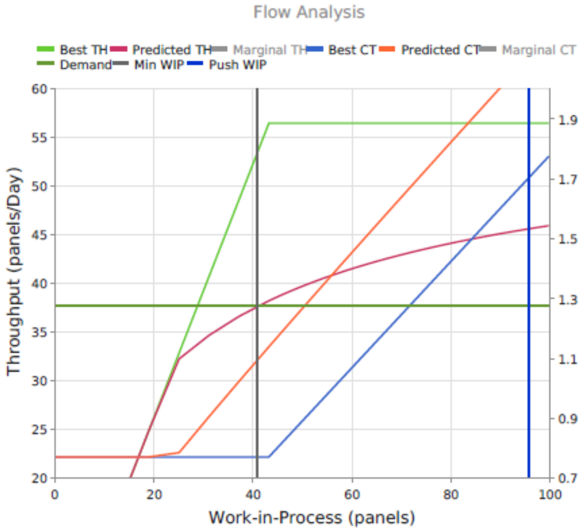
Cycle Time Analysis ▲

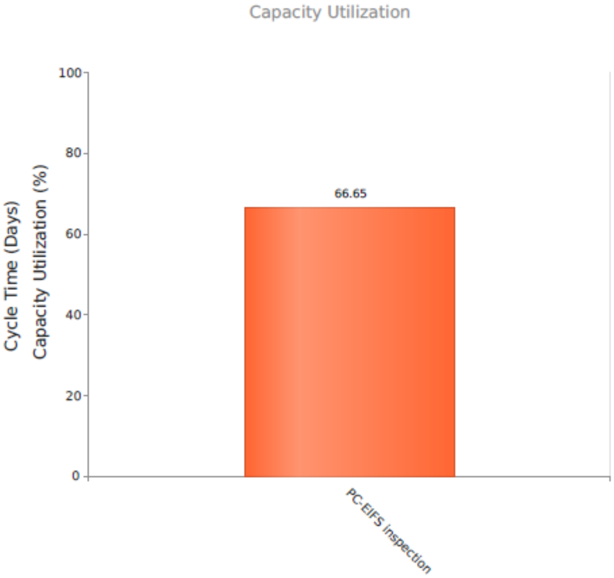
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	16.28	1.11	15.71	15.00	1.05	6.81	1.17	2.84	2.80	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	3.77	1.05	3.57	100.00	30.00	1.05	6.81	1.17	2.84	2.80	0.00	0.00	17.12	41.76	41.13	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	76.75	0.45	0.33	1.77	0.95	1.51	14.55
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	15.38

EIFS panels inspection





Based on Current Demand

THROUGHPUT
37.60 (panels/Day)

BOTTLENECK RATE
56.42 (panels/undefined)

BOTTLENECK UTILIZATION
66.65 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
41.12 (panels)

MIN CYCLE TIME
1.09 (Days) | **8.75** (Hours)

PUSH WIP
95.93 (panels)

PUSH CYCLE TIME
2.55 (Days) | **20.41** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT
1.30 (panels/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (panels)

BOTTLENECK UTILIZATION
2.30 %

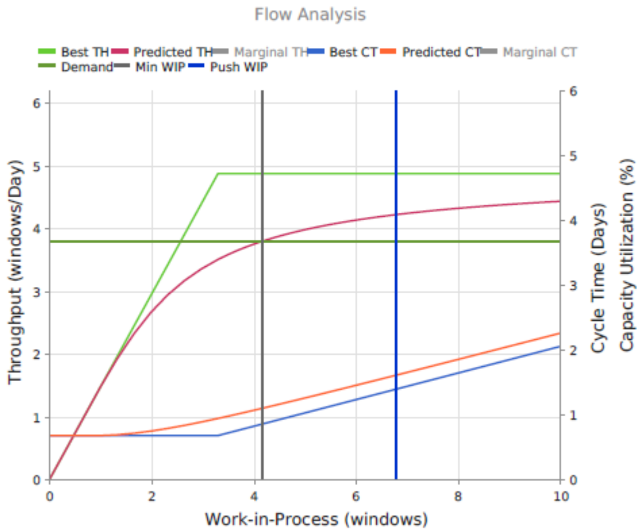
Cycle Time Analysis ▲

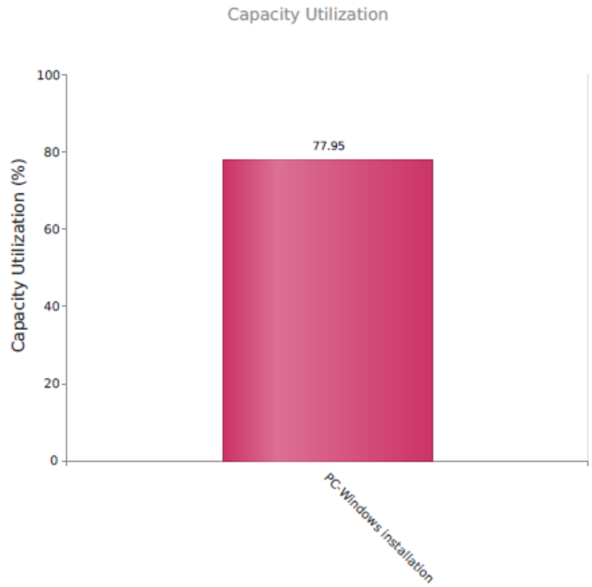
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	95.93	37.60	2.55	16.58	5.00	11.58	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	4.40	2.55	14.58	100.00	30.00	2.55	16.58	5.00	11.58	0.00	0.00	0.00	30.15	69.85	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	66.65	0.52	2.88	1.74	5.79	9.67	111.61

Windows installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
3.80 (windows/Day)	**4.88** (windows/undefined)	**77.95 %**	**0.21** (Days)

MIN WIP	MIN CYCLE TIME
4.18 (windows)	**1.10** (Days) | **8.80** (Hours)

PUSH WIP	PUSH CYCLE TIME
6.80 (windows)	**1.79** (Days) | **14.32** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.48 (windows/Day)	**4.40** (Hours)	**1.00** (windows)	**30.33 %**

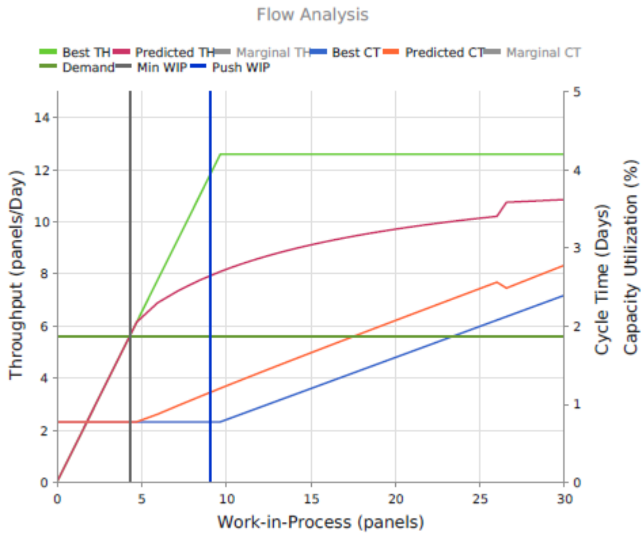
Cycle Time Analysis ▲

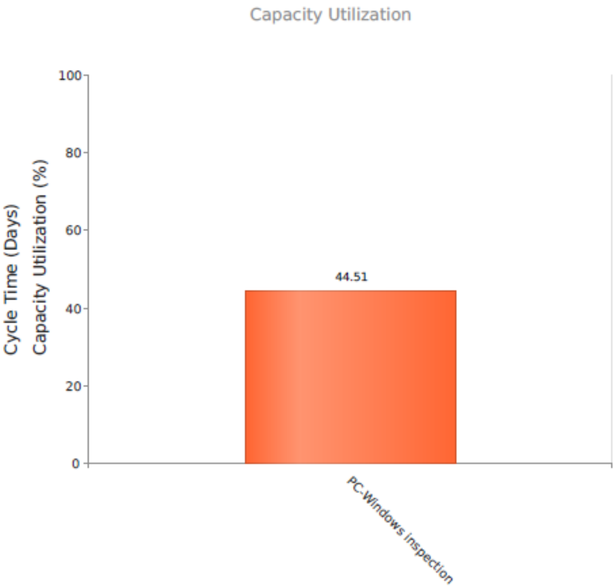
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	6.80	3.80	1.79	11.63	1.33	7.23	3.07	0.00	0.00

	CONWIP		PUSH														
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40	3.05	1.79	8.06	100.00	30.00	1.79	11.63	1.33	7.23	3.07	0.00	0.00	11.46	62.17	26.37	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	77.95	0.22	0.50	3.33	3.62	5.20	6.80

Windows inspection





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
5.60 (panels/Day)	**12.58** (panels/undefined)	**44.51 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
4.31 (panels)	**0.77** (Days) | **6.15** (Hours)

PUSH WIP	PUSH CYCLE TIME
9.10 (panels)	**1.62** (Days) | **13.00** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (panels/Day)	**5.00** (Hours)	**1.00** (panels)	**10.33 %**

Cycle Time Analysis ▲

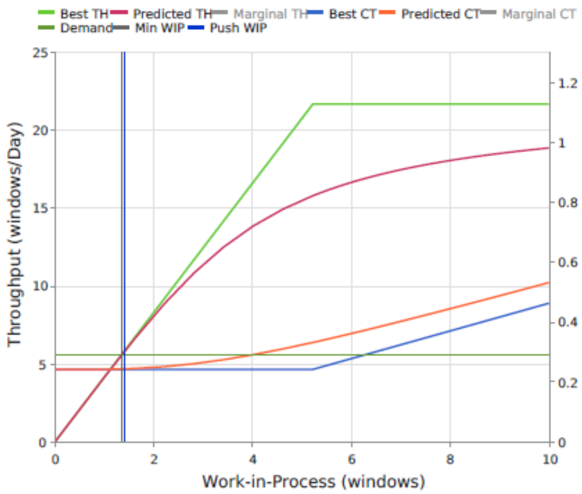
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	9.10	5.60	1.62	10.56	5.00	5.56	0.00	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	4.81	1.62	10.16	100.00	30.00	1.62	10.56	5.00	5.56	0.00	0.00	0.00	47.34	52.66	0.00	0.00	0.00

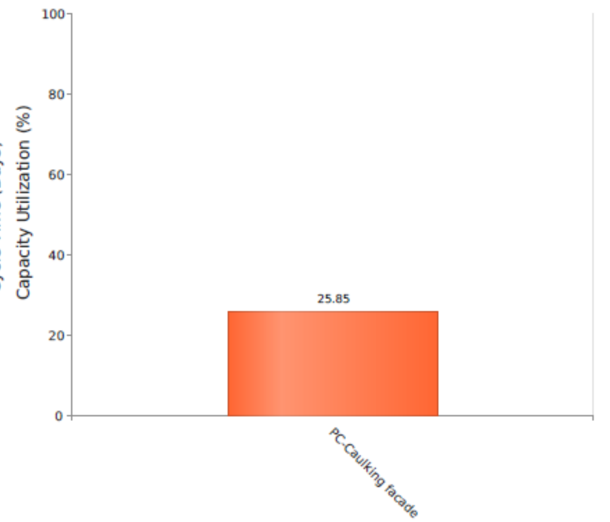
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	44.51	0.82	2.79	1.94	2.78	6.23	12.36

Development of caulking 1

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
5.60 (windows/Day)	**21.67** (windows/undefined)	**25.85 %**	**0.08** (Days)

MIN WIP	MIN CYCLE TIME
1.36 (windows)	**0.24** (Days) | **1.94** (Hours)

PUSH WIP	PUSH CYCLE TIME
1.41 (windows)	**0.25** (Days) | **2.02** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
4.15 (windows/Day)	**1.57** (Hours)	**1.00** (windows)	**19.15 %**

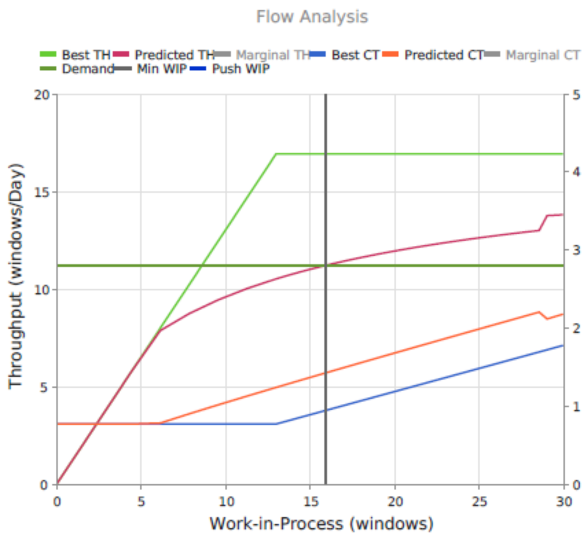
Cycle Time Analysis ▲

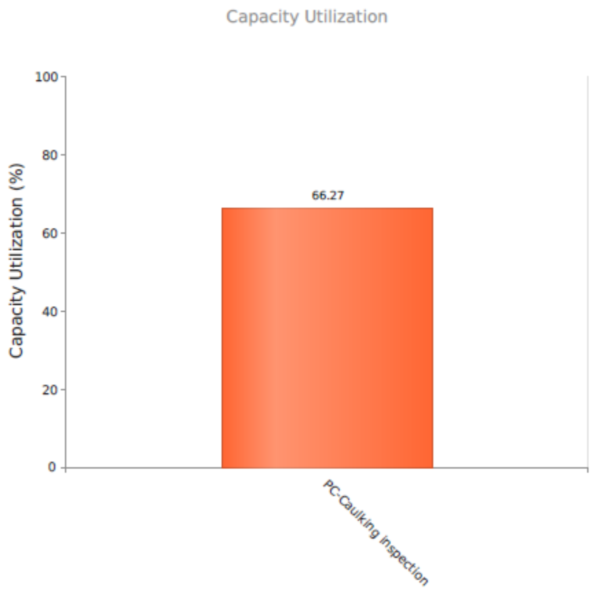
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	1.41	5.60	0.25	1.64	0.50	0.07	1.07	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.36	0.25	1.42	100.00	30.00	0.25	1.64	0.50	0.07	1.07	0.00	0.00	30.52	4.38	65.10	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	25.85	0.65	2.61	0.43	0.04	0.21	1.53

Inspection of caulking 1





Based on Current Demand

THROUGHPUT
11.20 (windows/Day)

BOTTLENECK RATE
16.90 (windows/undefined)

BOTTLENECK UTILIZATION
66.27 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
15.96 (windows)

MIN CYCLE TIME
1.42 (Days) | **11.40** (Hours)

PUSH WIP
32.90 (windows)

PUSH CYCLE TIME
2.94 (Days) | **23.50** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.30 (windows/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
7.69 %

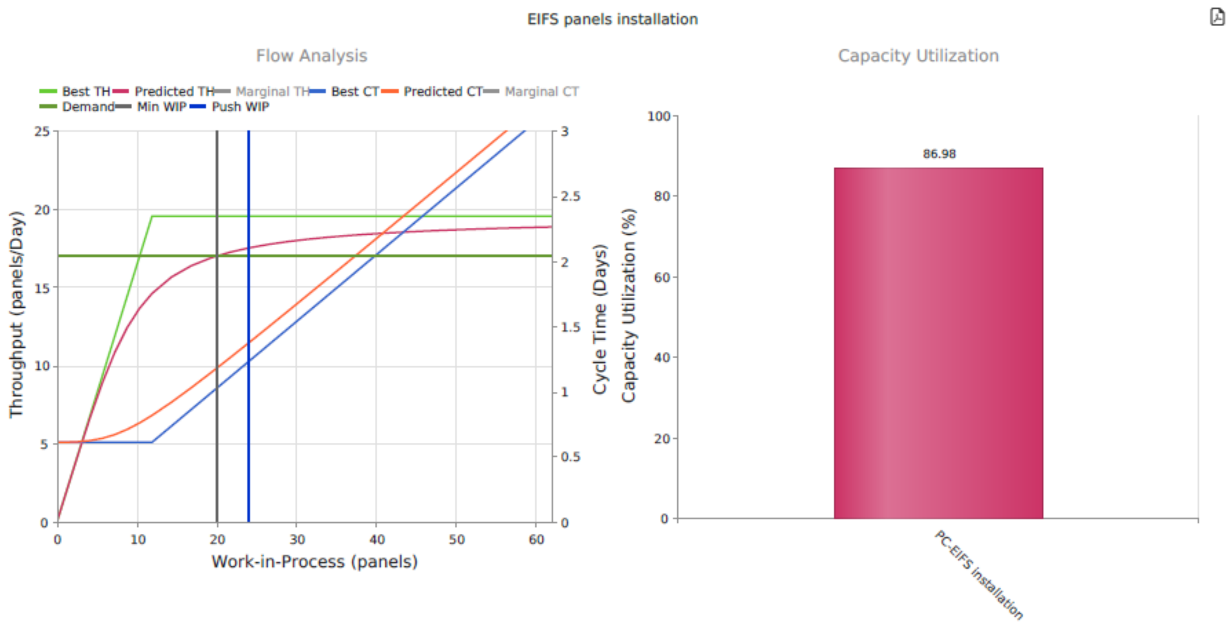
Cycle Time Analysis ▲

	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	32.90	11.20	2.94	19.09	5.00	14.09	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	4.52	2.94	17.24	100.00	30.00	2.94	19.09	5.00	14.09	0.00	0.00	0.00	26.19	73.81	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	66.27	0.54	2.40	2.50	7.05	11.66	32.90

Results sheets of the B2 production system based on D=17 EFIS panels.



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
17.00 (panels/Day)	**19.54** (panels/undefined)	**86.98 %**	**0.18** (Days)

MIN WIP	MIN CYCLE TIME
20.05 (panels)	**1.18** (Days) | **9.43** (Hours)

PUSH WIP	PUSH CYCLE TIME
23.95 (panels)	**1.41** (Days) | **11.27** (Hours)

Based on CONWIP Level of 20 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
16.99 (panels/Day)	**7.65** (Hours)	**20.00** (panels)	**86.95 %**

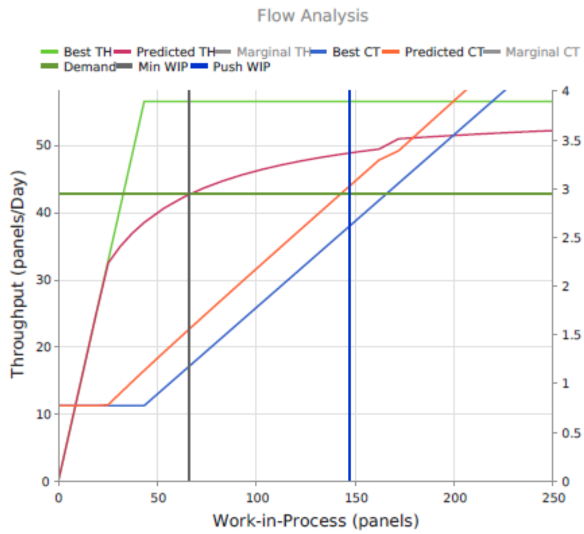
Cycle Time Analysis ▲

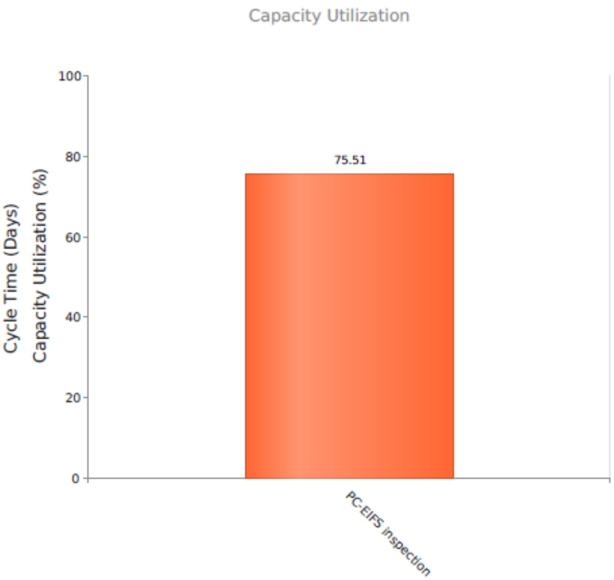
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	20.00	16.99	1.18	23.95	17.00	1.41	9.16	1.17	5.19	2.80	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	3.94	1.41	4.72	100.00	30.00	1.41	9.16	1.17	5.19	2.80	0.00	0.00	12.72	56.72	30.56	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	86.98	0.34	0.33	1.77	1.73	2.34	22.65
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	17.44

EIFS panels inspection





Based on Current Demand

THROUGHPUT
42.60 (panels/Day)

BOTTLENECK RATE
56.41 (panels/undefined)

BOTTLENECK UTILIZATION
75.51 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
66.32 (panels)

MIN CYCLE TIME
1.56 (Days) | **12.45** (Hours)

PUSH WIP
147.30 (panels)

PUSH CYCLE TIME
3.46 (Days) | **27.66** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT
1.30 (panels/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (panels)

BOTTLENECK UTILIZATION
2.30 %

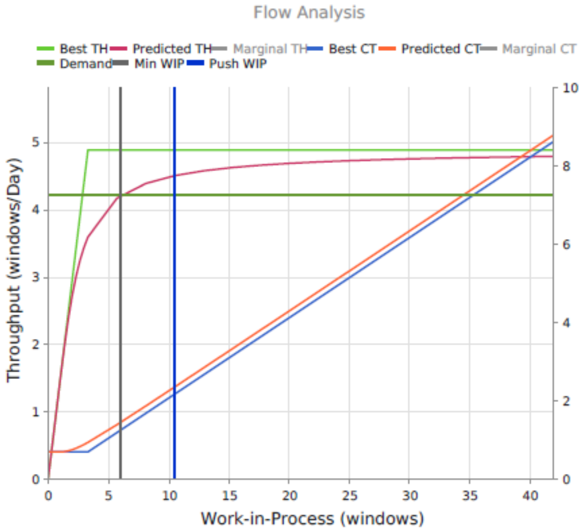
Cycle Time Analysis ▲

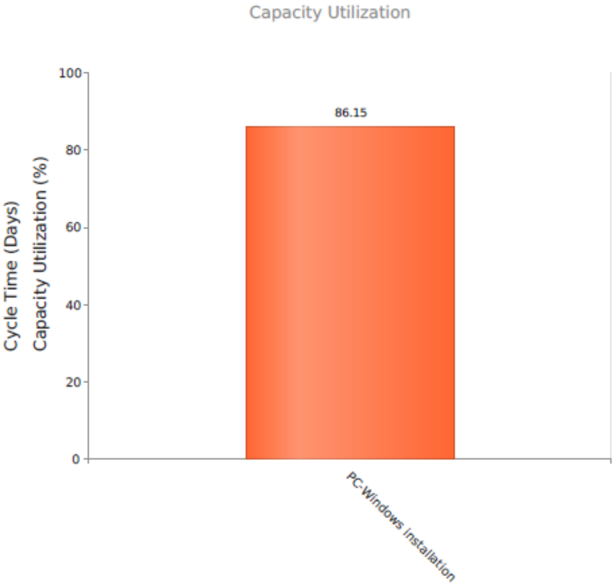
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	147.30	42.60	3.46	22.48	5.00	17.48	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	4.19	3.46	18.84	100.00	30.00	3.46	22.48	5.00	17.48	0.00	0.00	0.00	22.25	77.75	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	75.51	0.44	2.88	1.74	8.74	12.84	172.77

Windows installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
4.20 (windows/Day)	**4.88** (windows/undefined)	**86.15 %**	**0.21** (Days)

MIN WIP	MIN CYCLE TIME
6.04 (windows)	**1.44** (Days) | **11.51** (Hours)

PUSH WIP	PUSH CYCLE TIME
10.51 (windows)	**2.50** (Days) | **20.02** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.48 (windows/Day)	**4.40** (Hours)	**1.00** (windows)	**30.33 %**

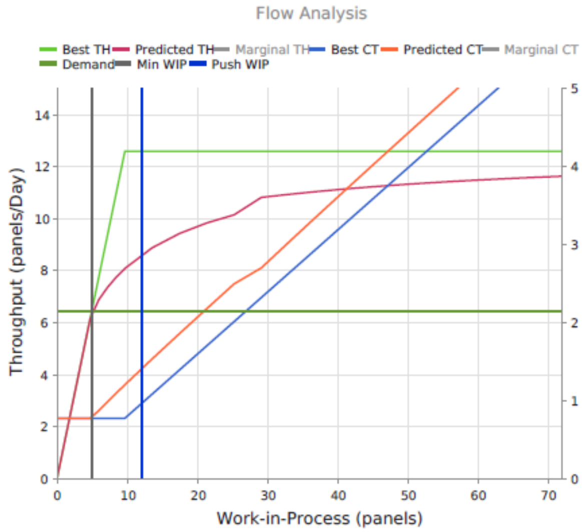
Cycle Time Analysis ▲

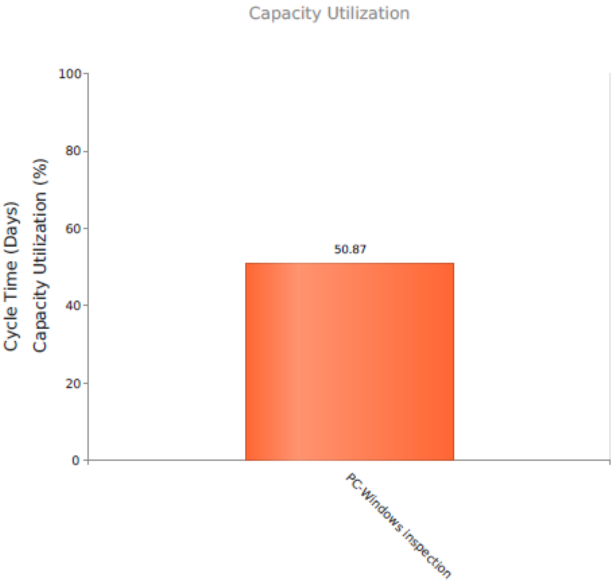
Product Flow	CONWIP			PUSH								
	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	10.51	4.20	2.50	16.27	1.33	11.87	3.07	0.00	0.00

Item	CONWIP		PUSH															
	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40	3.06	2.50	11.32	100.00	30.00	2.50	16.27	1.33	11.87	3.07	0.00	0.00	8.20	72.95	18.85	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	86.15	0.15	0.50	3.33	5.93	7.65	10.51

Windows inspection





Based on Current Demand

THROUGHPUT **6.40** (panels/Day) | BOTTLENECK RATE **12.58** (panels/undefined) | BOTTLENECK UTILIZATION **50.87 %** | RAW PROCESS TIME **0.77** (Days)

MIN WIP **4.93** (panels) | MIN CYCLE TIME **0.77** (Days) | **6.16** (Hours)

PUSH WIP **12.02** (panels) | PUSH CYCLE TIME **1.88** (Days) | **15.02** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT **1.30** (panels/Day) | CYCLE TIME **5.00** (Hours) | WIP LEVEL **1.00** (panels) | BOTTLENECK UTILIZATION **10.33 %**

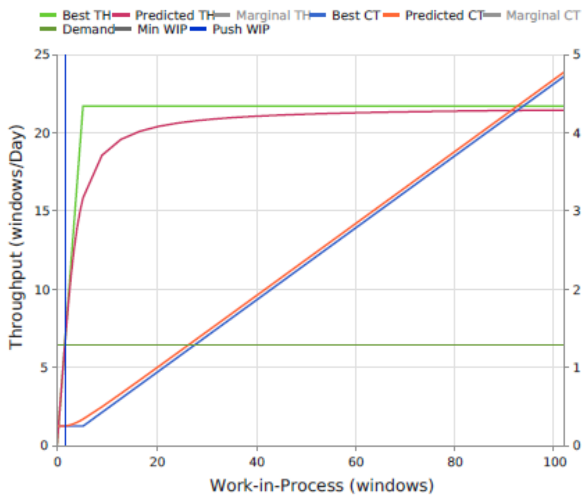
Cycle Time Analysis ▲

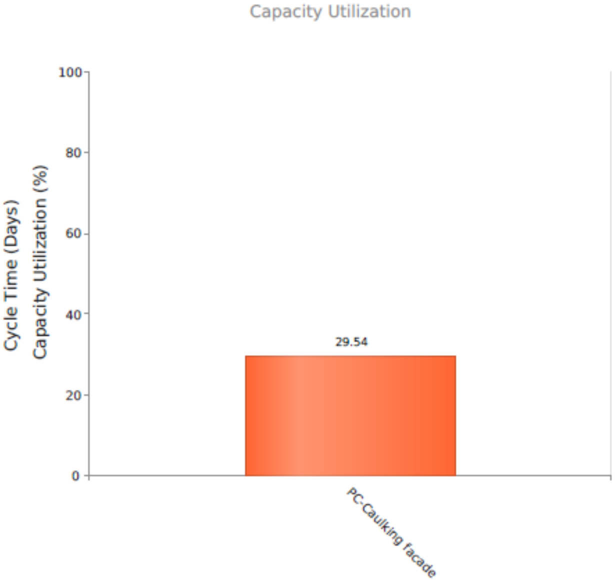
Product Flow	CONWIP			PUSH								
	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	12.02	6.40	1.88	12.21	5.00	7.21	0.00	0.00	0.00

Item	CONWIP		PUSH															
	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	4.70	1.88	11.46	100.00	30.00	1.88	12.21	5.00	7.21	0.00	0.00	0.00	40.97	59.03	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	50.87	0.82	2.79	1.94	3.60	7.28	16.55

Development of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
6.40 (windows/Day)	**21.67** (windows/undefined)	**29.54 %**	**0.08** (Days)

MIN WIP	MIN CYCLE TIME
1.56 (windows)	**0.24** (Days) | **1.95** (Hours)

PUSH WIP	PUSH CYCLE TIME
1.64 (windows)	**0.26** (Days) | **2.05** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
4.15 (windows/Day)	**1.57** (Hours)	**1.00** (windows)	**19.15 %**

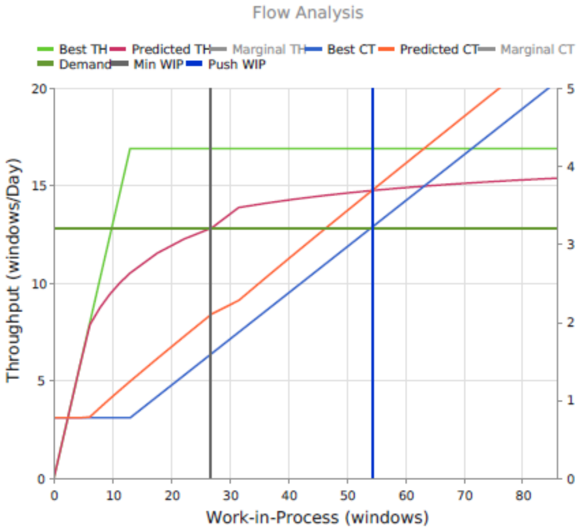
Cycle Time Analysis ▲

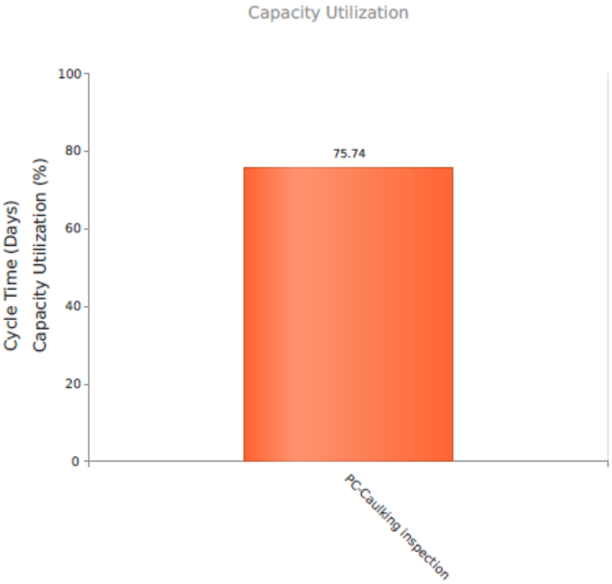
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	1.64	6.40	0.26	1.66	0.50	0.10	1.07	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.35	0.26	1.43	100.00	30.00	0.26	1.66	0.50	0.10	1.07	0.00	0.00	30.07	5.78	64.15	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	29.54	0.63	2.61	0.43	0.05	0.25	1.78

Inspection of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
12.80 (windows/Day)	**16.90** (windows/undefined)	**75.74 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
26.77 (windows)	**2.09** (Days) | **16.73** (Hours)

PUSH WIP	PUSH CYCLE TIME
54.33 (windows)	**4.24** (Days) | **33.96** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (windows/Day)	**5.00** (Hours)	**1.00** (windows)	**7.69 %**

Cycle Time Analysis ▲

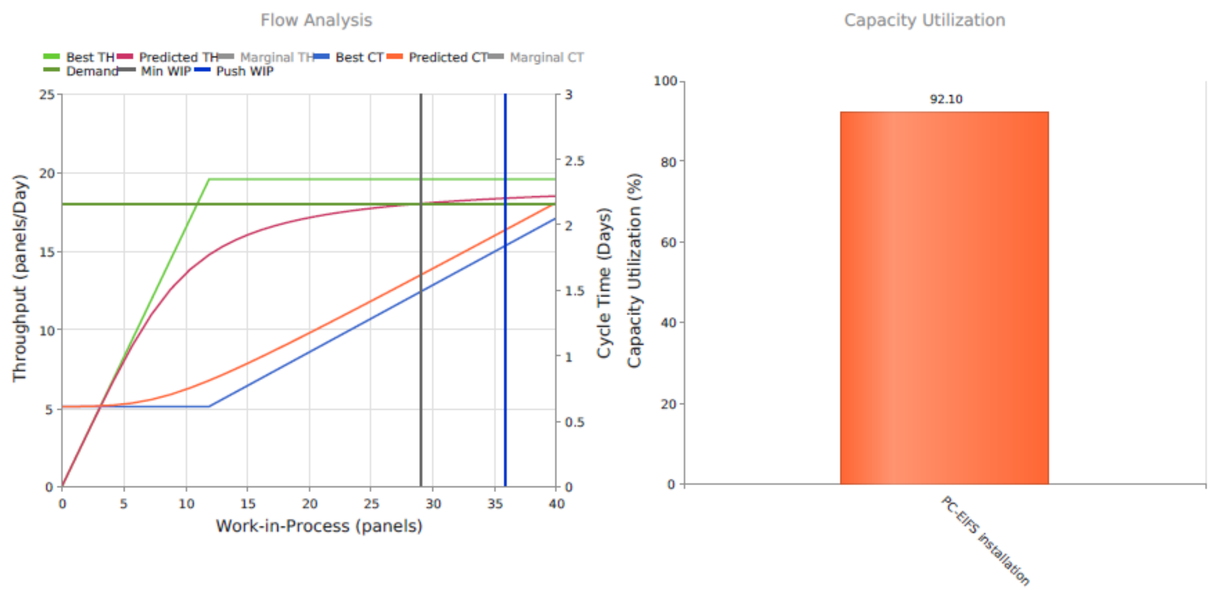
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	54.33	12.80	4.24	27.59	5.00	22.59	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	4.25	4.24	23.47	100.00	30.00	4.24	27.59	5.00	22.59	0.00	0.00	0.00	18.12	81.88	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	75.74	0.54	2.40	2.50	11.30	16.20	54.33

Results sheets of the B3 production system based on D=18 EFIS panels.

EIFS panels installation



Based on Current Demand

THROUGHPUT
18.00 (panels/Day)

BOTTLENECK RATE
19.54 (panels/undefined)

BOTTLENECK UTILIZATION
92.10 %

RAW PROCESS TIME
0.18 (Days)

MIN WIP
29.07 (panels)

MIN CYCLE TIME
1.61 (Days) | **12.92** (Hours)

PUSH WIP
35.95 (panels)

PUSH CYCLE TIME
2.00 (Days) | **15.98** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT
16.75 (panels/Day)

CYCLE TIME
6.99 (Hours)

WIP LEVEL
18.00 (panels)

BOTTLENECK UTILIZATION
85.72 %

Cycle Time Analysis ▲

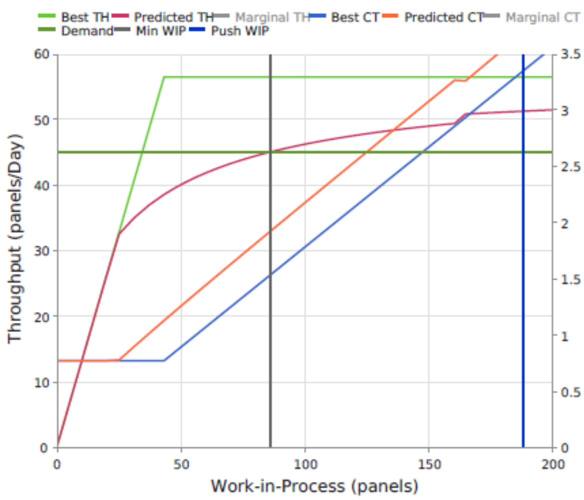
Product Flow	CONWIP			PUSH								
	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	16.75	1.07	35.95	18.00	2.00	12.98	1.17	9.02	2.80	0.00	0.00

Item	CONWIP		PUSH																
	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	3.65	2.00	6.77	100.00	30.00	2.00	12.98	1.17	9.02	2.80	0.00	0.00	8.97	69.47	21.56	0.00	0.00

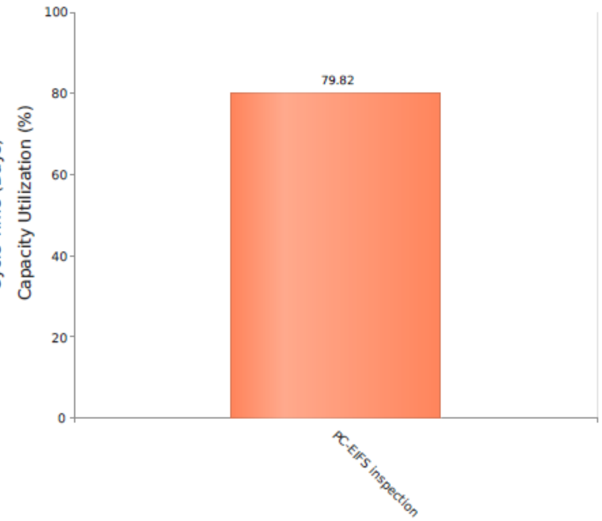
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	92.10	0.31	0.33	1.77	3.01	3.65	34.57
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	18.46

EIFS panels inspection

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT **45.00** (panels/Day)	BOTTLENECK RATE **56.37** (panels/undefined)	BOTTLENECK UTILIZATION **79.82 %**	RAW PROCESS TIME **0.77** (Days)
MIN WIP **86.58** (panels)	MIN CYCLE TIME **1.92** (Days) | **15.39** (Hours)		
PUSH WIP **188.34** (panels)	PUSH CYCLE TIME **4.19** (Days) | **33.48** (Hours)		

Based on CONWIP Level of 0 (panels)

THROUGHPUT **1.30** (panels/Day)	CYCLE TIME **5.00** (Hours)	WIP LEVEL **1.00** (panels)	BOTTLENECK UTILIZATION **2.31 %**

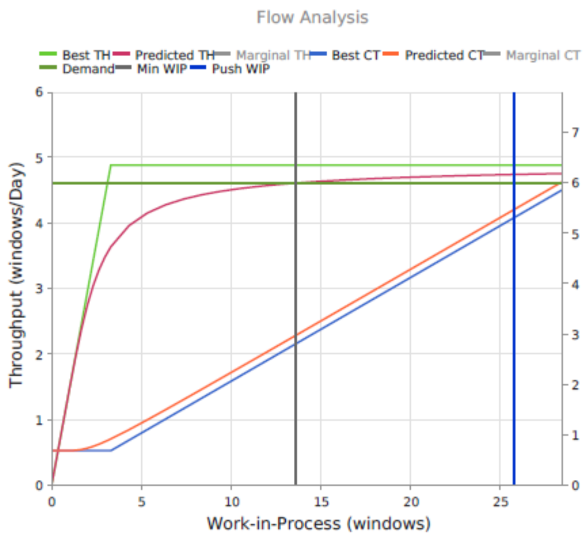
Cycle Time Analysis ▲

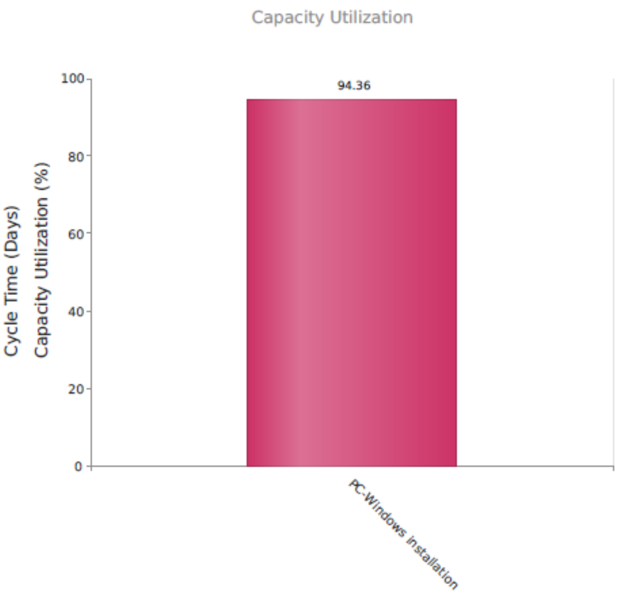
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	188.34	45.00	4.19	27.20	5.00	22.20	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	4.08	4.19	22.21	100.00	30.00	4.19	27.20	5.00	22.20	0.00	0.00	0.00	18.38	81.62	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	79.82	0.40	2.88	1.74	11.10	15.29	221.85

Windows installation





Based on Current Demand

THROUGHPUT
4.60 (windows/Day)

BOTTLENECK RATE
4.87 (windows/undefined)

BOTTLENECK UTILIZATION
94.36 %

RAW PROCESS TIME
0.21 (Days)

MIN WIP
13.61 (windows)

MIN CYCLE TIME
2.96 (Days) | **23.67** (Hours)

PUSH WIP
25.77 (windows)

PUSH CYCLE TIME
5.60 (Days) | **44.82** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.48 (windows/Day)

CYCLE TIME
4.40 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
30.39 %

Cycle Time Analysis ▲

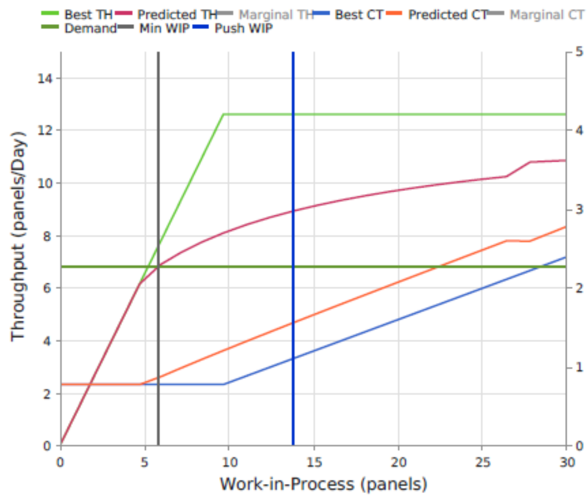
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	25.77	4.60	5.60	36.41	1.33	32.01	3.07	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40	3.09	5.60	25.57	100.00	30.00	5.60	36.41	1.33	32.01	3.07	0.00	0.00	3.66	87.92	8.42	0.00	0.00

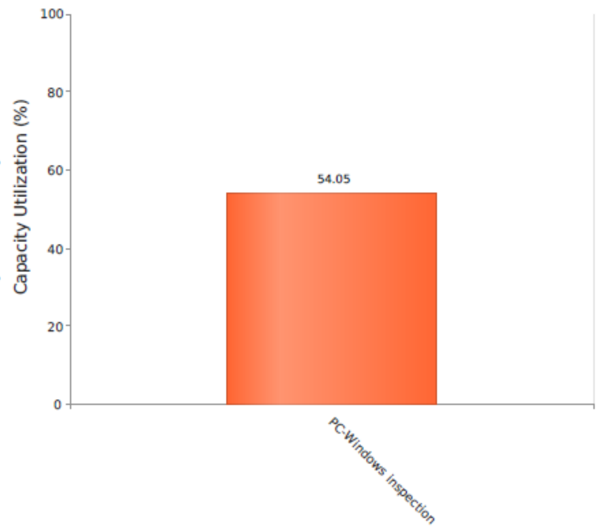
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	94.36	0.11	0.50	3.33	16.01	17.93	25.77

Windows inspection

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
6.80 (panels/Day)	**12.58** (panels/undefined)	**54.05 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
5.80 (panels)	**0.85** (Days) | **6.82** (Hours)

PUSH WIP	PUSH CYCLE TIME
13.82 (panels)	**2.03** (Days) | **16.26** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (panels/Day)	**5.00** (Hours)	**1.00** (panels)	**10.33 %**

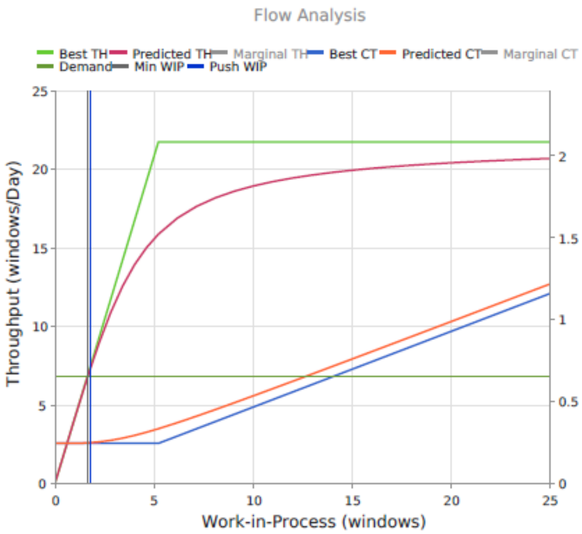
Cycle Time Analysis ▴

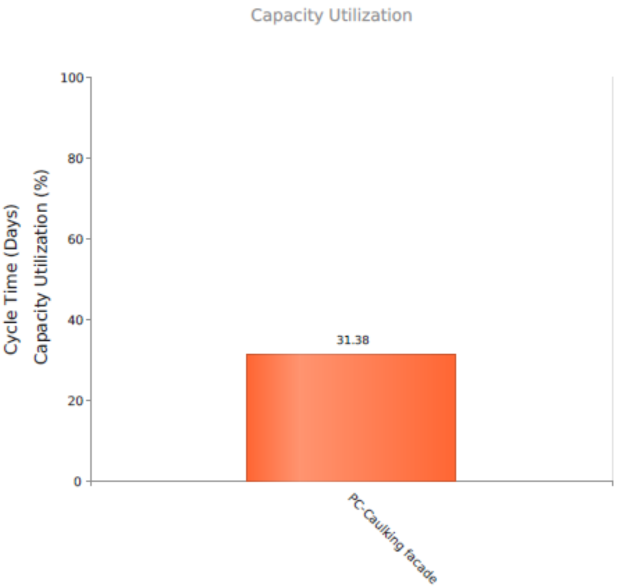
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	13.82	6.80	2.03	13.21	5.00	8.21	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	4.63	2.03	12.24	100.00	30.00	2.03	13.21	5.00	8.21	0.00	0.00	0.00	37.85	62.15	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	54.05	0.83	2.79	1.94	4.11	7.89	19.16

Development of caulking 1





Based on Current Demand

THROUGHPUT
6.80 (windows/Day)

BOTTLENECK RATE
21.67 (windows/undefined)

BOTTLENECK UTILIZATION
31.38 %

RAW PROCESS TIME
0.08 (Days)

MIN WIP
1.66 (windows)

MIN CYCLE TIME
0.24 (Days) | **1.96** (Hours)

PUSH WIP
1.75 (windows)

PUSH CYCLE TIME
0.26 (Days) | **2.06** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
4.15 (windows/Day)

CYCLE TIME
1.57 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
19.15 %

Cycle Time Analysis ▲

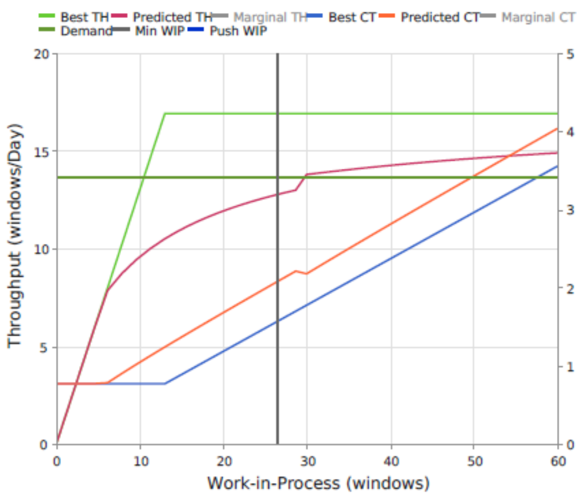
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	1.75	6.80	0.26	1.68	0.50	0.11	1.07	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.34	0.26	1.44	100.00	30.00	0.26	1.68	0.50	0.11	1.07	0.00	0.00	29.82	6.57	63.61	0.00	0.00

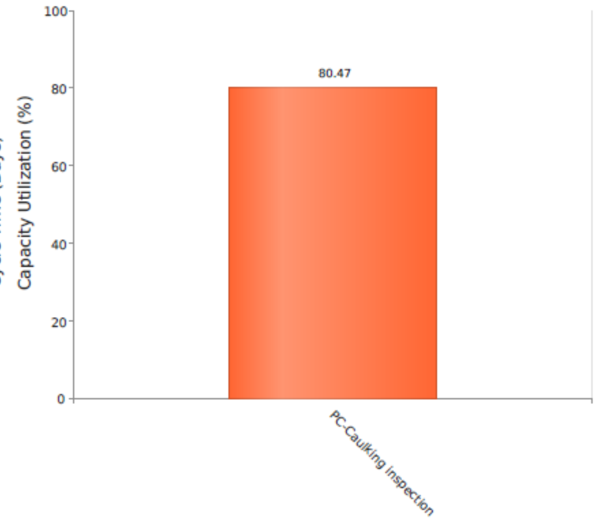
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	31.38	0.62	2.61	0.43	0.06	0.27	1.92

Inspection of caulking 1

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT
13.60 (windows/Day)

BOTTLENECK RATE
16.90 (windows/undefined)

BOTTLENECK UTILIZATION
80.47 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
26.52 (windows)

MIN CYCLE TIME
1.95 (Days) | **15.60** (Hours)

PUSH WIP
73.46 (windows)

PUSH CYCLE TIME
5.40 (Days) | **43.21** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.30 (windows/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
7.69 %

Cycle Time Analysis ▴

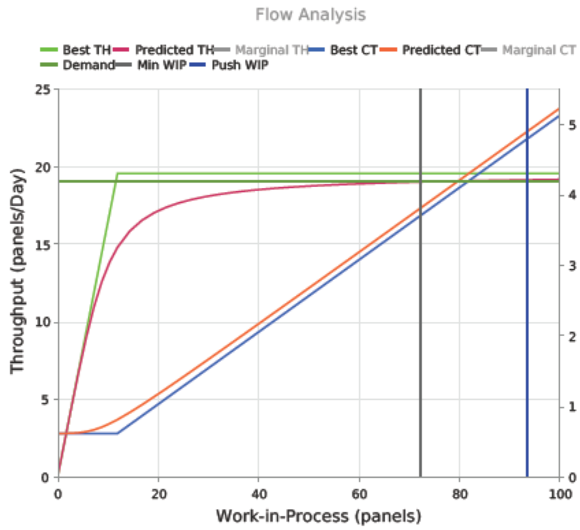
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	73.46	13.60	5.40	35.11	5.00	30.11	0.00	0.00	0.00

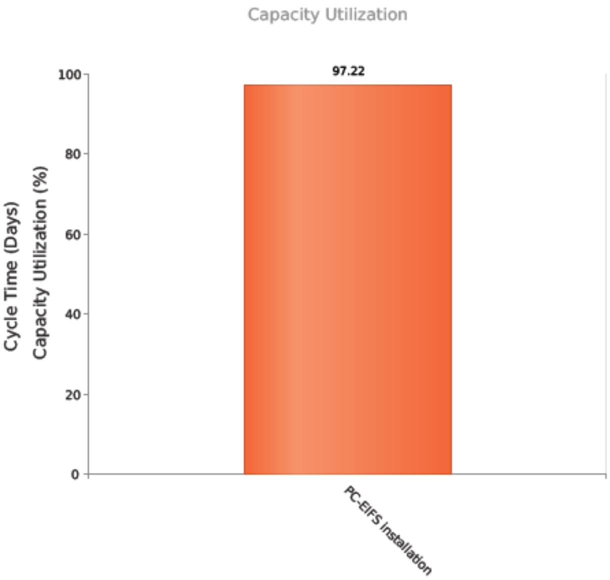
	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	4.11	5.40	28.89	100.00	30.00	5.40	35.11	5.00	30.11	0.00	0.00	0.00	14.24	85.76	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	80.47	0.55	2.40	2.50	15.06	20.11	73.46

Results sheets of the B4 production system based on D=19 EFIS panels.

EIFS panels installation





Based on Current Demand

THROUGHPUT
19.00 (panels/Day)

BOTTLENECK RATE
19.54 (panels/undefined)

BOTTLENECK UTILIZATION
97.22 %

RAW PROCESS TIME
0.18 (Days)

MIN WIP
72.34 (panels)

MIN CYCLE TIME
3.81 (Days) | **30.46** (Hours)

PUSH WIP
93.73 (panels)

PUSH CYCLE TIME
4.93 (Days) | **39.47** (Hours)

Based on CONWIP Level of 20 (panels)

THROUGHPUT
17.13 (panels/Day)

CYCLE TIME
7.59 (Hours)

WIP LEVEL
20.00 (panels)

BOTTLENECK UTILIZATION
87.67 %

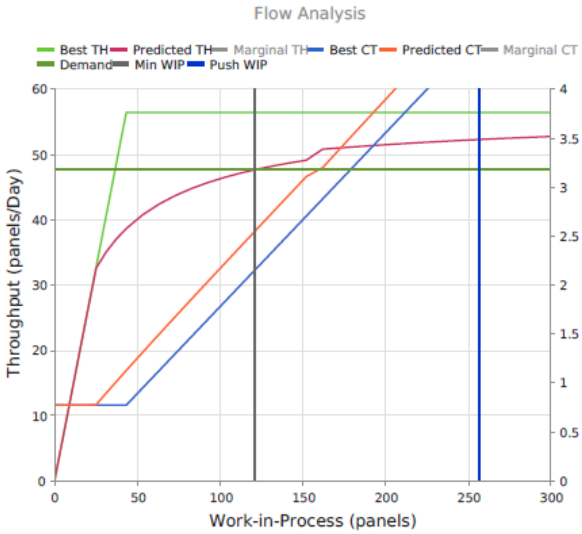
Cycle Time Analysis ▲

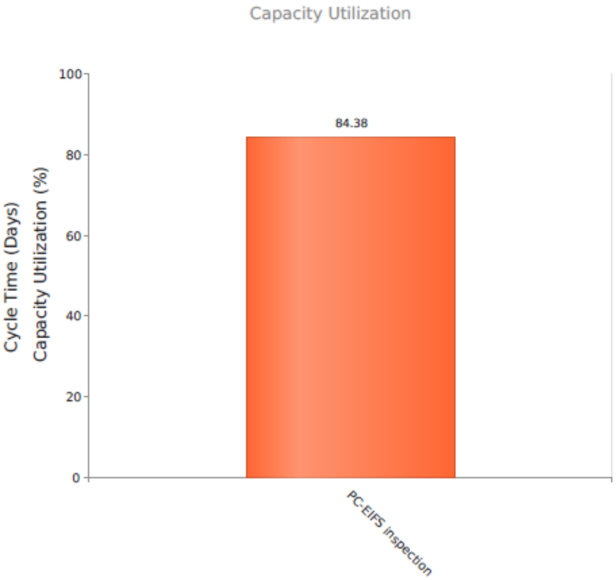
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	20.00	17.13	1.17	93.73	19.00	4.93	32.07	1.17	28.10	2.80	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	4.16	4.93	17.60	100.00	30.00	4.93	32.07	1.17	28.10	2.80	0.00	0.00	3.63	87.64	8.73	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	97.22	0.29	0.33	1.77	9.37	10.06	92.27
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	19.49

EIFS panels inspection





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
47.60 (panels/Day)	**56.41** (panels/undefined)	**84.38 %**	**0.77** (Days)
MIN WIP	MIN CYCLE TIME		
120.85 (panels)	**2.54** (Days) | **20.31** (Hours)		
PUSH WIP	PUSH CYCLE TIME		
257.40 (panels)	**5.41** (Days) | **43.26** (Hours)		

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (panels/Day)	**5.00** (Hours)	**1.00** (panels)	**2.30 %**

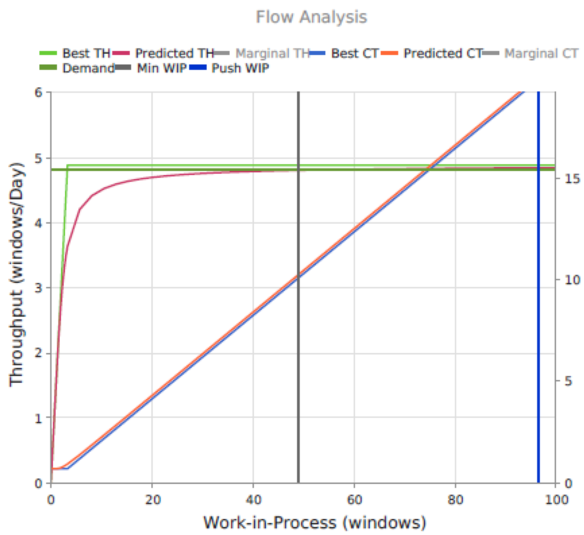
Cycle Time Analysis ▲

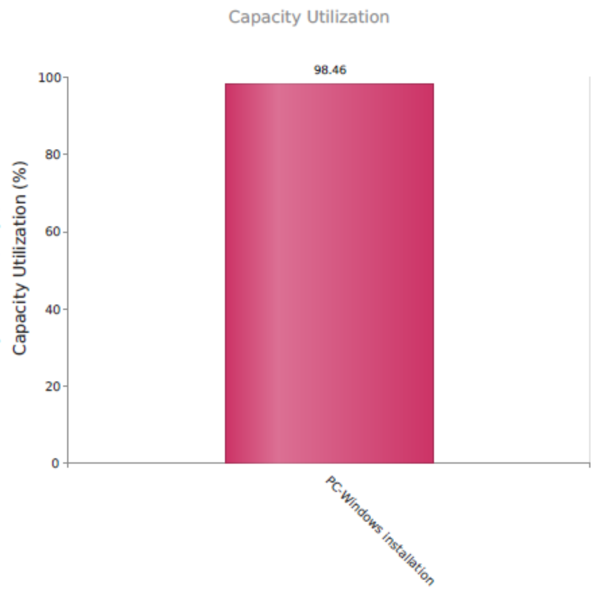
Product Flow	CONWIP			PUSH								
	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	257.40	47.60	5.41	35.15	5.00	30.15	0.00	0.00	0.00

Item	CONWIP		PUSH															
	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	3.96	5.41	27.85	100.00	30.00	5.41	35.15	5.00	30.15	0.00	0.00	0.00	14.23	85.77	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	84.38	0.37	2.88	1.74	15.07	19.36	304.39

Windows installation





Based on Current Demand

THROUGHPUT
4.80 (windows/Day)

BOTTLENECK RATE
4.87 (windows/undefined)

BOTTLENECK UTILIZATION
98.46 %

RAW PROCESS TIME
0.21 (Days)

MIN WIP
49.07 (windows)

MIN CYCLE TIME
10.22 (Days) | **81.78** (Hours)

PUSH WIP
96.79 (windows)

PUSH CYCLE TIME
20.16 (Days) | **161.31** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.48 (windows/Day)

CYCLE TIME
4.40 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
30.39 %

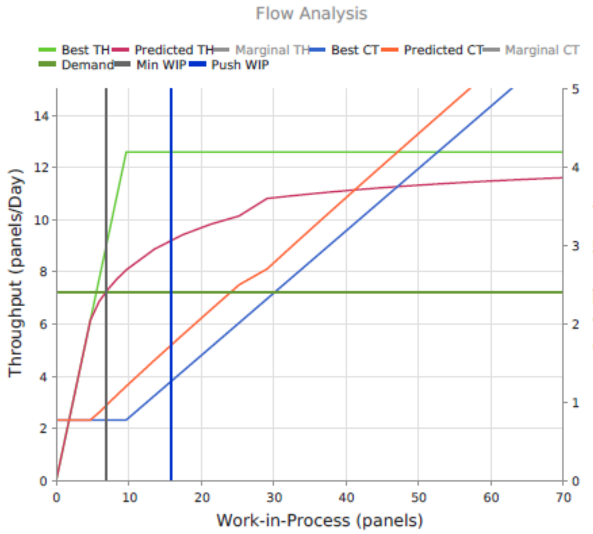
Cycle Time Analysis ▲

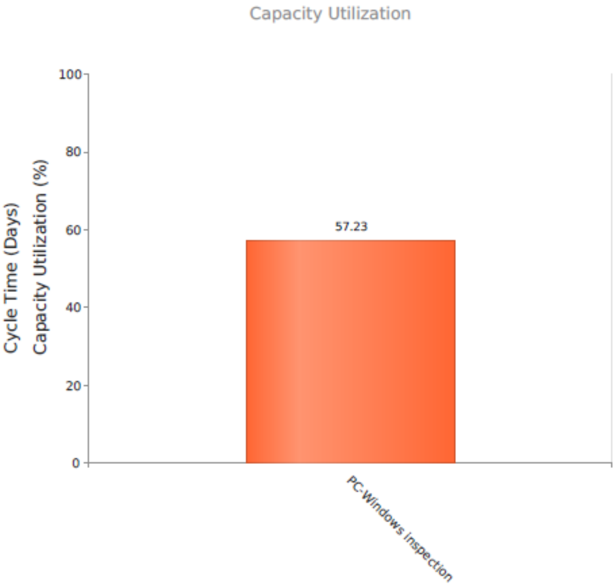
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	96.79	4.80	20.16	131.07	1.33	126.67	3.07	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40	3.11	20.16	92.51	75.53	30.00	20.16	131.07	1.33	126.67	3.07	0.00	0.00	1.02	96.64	2.34	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	98.46	0.10	0.50	3.33	63.33	65.38	96.79

Windows inspection





Based on Current Demand

THROUGHPUT
7.20 (panels/Day)

BOTTLENECK RATE
12.58 (panels/undefined)

BOTTLENECK UTILIZATION
57.23 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
6.82 (panels)

MIN CYCLE TIME
0.95 (Days) | **7.58** (Hours)

PUSH WIP
15.93 (panels)

PUSH CYCLE TIME
2.21 (Days) | **17.70** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT
1.30 (panels/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (panels)

BOTTLENECK UTILIZATION
10.33 %

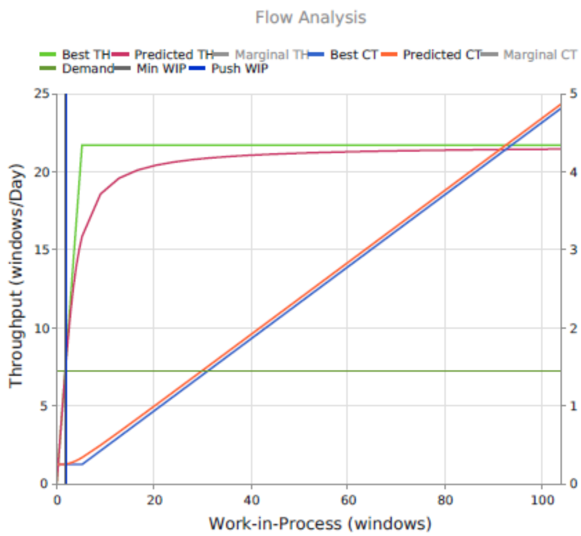
Cycle Time Analysis ▲

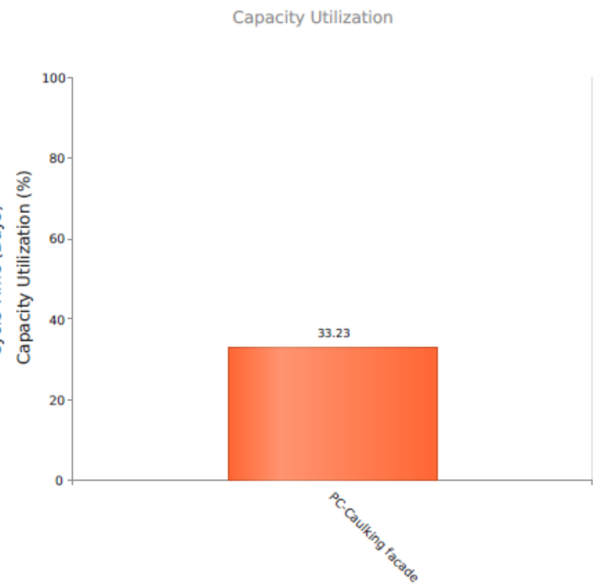
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	15.93	7.20	2.21	14.38	5.00	9.38	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	4.57	2.21	13.14	100.00	30.00	2.21	14.38	5.00	9.38	0.00	0.00	0.00	34.77	65.23	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	57.23	0.84	2.79	1.94	4.69	8.58	22.23

Development of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
7.20 (windows/Day)	**21.67** (windows/undefined)	**33.23 %**	**0.08** (Days)

MIN WIP	MIN CYCLE TIME
1.77 (windows)	**0.25** (Days) | **1.96** (Hours)

PUSH WIP	PUSH CYCLE TIME
1.87 (windows)	**0.26** (Days) | **2.08** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
4.15 (windows/Day)	**1.57** (Hours)	**1.00** (windows)	**19.15 %**

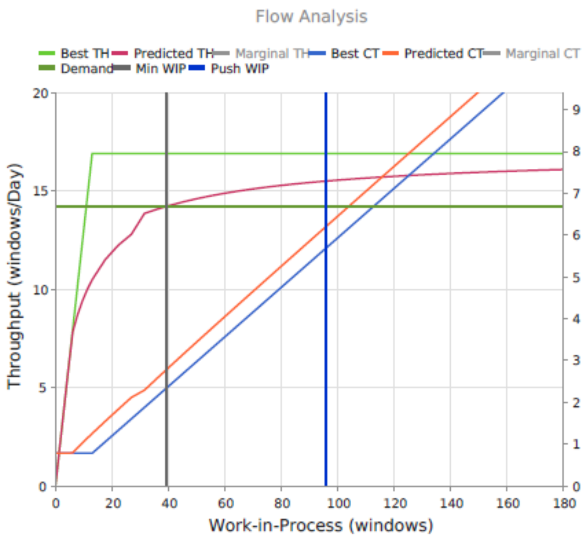
Cycle Time Analysis ▲

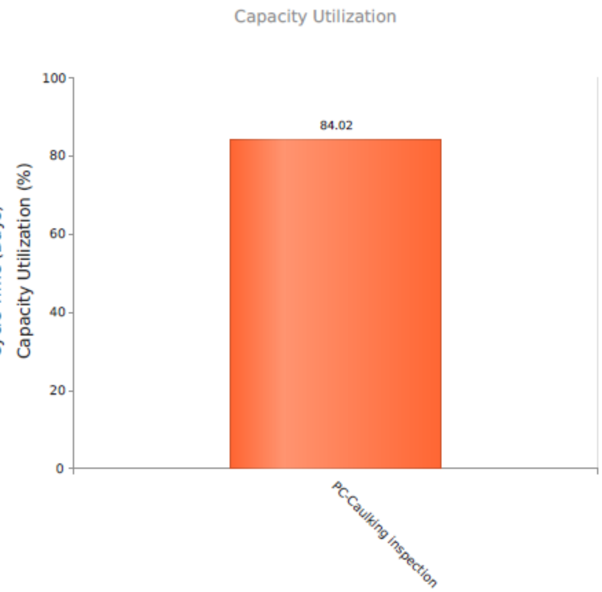
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	1.87	7.20	0.26	1.69	0.50	0.13	1.07	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.34	0.26	1.44	100.00	30.00	0.26	1.69	0.50	0.13	1.07	0.00	0.00	29.55	7.41	63.04	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	33.23	0.60	2.61	0.43	0.06	0.29	2.05

Inspection of caulking 1





Based on Current Demand

THROUGHPUT
14.20 (windows/Day)

BOTTLENECK RATE
16.90 (windows/undefined)

BOTTLENECK UTILIZATION
84.02 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
39.27 (windows)

MIN CYCLE TIME
2.77 (Days) | **22.13** (Hours)

PUSH WIP
95.68 (windows)

PUSH CYCLE TIME
6.74 (Days) | **53.90** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.30 (windows/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
7.69 %

Cycle Time Analysis ▲

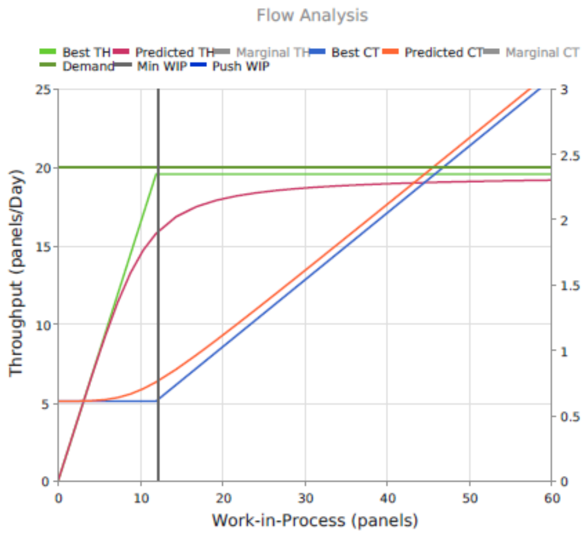
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	95.68	14.20	6.74	43.80	5.00	38.80	0.00	0.00	0.00

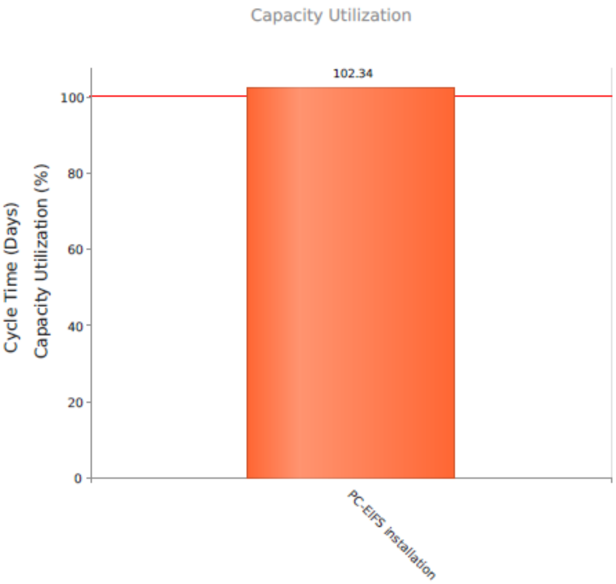
	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	4.01	6.74	35.12	100.00	30.00	6.74	43.80	5.00	38.80	0.00	0.00	0.00	11.42	88.58	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	84.02	0.57	2.40	2.50	19.40	24.57	95.68

Results sheets of the B5 production system based on D=20 EFIS panels.

EIFS panels installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
20.00 (panels/Day)	**19.54** (panels/undefined)	**102.34 %**	**0.18** (Days)

MIN WIP	MIN CYCLE TIME
12.20 (panels)	**0.61** (Days) | **4.88** (Hours)

PUSH WIP	PUSH CYCLE TIME
0.00 (panels)	**Infinity | Infinity**

Based on CONWIP Level of 18 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
17.69 (panels/Day)	**6.61** (Hours)	**18.00** (panels)	**90.53 %**

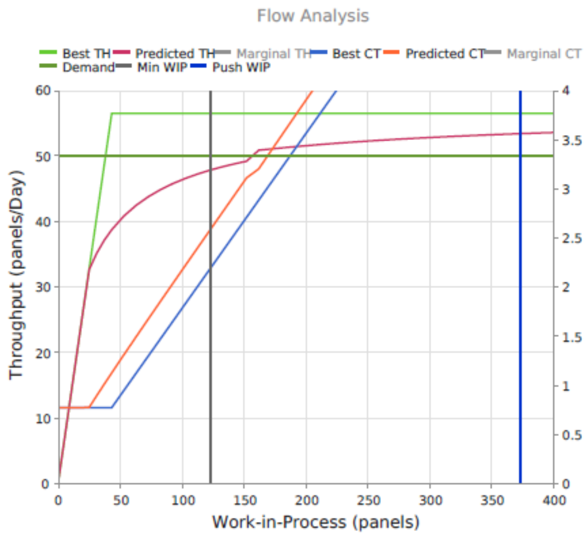
Cycle Time Analysis ▴

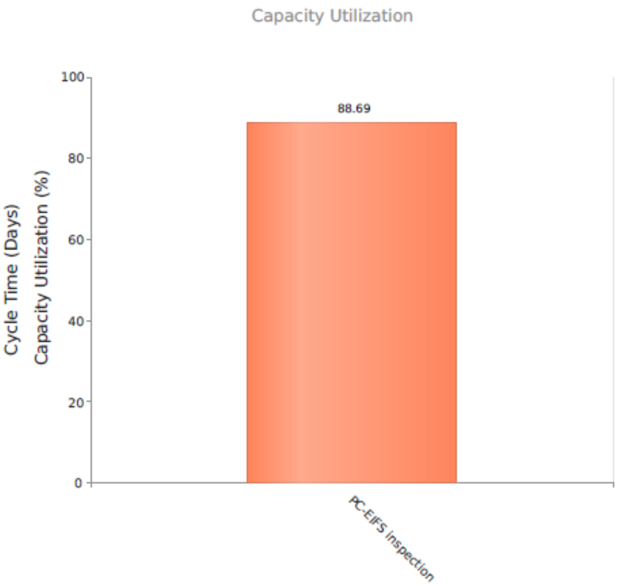
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	17.69	1.02	Infinity	20.00	Infinity	Infinity	1.17	Infinity	2.80	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00		Infinity	Infinity	50.00	30.00	1,250,000.00	Infinity	1.17	Infinity	2.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	102.34	0.01	0.33	1.77	Infinity	Infinity	Infinity
PC-Transportation EIFS panels	3	0.00	0.88	5.66	1.98	0.00	0.00	20.51

EIFS panels inspection





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
50.00 (panels/Day)	**56.37** (panels/undefined)	**88.69 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
123.32 (panels)	**2.47** (Days) | **19.73** (Hours)

PUSH WIP	PUSH CYCLE TIME
374.29 (panels)	**7.49** (Days) | **59.89** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (panels/Day)	**5.00** (Hours)	**1.00** (panels)	**2.31 %**

Cycle Time Analysis ▲

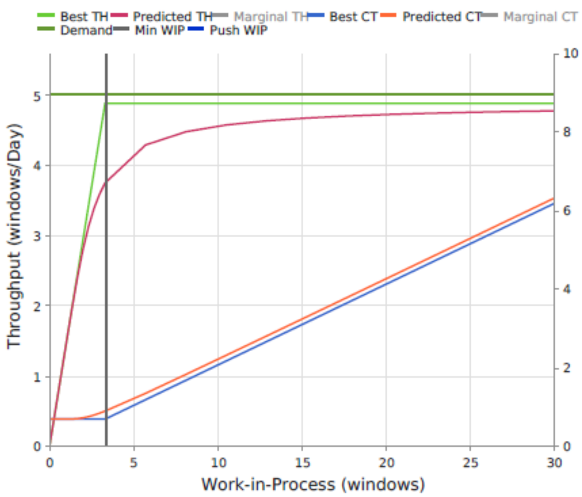
Product Flow	CONWIP			PUSH								
	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	374.29	50.00	7.49	48.66	5.00	43.66	0.00	0.00	0.00

Item	CONWIP		PUSH															
	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	3.84	7.49	37.41	100.00	30.00	7.49	48.66	5.00	43.66	0.00	0.00	0.00	10.28	89.72	0.00	0.00	0.00

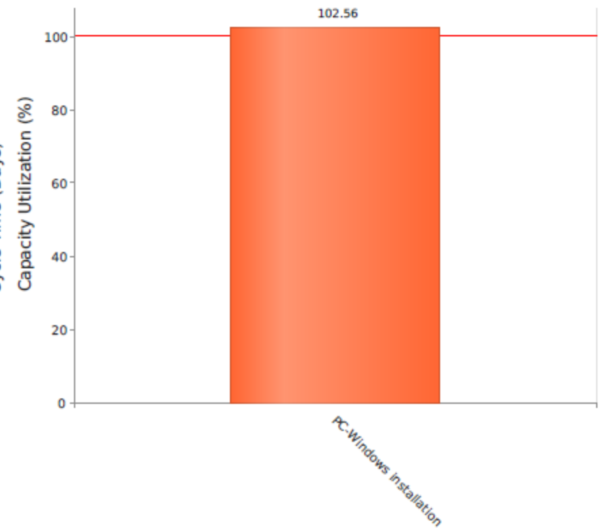
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	88.69	0.35	2.88	1.74	21.83	26.21	444.54

Windows installation

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT
5.00 (windows/Day)

BOTTLENECK RATE
4.87 (windows/undefined)

BOTTLENECK UTILIZATION
102.56 %

RAW PROCESS TIME
0.21 (Days)

MIN WIP
3.38 (windows)

MIN CYCLE TIME
0.68 (Days) | **5.42** (Hours)

PUSH WIP
0.00 (windows)

PUSH CYCLE TIME
Infinity | Infinity

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.48 (windows/Day)

CYCLE TIME
4.40 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
30.39 %

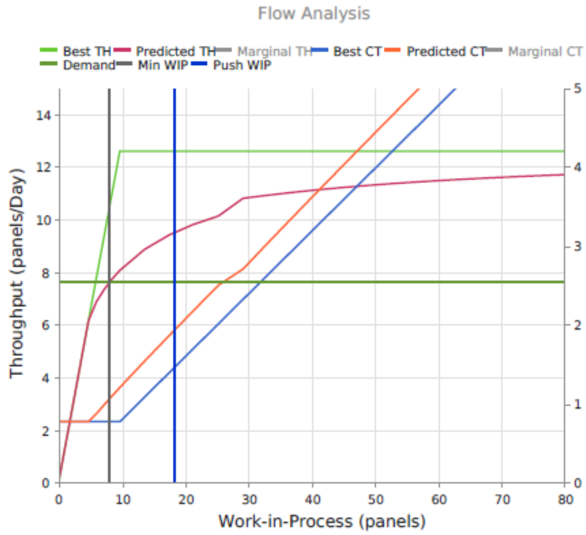
Cycle Time Analysis ▲

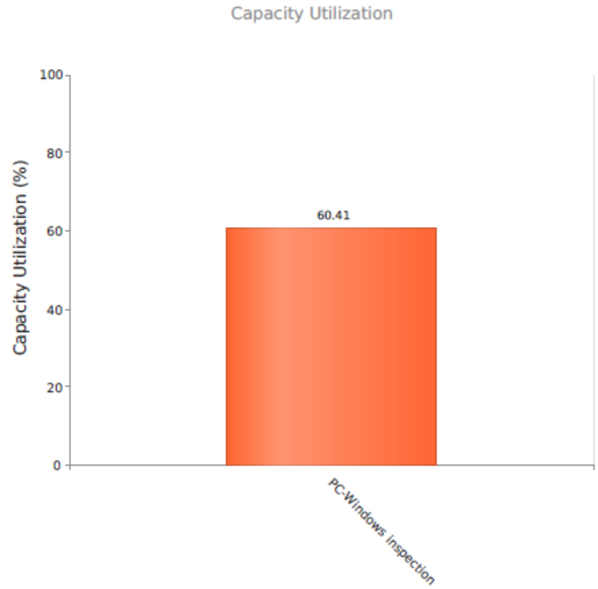
Product Flow	CONWIP			PUSH								
	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	Infinity	5.00	Infinity	Infinity	1.33	Infinity	3.07	0.00	0.00

Item	CONWIP		PUSH															
	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40		Infinity	Infinity	50.00	30.00	1,250,000.00	Infinity	1.33	Infinity	3.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	102.56	0.01	0.50	3.33	Infinity	Infinity	Infinity

Windows inspection





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
7.60 (panels/Day)	**12.58** (panels/undefined)	**60.41 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
8.04 (panels)	**1.06** (Days) | **8.46** (Hours)

PUSH WIP	PUSH CYCLE TIME
18.42 (panels)	**2.42** (Days) | **19.39** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (panels/Day)	**5.00** (Hours)	**1.00** (panels)	**10.33 %**

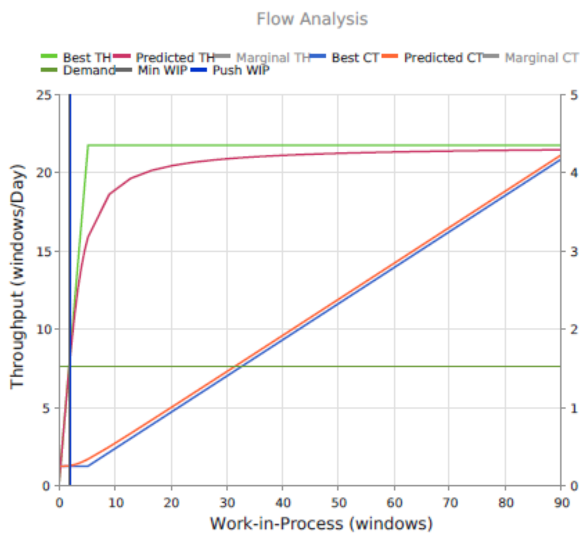
Cycle Time Analysis ▲

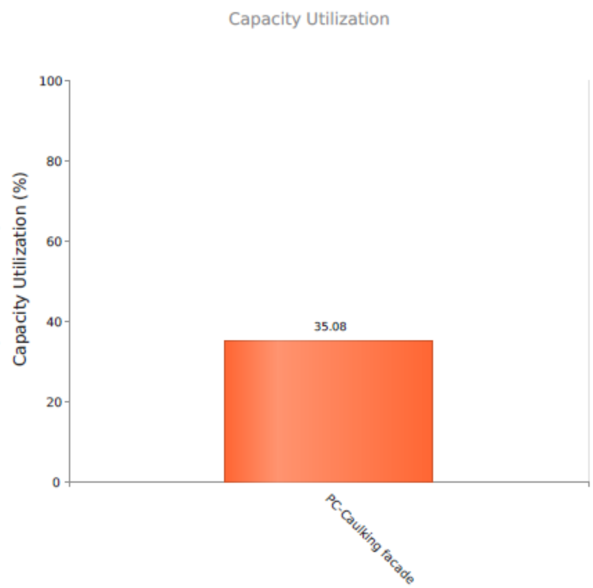
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	18.42	7.60	2.42	15.76	5.00	10.76	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	4.50	2.42	14.18	100.00	30.00	2.42	15.76	5.00	10.76	0.00	0.00	0.00	31.73	68.27	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	60.41	0.86	2.79	1.94	5.38	9.37	25.88

Development of caulking 1





Based on Current Demand

THROUGHPUT
7.60 (windows/Day)

BOTTLENECK RATE
21.67 (windows/undefined)

BOTTLENECK UTILIZATION
35.08 %

RAW PROCESS TIME
0.08 (Days)

MIN WIP
1.87 (windows)

MIN CYCLE TIME
0.25 (Days) | **1.97** (Hours)

PUSH WIP
2.00 (windows)

PUSH CYCLE TIME
0.26 (Days) | **2.10** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
4.15 (windows/Day)

CYCLE TIME
1.57 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
19.15 %

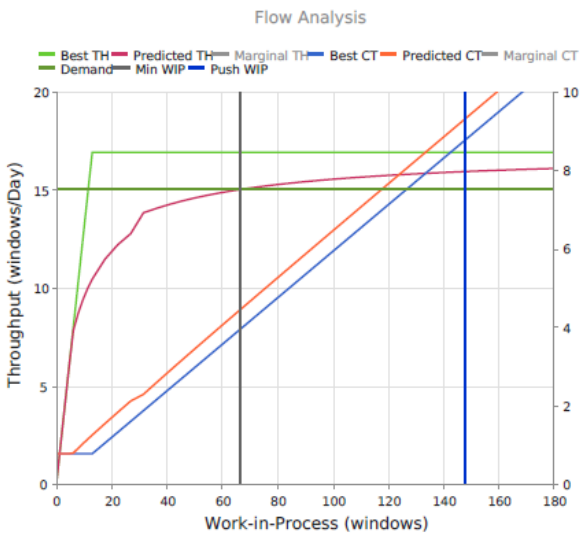
Cycle Time Analysis ▲

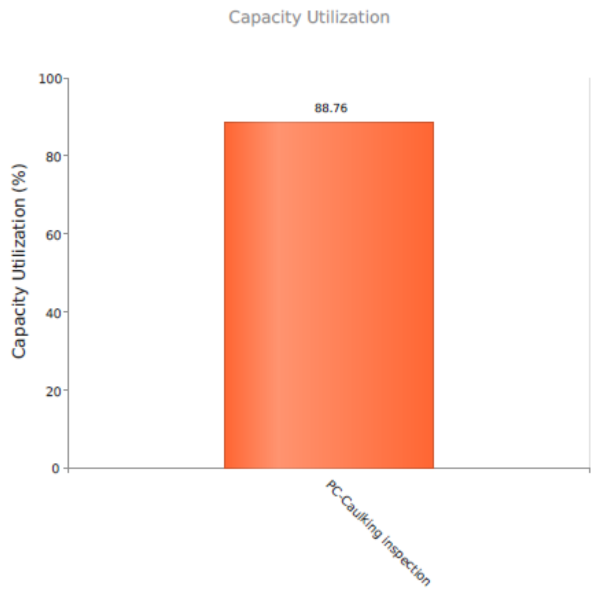
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	2.00	7.60	0.26	1.71	0.50	0.14	1.07	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.33	0.26	1.45	100.00	30.00	0.26	1.71	0.50	0.14	1.07	0.00	0.00	29.26	8.32	62.42	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	35.08	0.59	2.61	0.43	0.07	0.31	2.20

Inspection of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
15.00 (windows/Day)	**16.90** (windows/undefined)	**88.76 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
66.47 (windows)	**4.43** (Days) | **35.45** (Hours)

PUSH WIP	PUSH CYCLE TIME
148.10 (windows)	**9.87** (Days) | **78.99** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (windows/Day)	**5.00** (Hours)	**1.00** (windows)	**7.69 %**

Cycle Time Analysis ▲

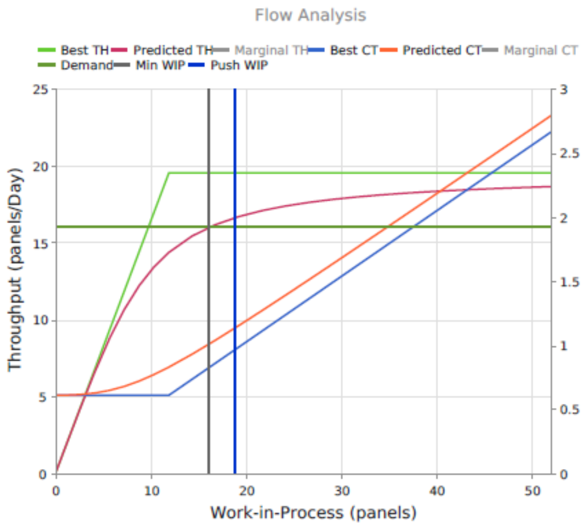
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	148.10	15.00	9.87	64.18	5.00	59.18	0.00	0.00	0.00

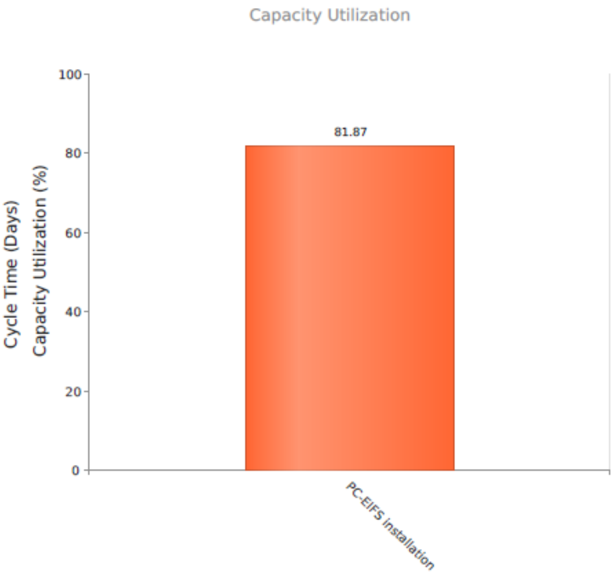
	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	3.87	9.87	49.65	99.58	30.00	9.87	64.18	5.00	59.18	0.00	0.00	0.00	7.79	92.21	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	88.76	0.61	2.40	2.50	29.59	34.93	148.10

Results sheets of the C1 production system based on changes in batch size (C1 reduced TB to half).

EIFS panels installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
16.00 (panels/Day)	**19.54** (panels/undefined)	**81.87 %**	**0.18** (Days)

MIN WIP	MIN CYCLE TIME
16.15 (panels)	**1.01** (Days) | **8.08** (Hours)

PUSH WIP	PUSH CYCLE TIME
18.85 (panels)	**1.18** (Days) | **9.42** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
16.45 (panels/Day)	**7.11** (Hours)	**18.00** (panels)	**84.19 %**

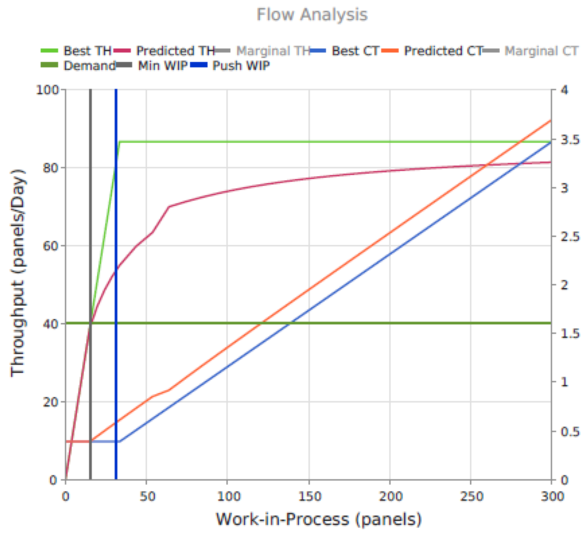
Cycle Time Analysis ▲

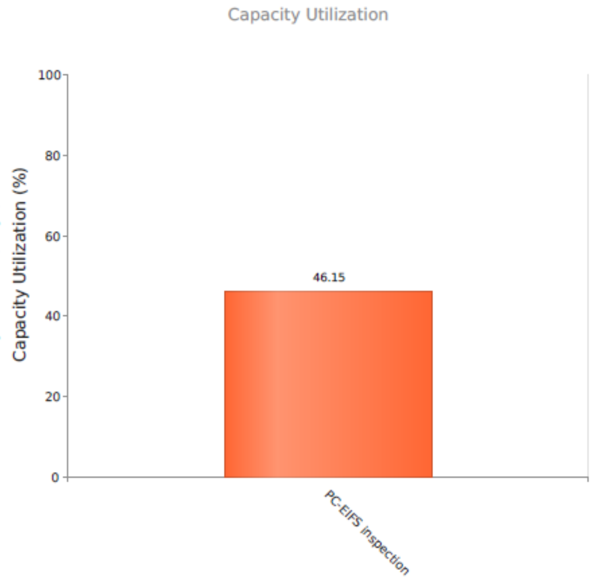
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	16.45	1.09	18.85	16.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	3.69	1.18	3.97	100.00	30.00	1.18	7.66	1.17	3.69	2.80	0.00	0.00	15.22	48.23	36.55	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	81.87	0.39	0.33	1.77	1.23	1.81	17.62
PC-Transportation EIFS panels	3	0.00	0.88	5.78	1.96	0.00	0.00	16.25

EIFS panels inspection





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
40.00 (panels/Day)	**86.67** (panels/undefined)	**46.15 %**	**0.38** (Days)

MIN WIP	MIN CYCLE TIME
15.74 (panels)	**0.39** (Days) | **3.15** (Hours)

PUSH WIP	PUSH CYCLE TIME
31.39 (panels)	**0.78** (Days) | **6.28** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
2.60 (panels/Day)	**2.50** (Hours)	**1.00** (panels)	**3.00 %**

Cycle Time Analysis ▴

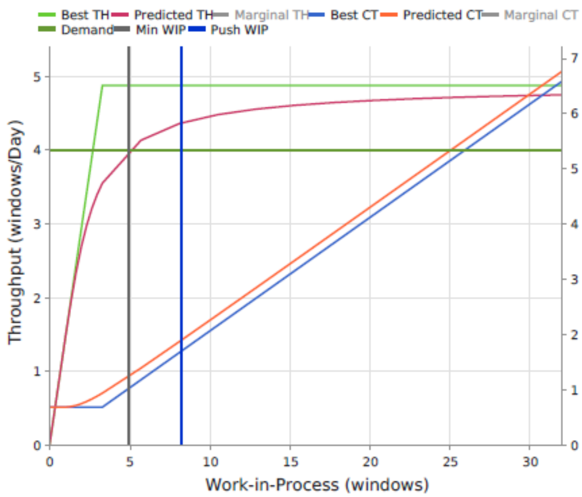
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	2.60	0.38	31.39	40.00	0.78	5.10	2.50	2.60	0.00	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	2.32	0.78	4.74	100.00	30.00	0.78	5.10	2.50	2.60	0.00	0.00	0.00	49.01	50.99	0.00	0.00	0.00

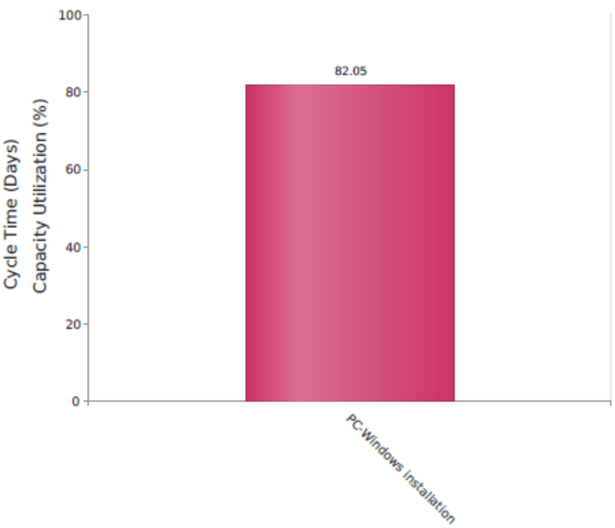
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	46.15	0.69	2.09	1.13	1.30	2.84	37.05

Windows installation

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
4.00 (windows/Day)	**4.87** (windows/undefined)	**82.05 %**	**0.21** (Days)

MIN WIP	MIN CYCLE TIME
4.90 (windows)	**1.23** (Days) | **9.81** (Hours)

PUSH WIP	PUSH CYCLE TIME
8.22 (windows)	**2.06** (Days) | **16.45** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.48 (windows/Day)	**4.40** (Hours)	**1.00** (windows)	**30.39 %**

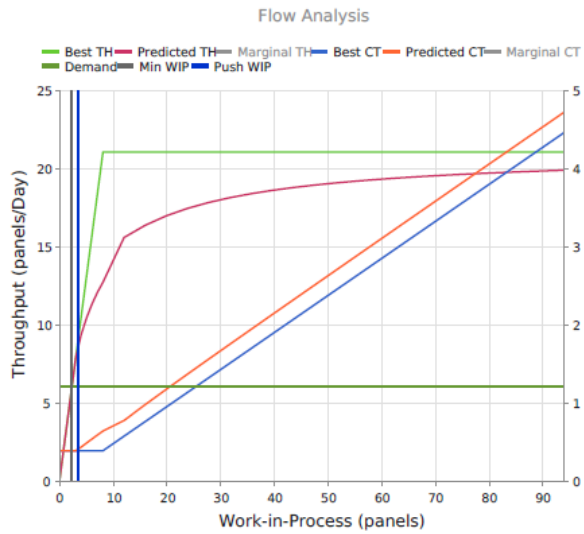
Cycle Time Analysis ▲

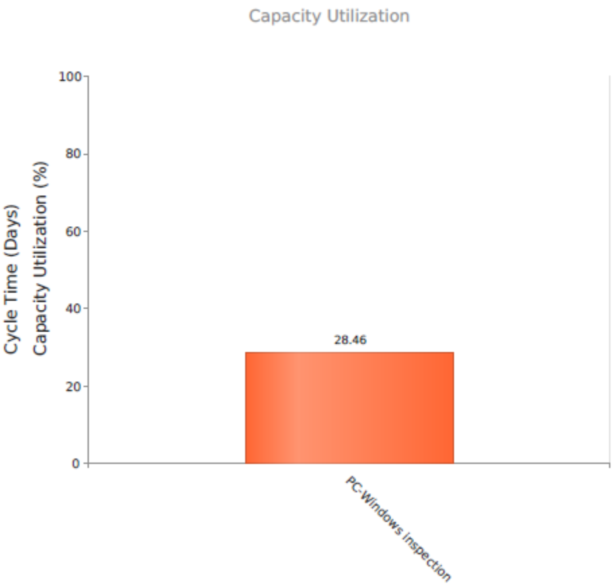
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.48	0.68	8.22	4.00	2.06	13.36	1.33	8.96	3.07	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	4.40	3.05	2.06	9.28	100.00	30.00	2.06	13.36	1.33	8.96	3.07	0.00	0.00	9.98	67.08	22.95	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	82.05	0.18	0.50	3.33	4.48	6.12	8.22

Windows inspection





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
6.00 (panels/Day)	**21.08** (panels/undefined)	**28.46 %**	**0.38** (Days)

MIN WIP	MIN CYCLE TIME
2.31 (panels)	**0.38** (Days) | **3.08** (Hours)

PUSH WIP	PUSH CYCLE TIME
3.59 (panels)	**0.60** (Days) | **4.79** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
2.60 (panels/Day)	**2.50** (Hours)	**1.00** (panels)	**12.33 %**

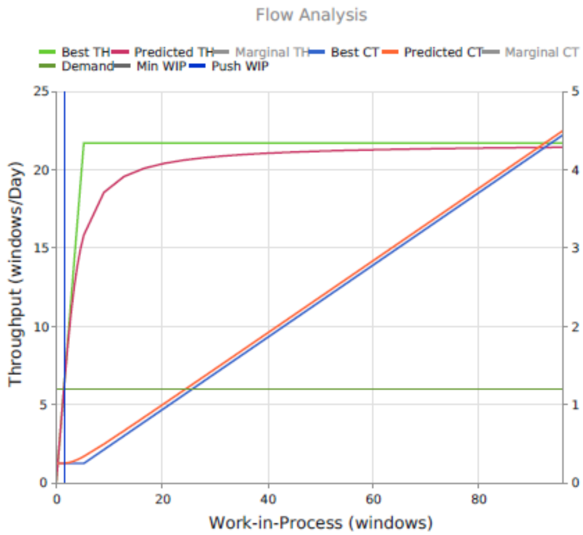
Cycle Time Analysis ▲

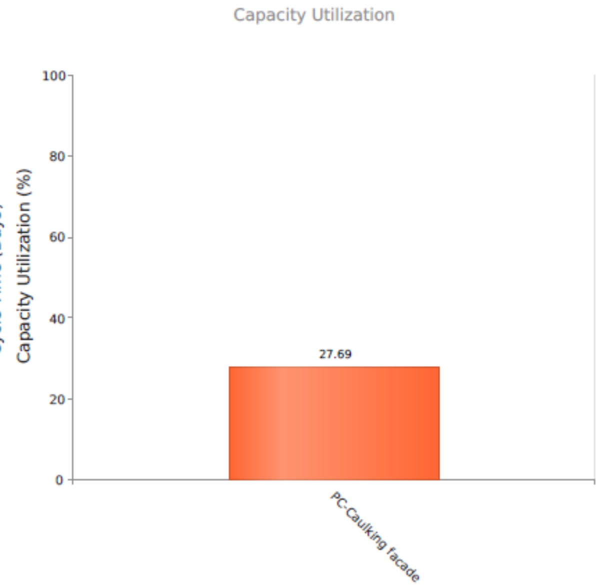
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	2.60	0.38	3.59	6.00	0.60	3.89	2.50	1.39	0.00	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	2.45	0.60	3.82	100.00	30.00	0.60	3.89	2.50	1.39	0.00	0.00	0.00	64.21	35.79	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	28.46	0.87	2.18	1.16	0.70	2.03	5.16

Development of caulking 1





Based on Current Demand

THROUGHPUT
6.00 (windows/Day)

BOTTLENECK RATE
21.67 (windows/undefined)

BOTTLENECK UTILIZATION
27.69 %

RAW PROCESS TIME
0.08 (Days)

MIN WIP
1.46 (windows)

MIN CYCLE TIME
0.24 (Days) | **1.94** (Hours)

PUSH WIP
1.52 (windows)

PUSH CYCLE TIME
0.25 (Days) | **2.03** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
4.15 (windows/Day)

CYCLE TIME
1.57 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
19.15 %

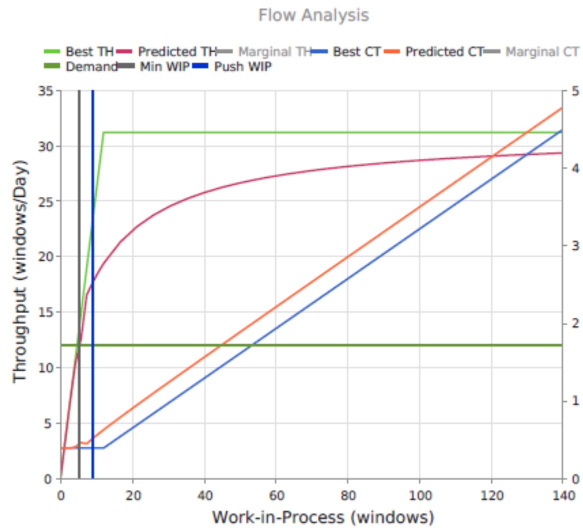
Cycle Time Analysis ▲

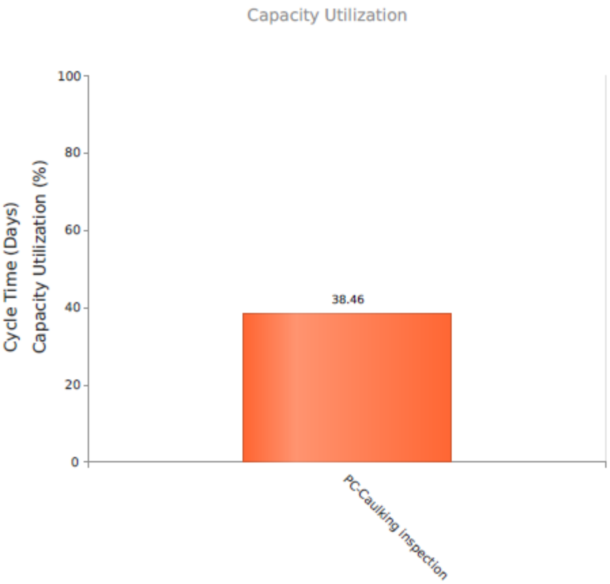
Product Flow	CONWIP			PUSH								
	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	4.15	0.24	1.52	6.00	0.25	1.65	0.50	0.08	1.07	0.00	0.00

Item	CONWIP		PUSH															
	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.35	0.25	1.42	100.00	30.00	0.25	1.65	0.50	0.08	1.07	0.00	0.00	30.30	5.05	64.65	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	27.69	0.64	2.61	0.43	0.04	0.23	1.65

Inspection of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
12.00 (windows/Day)	**31.20** (windows/undefined)	**38.46 %**	**0.38** (Days)

MIN WIP	MIN CYCLE TIME
5.29 (windows)	**0.44** (Days) | **3.53** (Hours)

PUSH WIP	PUSH CYCLE TIME
8.82 (windows)	**0.74** (Days) | **5.88** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
2.60 (windows/Day)	**2.50** (Hours)	**1.00** (windows)	**8.33 %**

Cycle Time Analysis ▲

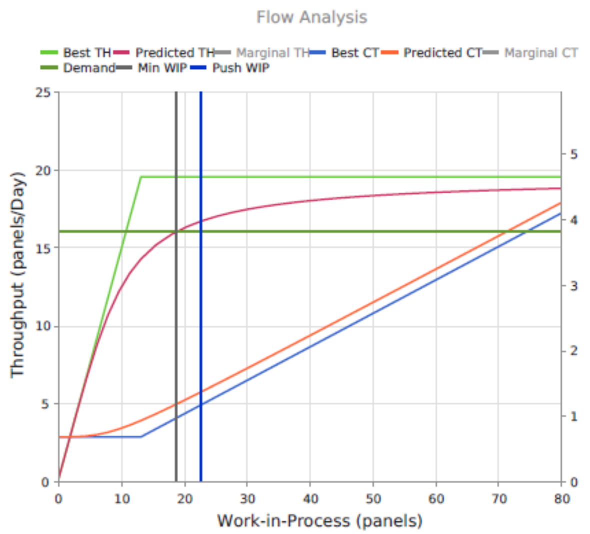
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	2.60	0.38	8.82	12.00	0.74	4.78	2.50	2.28	0.00	0.00	0.00

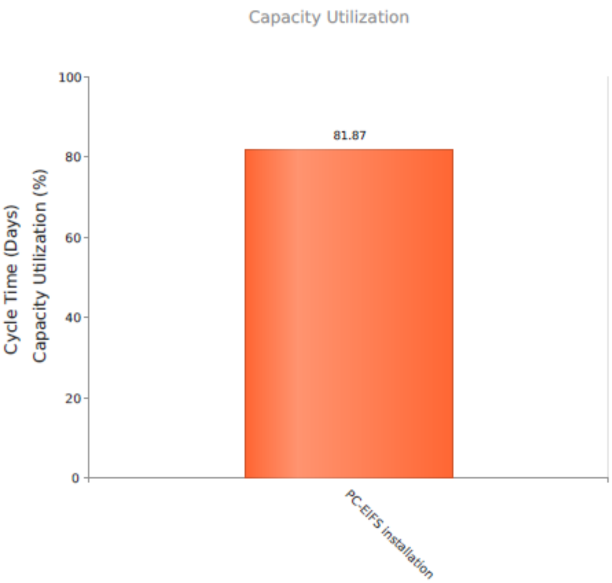
	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	2.54	0.74	4.85	100.00	30.00	0.74	4.78	2.50	2.28	0.00	0.00	0.00	52.31	47.69	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	38.46	0.65	2.40	1.25	1.14	2.93	8.82

Results sheets of the C2 production system based on changes in batch size (C2 doubled TB).

EIFS panels installation





Based on Current Demand

THROUGHPUT
16.00 (panels/Day)

BOTTLENECK RATE
19.54 (panels/undefined)

BOTTLENECK UTILIZATION
81.87 %

RAW PROCESS TIME
0.28 (Days)

MIN WIP
18.76 (panels)

MIN CYCLE TIME
1.17 (Days) | **9.38** (Hours)

PUSH WIP
22.68 (panels)

PUSH CYCLE TIME
1.42 (Days) | **11.34** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT
15.83 (panels/Day)

CYCLE TIME
7.39 (Hours)

WIP LEVEL
18.00 (panels)

BOTTLENECK UTILIZATION
81.01 %

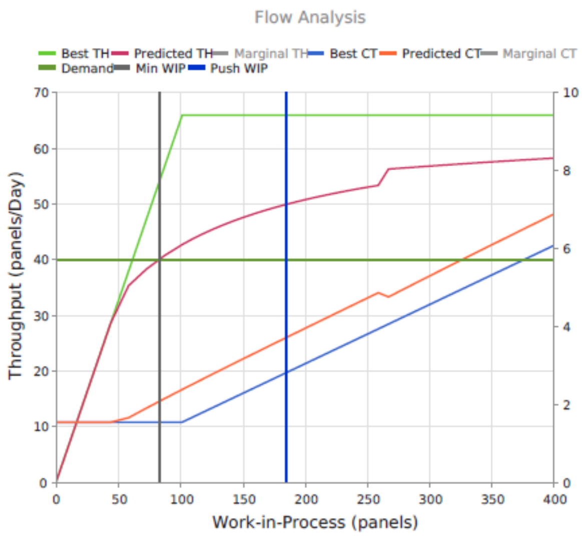
Cycle Time Analysis ▲

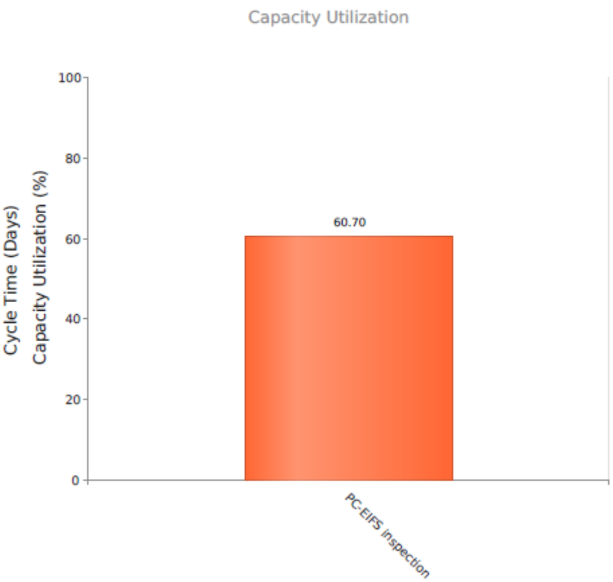
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	15.83	1.14	22.68	16.00	1.42	9.21	1.83	4.82	2.56	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	3.86	1.42	4.81	100.00	30.00	1.42	9.21	1.83	4.82	2.56	0.00	0.00	19.87	52.31	27.82	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	81.87	0.44	0.54	1.77	1.61	2.30	21.44
PC-Transportation EIFS panels	3	0.00	0.84	8.78	2.72	0.00	0.00	31.02

EIFS panels inspection





Based on Current Demand

THROUGHPUT **40.00** (panels/Day)
BOTTLENECK RATE **65.90** (panels/undefined)
BOTTLENECK UTILIZATION **60.70 %**
RAW PROCESS TIME **1.54** (Days)

MIN WIP **82.76** (panels)
MIN CYCLE TIME **2.07** (Days) | **16.55** (Hours)

PUSH WIP **185.50** (panels)
PUSH CYCLE TIME **4.64** (Days) | **37.10** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT **0.65** (panels/Day)
CYCLE TIME **10.00** (Hours)
WIP LEVEL **1.00** (panels)
BOTTLENECK UTILIZATION **0.99 %**

Cycle Time Analysis ▲

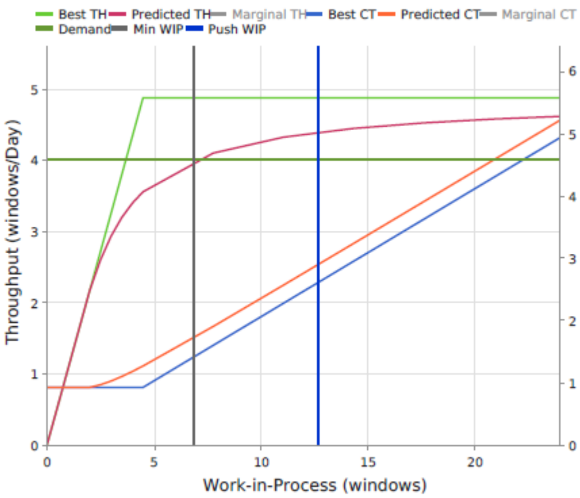
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	0.65	1.54	185.50	40.00	4.64	30.14	10.00	20.14	0.00	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	9.38	4.64	28.26	100.00	30.00	4.64	30.14	10.00	20.14	0.00	0.00	0.00	33.17	66.83	0.00	0.00	0.00

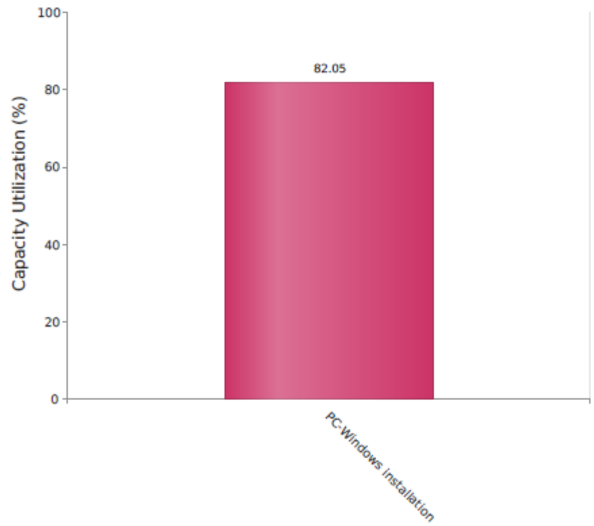
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	60.70	0.57	3.88	2.98	10.07	18.67	212.76

Windows installation

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
4.00 (windows/Day)	**4.87** (windows/undefined)	**82.05 %**	**0.41** (Days)

MIN WIP	MIN CYCLE TIME
6.89 (windows)	**1.72** (Days) | **13.78** (Hours)

PUSH WIP	PUSH CYCLE TIME
12.70 (windows)	**3.17** (Days) | **25.40** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.08 (windows/Day)	**6.00** (Hours)	**1.00** (windows)	**22.18 %**

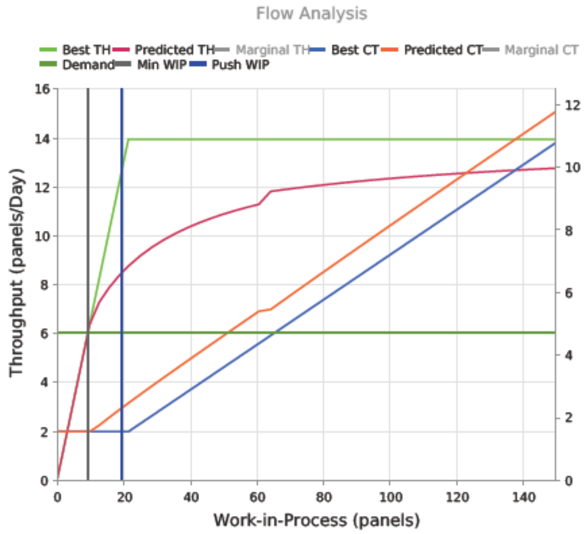
Cycle Time Analysis ▲

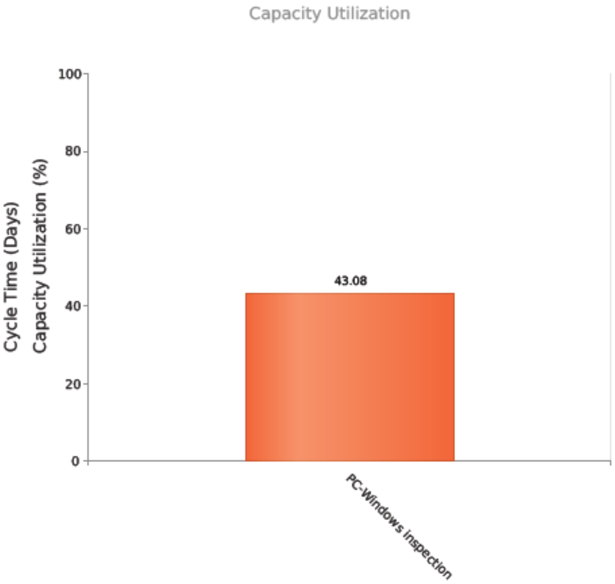
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	1.08	0.92	12.70	4.00	3.17	20.64	2.67	14.64	3.33	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	6.00	4.18	3.17	14.38	100.00	30.00	3.17	20.64	2.67	14.64	3.33	0.00	0.00	12.92	70.92	16.15	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	82.05	0.22	0.67	4.00	7.32	9.73	12.70

Windows inspection





Based on Current Demand

THROUGHPUT
6.00 (panels/Day)

BOTTLENECK RATE
13.93 (panels/undefined)

BOTTLENECK UTILIZATION
43.08 %

RAW PROCESS TIME
1.54 (Days)

MIN WIP
9.23 (panels)

MIN CYCLE TIME
1.54 (Days) | **12.31** (Hours)

PUSH WIP
19.33 (panels)

PUSH CYCLE TIME
3.22 (Days) | **25.78** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT
0.65 (panels/Day)

CYCLE TIME
10.00 (Hours)

WIP LEVEL
1.00 (panels)

BOTTLENECK UTILIZATION
4.67 %

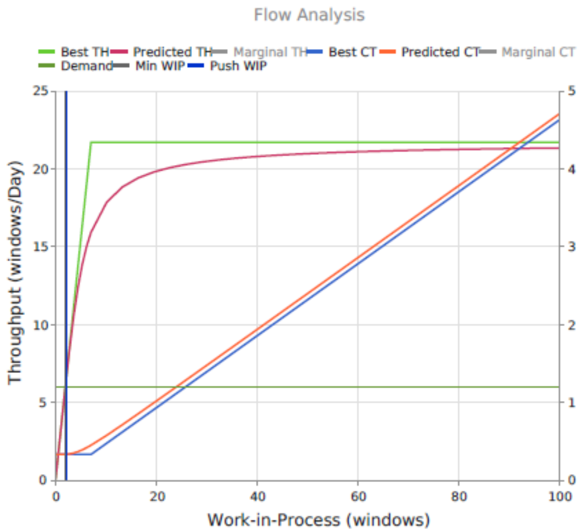
Cycle Time Analysis ▲

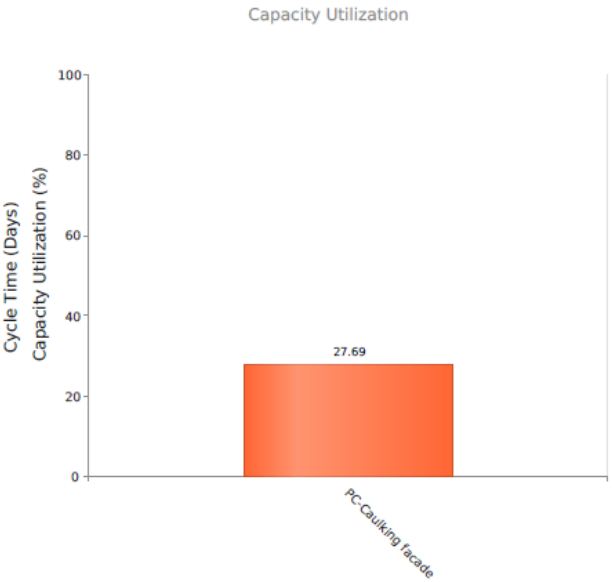
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	0.65	1.54	19.33	6.00	3.22	20.94	10.00	10.94	0.00	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	9.99	3.22	20.92	100.00	30.00	3.22	20.94	10.00	10.94	0.00	0.00	0.00	47.75	52.25	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	43.08	0.77	3.41	3.50	5.47	12.96	25.31

Development of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
6.00 (windows/Day)	**21.67** (windows/undefined)	**27.69 %**	**0.15** (Days)

MIN WIP	MIN CYCLE TIME
1.95 (windows)	**0.32** (Days) | **2.60** (Hours)

PUSH WIP	PUSH CYCLE TIME
2.07 (windows)	**0.34** (Days) | **2.76** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
3.08 (windows/Day)	**2.11** (Hours)	**1.00** (windows)	**14.21 %**

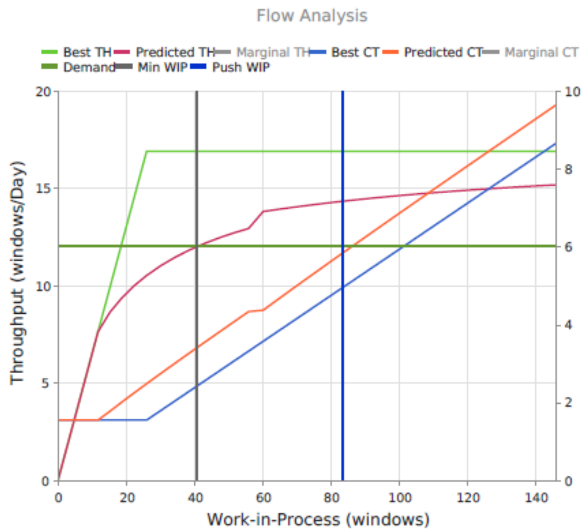
Cycle Time Analysis ▲

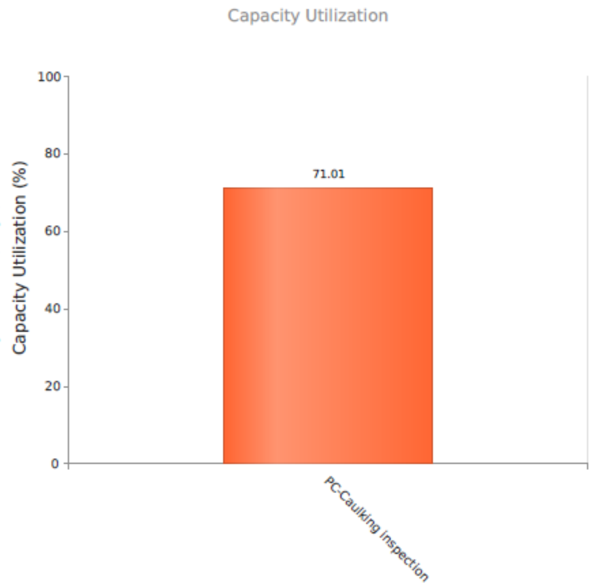
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	3.08	0.32	2.07	6.00	0.34	2.24	1.00	0.13	1.11	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	1.80	0.34	1.91	100.00	30.00	0.34	2.24	1.00	0.13	1.11	0.00	0.00	44.65	5.75	49.61	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	27.69	0.73	2.01	0.72	0.06	0.32	2.31

Inspection of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
12.00 (windows/Day)	**16.90** (windows/undefined)	**71.01 %**	**1.54** (Days)

MIN WIP	MIN CYCLE TIME
40.85 (windows)	**3.40** (Days) | **27.23** (Hours)

PUSH WIP	PUSH CYCLE TIME
83.49 (windows)	**6.96** (Days) | **55.66** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
0.65 (windows/Day)	**10.00** (Hours)	**1.00** (windows)	**3.85 %**

Cycle Time Analysis ▲

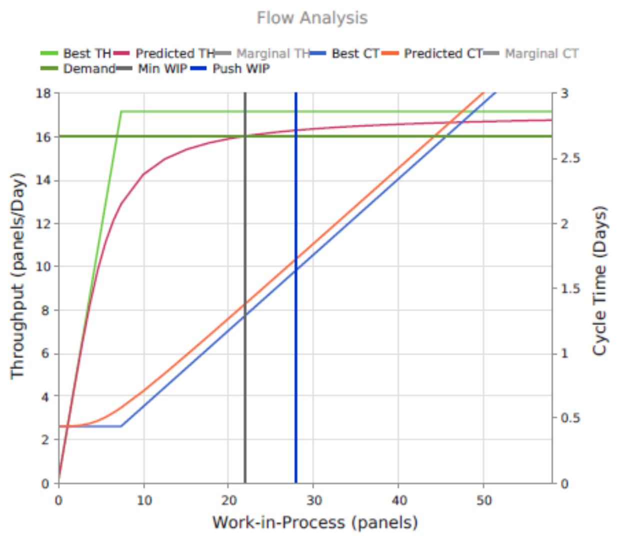
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	0.65	1.54	83.49	12.00	6.96	45.22	10.00	35.22	0.00	0.00	0.00

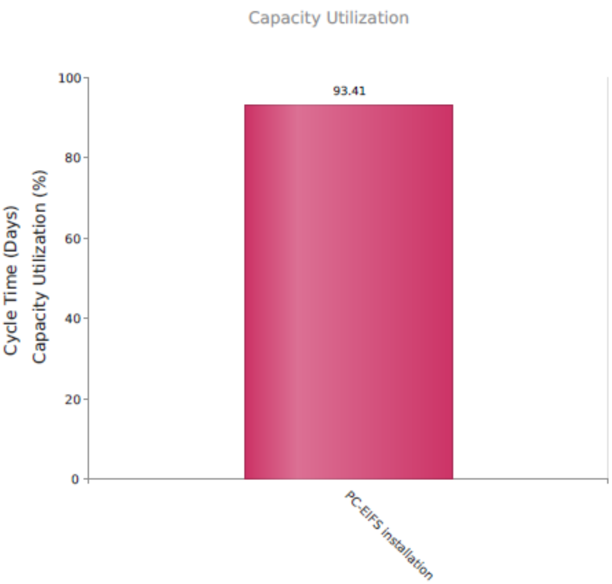
	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	8.77	6.96	39.68	99.99	30.00	6.96	45.22	10.00	35.22	0.00	0.00	0.00	22.11	77.89	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	71.01	0.53	2.40	5.00	17.61	27.13	83.49

Results sheets of the E1 production system based on changes in batch size (E1 reduced PB to half).

EIFS panels installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
16.00 (panels/Day)	**17.13** (panels/undefined)	**93.41 %**	**0.19** (Days)

MIN WIP	MIN CYCLE TIME
22.01 (panels)	**1.38** (Days) | **11.00** (Hours)

PUSH WIP	PUSH CYCLE TIME
27.98 (panels)	**1.75** (Days) | **13.99** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
15.71 (panels/Day)	**7.45** (Hours)	**18.00** (panels)	**91.71 %**

Cycle Time Analysis ▴

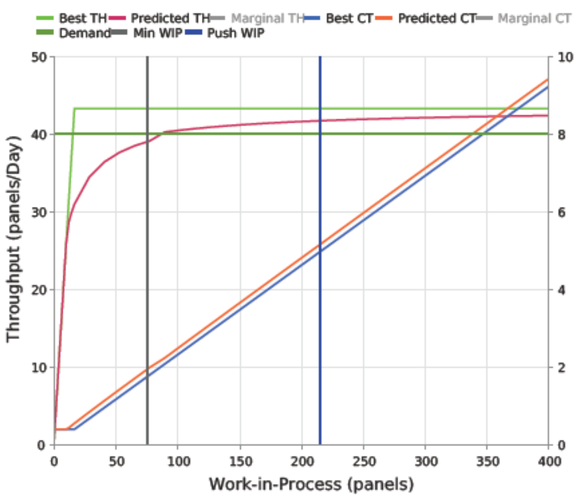
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	15.71	1.15	27.98	16.00	1.75	11.37	1.26	8.55	1.56	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	3.86	1.75	5.89	100.00	30.00	1.75	11.37	1.26	8.55	1.56	0.00	0.00	11.07	75.18	13.74	0.00	0.00

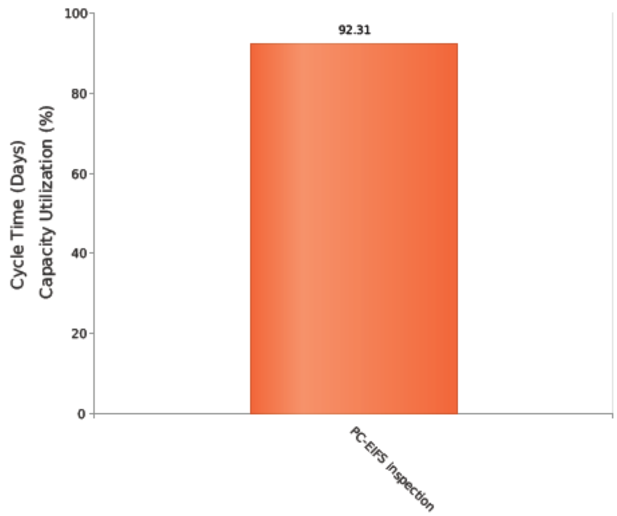
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	93.41	0.37	0.48	1.01	2.85	3.29	26.75
PC-Transportation EIFS panels	3	0.00	0.88	5.78	1.96	0.00	0.00	16.25

EIFS panels inspection

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
40.00 (panels/Day)	**43.33** (panels/undefined)	**92.31 %**	**0.38** (Days)

MIN WIP	MIN CYCLE TIME
75.91 (panels)	**1.90** (Days) | **15.18** (Hours)

PUSH WIP	PUSH CYCLE TIME
215.53 (panels)	**5.39** (Days) | **43.11** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
2.60 (panels/Day)	**2.50** (Hours)	**1.00** (panels)	**6.00 %**

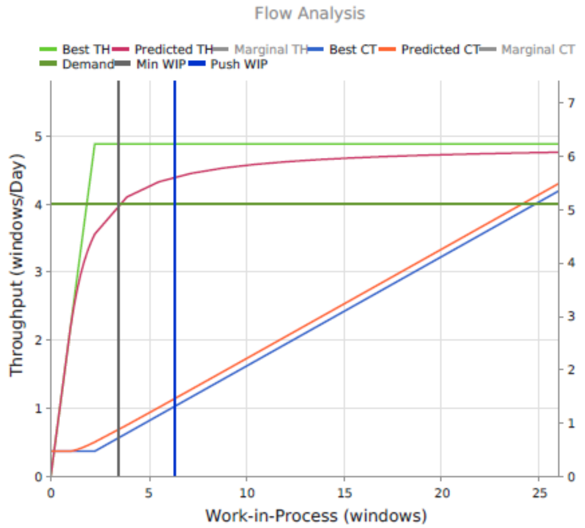
Cycle Time Analysis ▲

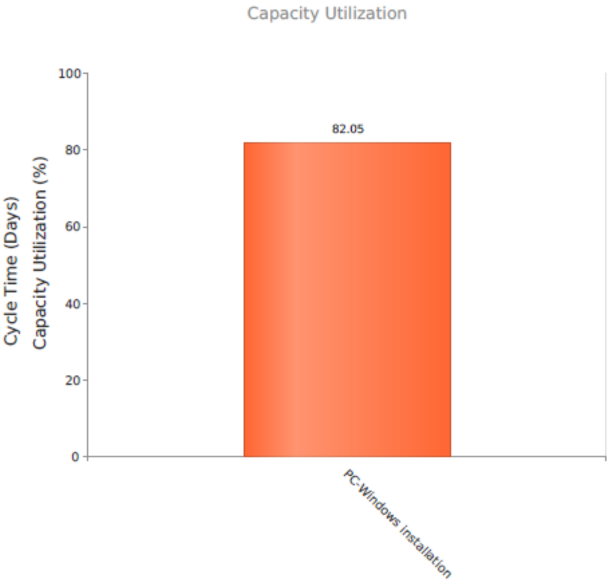
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	2.60	0.38	215.53	40.00	5.39	35.02	2.50	32.52	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	1.86	5.39	26.04	100.00	30.00	5.39	35.02	2.50	32.52	0.00	0.00	0.00	7.14	92.86	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	92.31	0.35	2.09	1.13	16.26	18.32	258.02

Windows installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
4.00 (windows/Day)	**4.87** (windows/undefined)	**82.05 %**	**0.21** (Days)

MIN WIP	MIN CYCLE TIME
3.46 (windows)	**0.86** (Days) | **6.92** (Hours)

PUSH WIP	PUSH CYCLE TIME
6.38 (windows)	**1.60** (Days) | **12.76** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
2.17 (windows/Day)	**3.00** (Hours)	**1.00** (windows)	**44.56 %**

Cycle Time Analysis ▲

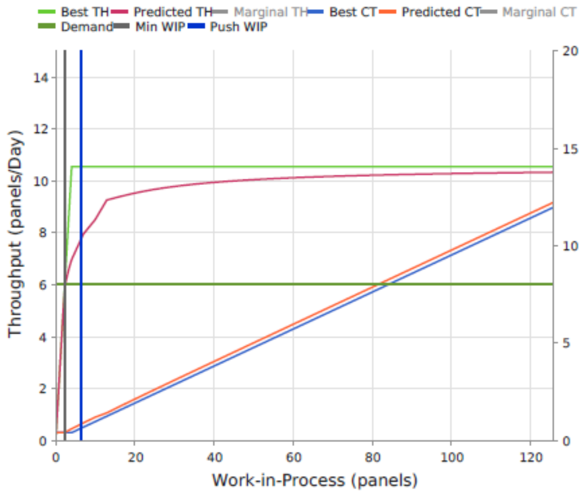
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	2.17	0.46	6.38	4.00	1.60	10.37	1.33	7.37	1.67	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	3.00	2.09	1.60	7.23	100.00	30.00	1.60	10.37	1.33	7.37	1.67	0.00	0.00	12.86	71.07	16.07	0.00	0.00

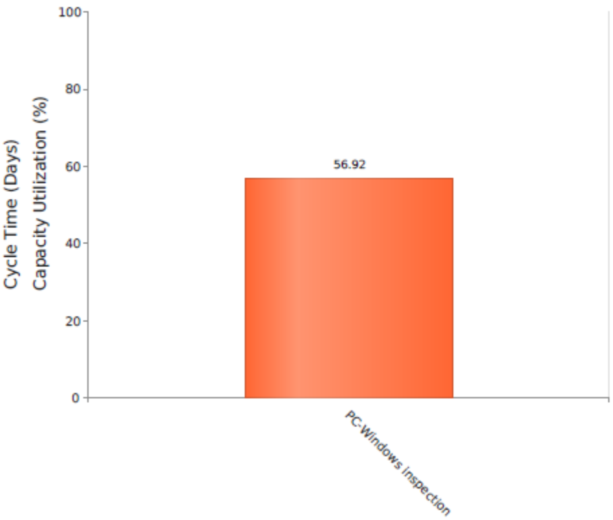
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	82.05	0.22	0.67	2.00	3.69	4.89	6.38

Windows inspection

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
6.00 (panels/Day)	**10.54** (panels/undefined)	**56.92 %**	**0.38** (Days)

MIN WIP	MIN CYCLE TIME
2.46 (panels)	**0.41** (Days) | **3.28** (Hours)

PUSH WIP	PUSH CYCLE TIME
6.47 (panels)	**1.08** (Days) | **8.63** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
2.60 (panels/Day)	**2.50** (Hours)	**1.00** (panels)	**24.67 %**

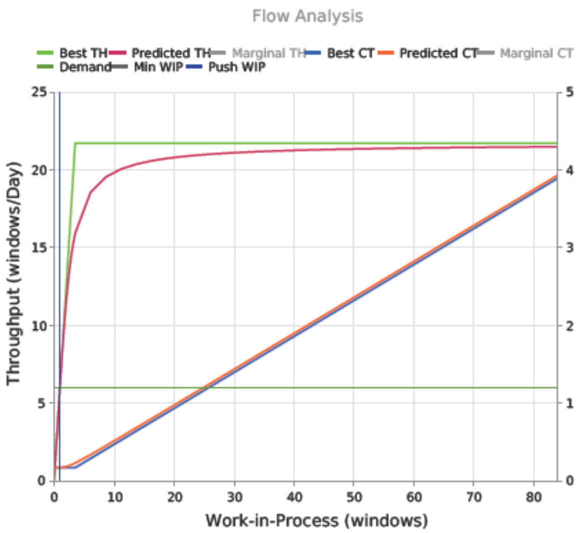
Cycle Time Analysis ▲

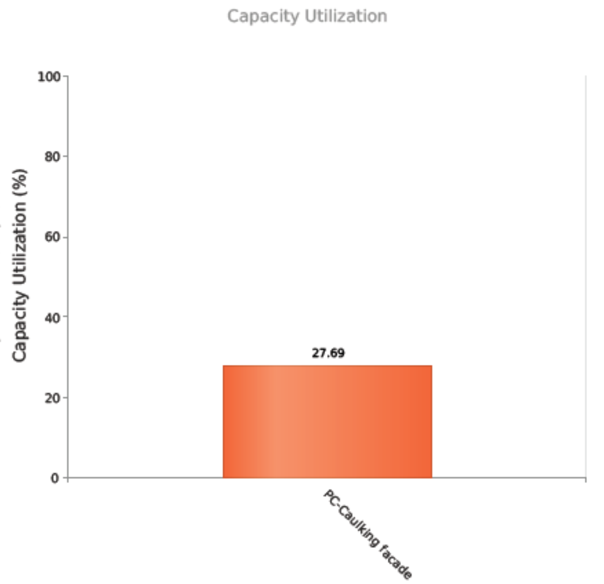
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows inspection	1.00	2.60	0.38	6.47	6.00	1.08	7.01	2.50	4.51	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows inspected	0.00	2.25	1.08	6.30	100.00	30.00	1.08	7.01	2.50	4.51	0.00	0.00	0.00	35.67	64.33	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	56.92	0.79	2.18	1.16	2.25	4.08	9.47

Development of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
6.00 (windows/Day)	**21.67** (windows/undefined)	**27.69 %**	**0.08** (Days)

MIN WIP	MIN CYCLE TIME
0.97 (windows)	**0.16** (Days) | **1.30** (Hours)

PUSH WIP	PUSH CYCLE TIME
1.03 (windows)	**0.17** (Days) | **1.38** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
6.16 (windows/Day)	**1.06** (Hours)	**1.00** (windows)	**28.43 %**

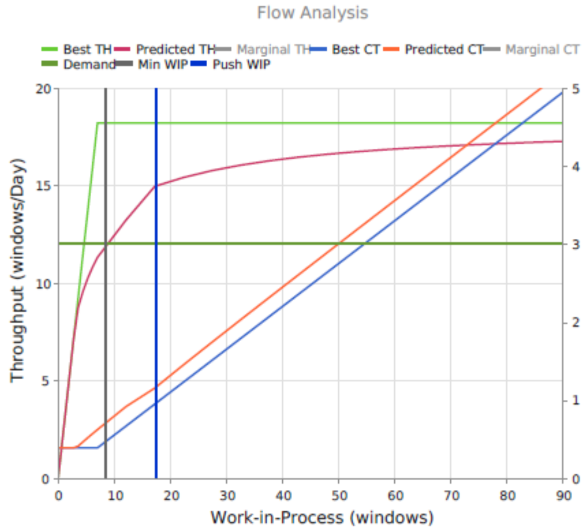
Cycle Time Analysis ▲

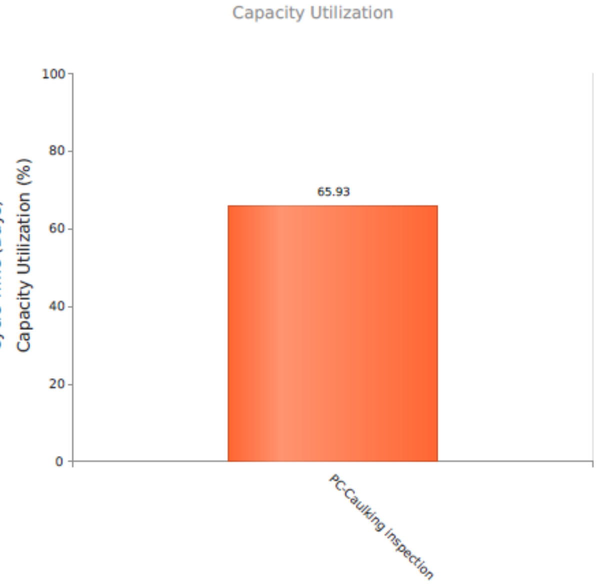
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	6.16	0.16	1.03	6.00	0.17	1.12	0.50	0.06	0.56	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	0.90	0.17	0.96	100.00	30.00	0.17	1.12	0.50	0.06	0.56	0.00	0.00	44.64	5.76	49.60	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	27.69	0.74	2.01	0.36	0.03	0.16	1.16

Inspection of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
12.00 (windows/Day)	**18.20** (windows/undefined)	**65.93 %**	**0.38** (Days)

MIN WIP	MIN CYCLE TIME
8.45 (windows)	**0.70** (Days) | **5.63** (Hours)

PUSH WIP	PUSH CYCLE TIME
17.43 (windows)	**1.45** (Days) | **11.62** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
2.60 (windows/Day)	**2.50** (Hours)	**1.00** (windows)	**14.29 %**

Cycle Time Analysis ▲

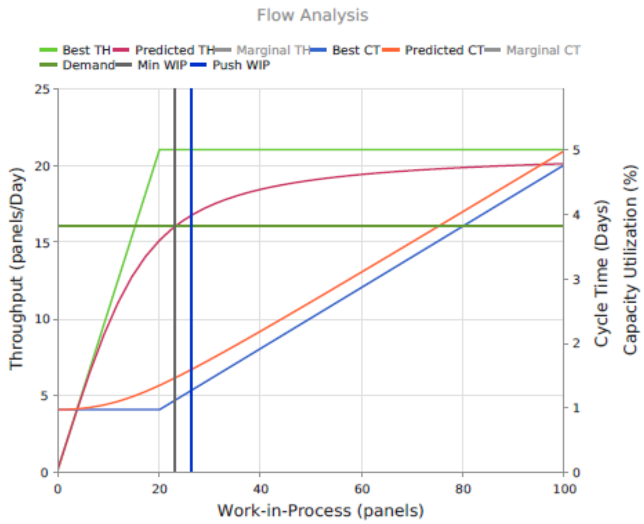
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	2.60	0.38	17.43	12.00	1.45	9.44	2.50	6.94	0.00	0.00	0.00

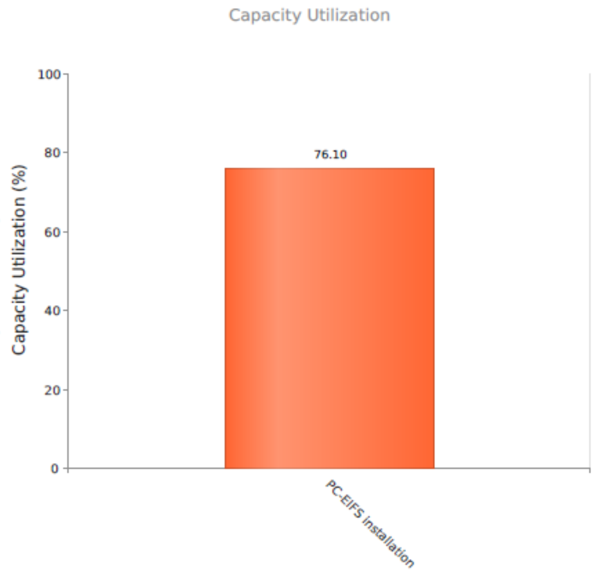
	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	2.26	1.45	8.54	100.00	30.00	1.45	9.44	2.50	6.94	0.00	0.00	0.00	26.48	73.52	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	65.93	0.54	2.40	1.25	3.47	5.77	17.43

Results sheets of the E2 production system based on changes in batch size (E2 doubled PB).

EIFS panels installation





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
16.00 (panels/Day)	**21.03** (panels/undefined)	**76.10 %**	**0.17** (Days)

MIN WIP	MIN CYCLE TIME
23.27 (panels)	**1.45** (Days) | **11.64** (Hours)

PUSH WIP	PUSH CYCLE TIME
26.37 (panels)	**1.65** (Days) | **13.19** (Hours)

Based on CONWIP Level of 18 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
14.27 (panels/Day)	**8.20** (Hours)	**18.00** (panels)	**67.86 %**

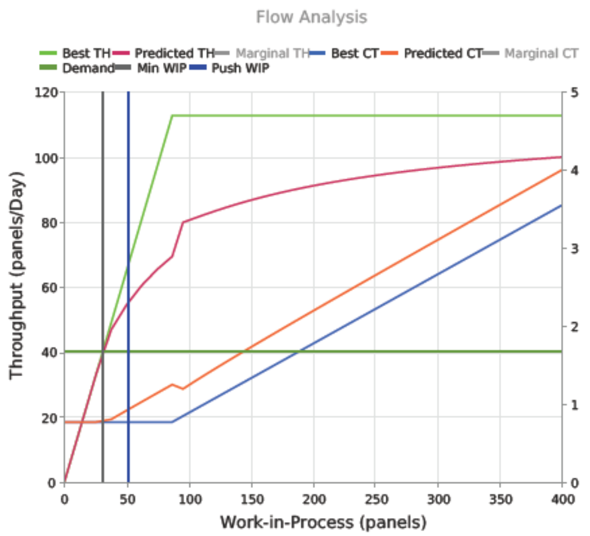
Cycle Time Analysis ▴

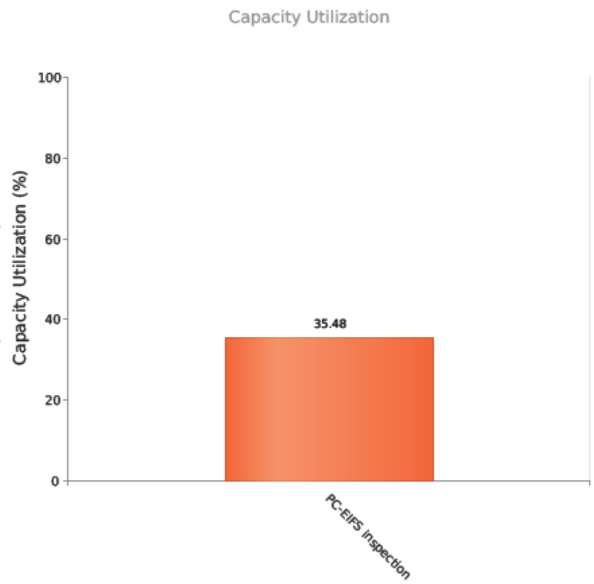
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels installation	18.00	14.27	1.26	26.37	16.00	1.65	10.71	1.12	4.46	5.13	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS installed	0.00	4.60	1.65	6.01	100.00	30.00	1.65	10.71	1.12	4.46	5.13	0.00	0.00	10.44	41.66	47.90	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS installation	2	76.10	0.43	0.24	3.30	1.49	2.44	25.14
PC-Transportation EIFS panels	3	0.00	0.88	5.78	1.96	0.00	0.00	16.25

EIFS panels inspection





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
40.00 (panels/Day)	**112.75** (panels/undefined)	**35.48 %**	**0.77** (Days)

MIN WIP	MIN CYCLE TIME
30.77 (panels)	**0.77** (Days) | **6.15** (Hours)

PUSH WIP	PUSH CYCLE TIME
51.70 (panels)	**1.29** (Days) | **10.34** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
1.30 (panels/Day)	**5.00** (Hours)	**1.00** (panels)	**1.15 %**

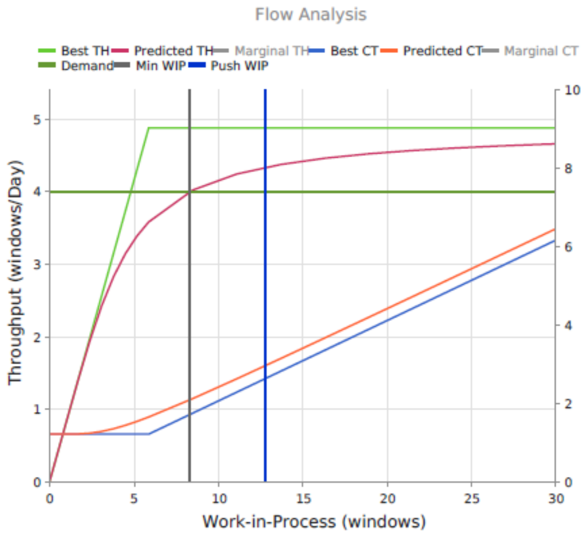
Cycle Time Analysis ▲

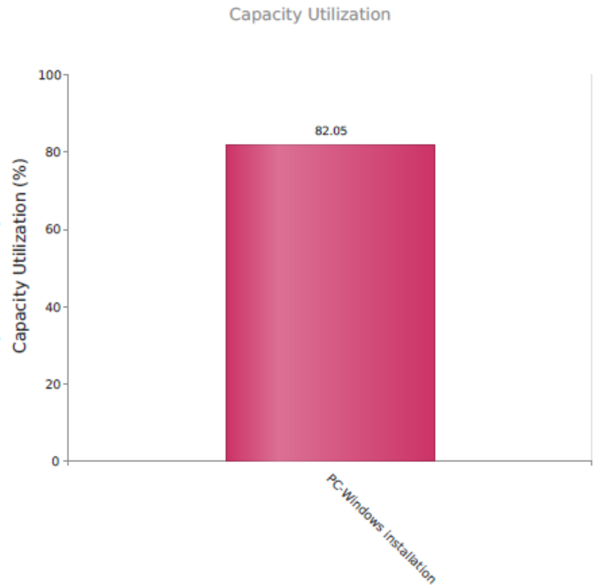
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
EIFS panels inspection	1.00	1.30	0.77	51.70	40.00	1.29	8.40	5.00	3.40	0.00	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS inspected	0.00	4.89	1.29	8.22	100.00	30.00	1.29	8.40	5.00	3.40	0.00	0.00	0.00	59.51	40.49	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-EIFS inspection	1	35.48	0.75	2.88	1.74	1.70	4.59	58.35

Windows installation





Based on Current Demand

THROUGHPUT
4.00 (windows/Day)

BOTTLENECK RATE
4.87 (windows/undefined)

BOTTLENECK UTILIZATION
82.05 %

RAW PROCESS TIME
0.21 (Days)

MIN WIP
8.33 (windows)

MIN CYCLE TIME
2.08 (Days) | **16.67** (Hours)

PUSH WIP
12.81 (windows)

PUSH CYCLE TIME
3.20 (Days) | **25.62** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
0.83 (windows/Day)

CYCLE TIME
7.83 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
17.04 %

Cycle Time Analysis ▲

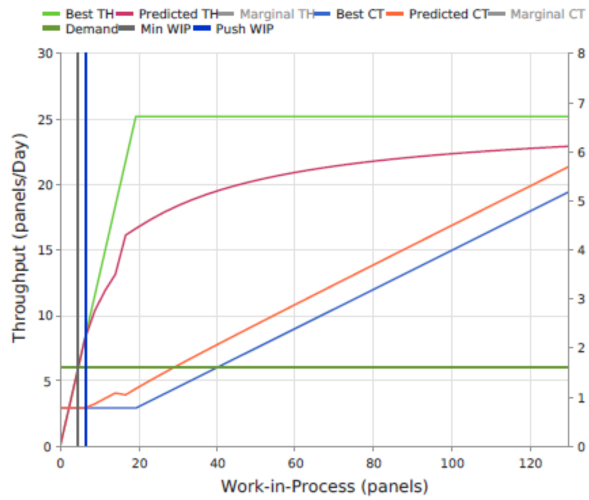
Product Flow	CONWIP			PUSH								
	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Windows installation	1.00	0.83	1.21	12.81	4.00	3.20	20.81	1.33	12.98	6.50	0.00	0.00

Item	CONWIP		PUSH															
	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
Windows installed	7.83	5.44	3.20	14.46	100.00	30.00	3.20	20.81	1.33	12.98	6.50	0.00	0.00	6.41	62.36	31.23	0.00	0.00

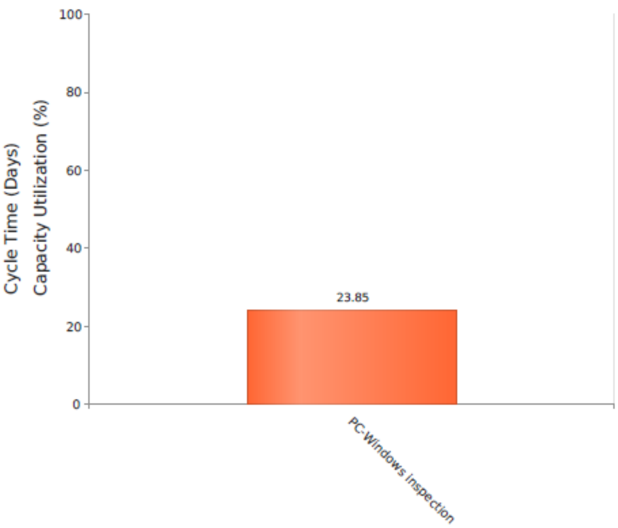
Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows installation	1	82.05	0.15	0.37	6.67	6.49	9.21	12.81

Windows inspection

Flow Analysis



Capacity Utilization



Based on Current Demand

THROUGHPUT
6.00 (panels/Day)

BOTTLENECK RATE
25.16 (panels/undefined)

BOTTLENECK UTILIZATION
23.85 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
4.62 (panels)

MIN CYCLE TIME
0.77 (Days) | **6.15** (Hours)

PUSH WIP
6.61 (panels)

PUSH CYCLE TIME
1.10 (Days) | **8.81** (Hours)

Based on CONWIP Level of 0 (panels)

THROUGHPUT
1.30 (panels/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (panels)

BOTTLENECK UTILIZATION
5.17 %

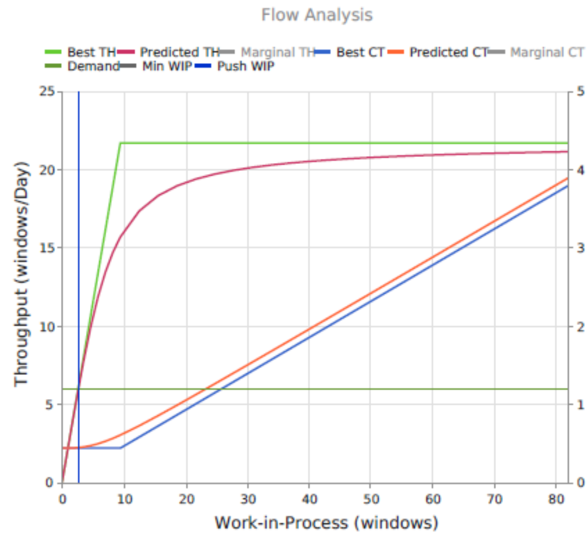
Cycle Time Analysis ▲

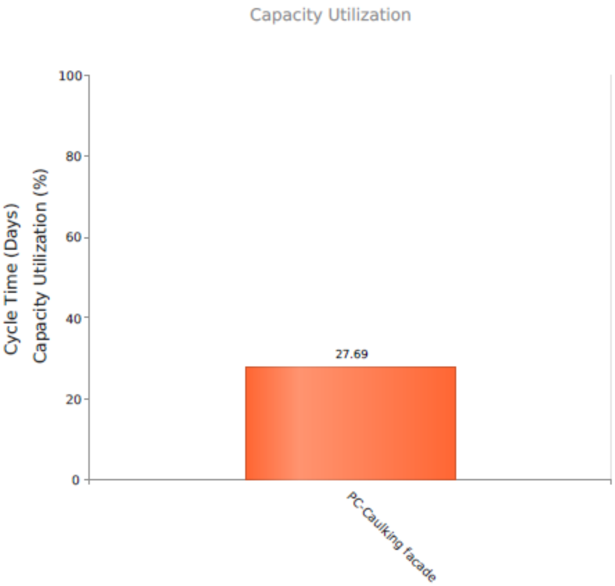
Product Flow	CONWIP WIP (Units)	CONWIP Throughput (Units/Day)	CONWIP Cycle Time (Days)	PUSH WIP (Predicted) (Units)	PUSH Throughput (Units/Day)	PUSH Cycle Time (Days)	PUSH Cycle Time = (Hours)	PUSH Raw Process Time + (Hours)	PUSH Queue Time + (Hours)	PUSH Batch Time + (Hours)	PUSH Move Time + (Hours)	PUSH Shift Diff. Time (Hours)
Windows inspection	1.00	1.30	0.77	6.61	6.00	1.10	7.16	5.00	2.16	0.00	0.00	0.00

Item	CONWIP Cycle Time (Hours)	CONWIP Cycle Time SD (Hours)	PUSH Cycle Time (Days)	PUSH Cycle Time SD (Hours)	PUSH On Time Delivery (%)	PUSH Planned Lead Time (Days)	PUSH Replenish. Time (Days)	PUSH Cycle Time = (Hours)	PUSH Raw Process Time + (Hours)	PUSH Queue Time + (Hours)	PUSH Batch Time + (Hours)	PUSH Move Time + (Hours)	PUSH Shift Diff. Time (Hours)	PUSH Raw Process Time (%)	PUSH Queue Time (%)	PUSH Batch Time (%)	PUSH Move Time (%)	PUSH Shift Diff. Time (%)
Windows inspected	0.00	5.05	1.10	7.23	100.00	30.00	1.10	7.16	5.00	2.16	0.00	0.00	0.00	69.86	30.14	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Windows inspection	1	23.85	0.83	2.79	1.94	1.08	3.66	8.53

Development of caulking 1





Based on Current Demand

THROUGHPUT	BOTTLENECK RATE	BOTTLENECK UTILIZATION	RAW PROCESS TIME
6.00 (windows/Day)	**21.67** (windows/undefined)	**27.69 %**	**0.08** (Days)

MIN WIP	MIN CYCLE TIME
2.66 (windows)	**0.44** (Days) | **3.54** (Hours)

PUSH WIP	PUSH CYCLE TIME
2.75 (windows)	**0.46** (Days) | **3.67** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT	CYCLE TIME	WIP LEVEL	BOTTLENECK UTILIZATION
2.29 (windows/Day)	**2.83** (Hours)	**1.00** (windows)	**10.57 %**

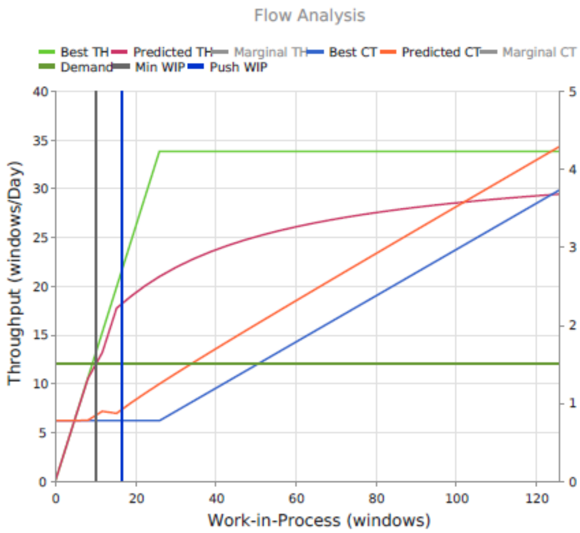
Cycle Time Analysis ▲

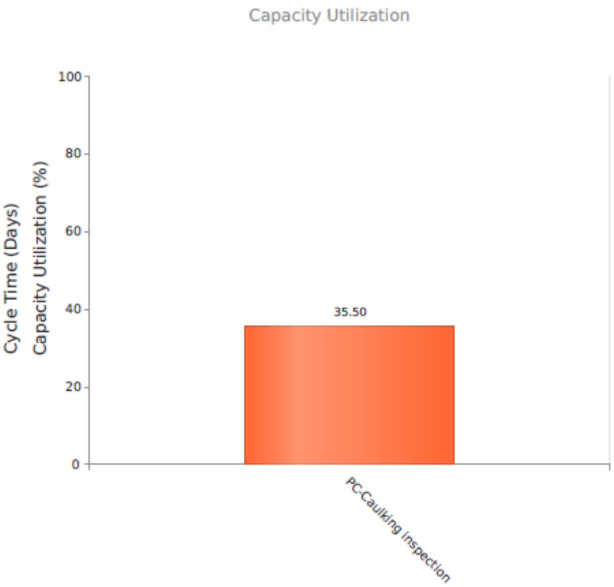
	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Development of caulking 1	1.00	2.29	0.44	2.75	6.00	0.46	2.98	0.50	0.15	2.33	0.00	0.00

	CONWIP		PUSH															
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS and windows caulked 1	0.00	2.42	0.46	2.54	100.00	30.00	0.46	2.98	0.50	0.15	2.33	0.00	0.00	16.76	5.01	78.23	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking facade	2	27.69	0.64	2.17	0.86	0.07	0.40	2.96

Inspection of caulking 1





Based on Current Demand

THROUGHPUT
12.00 (windows/Day)

BOTTLENECK RATE
33.80 (windows/undefined)

BOTTLENECK UTILIZATION
35.50 %

RAW PROCESS TIME
0.77 (Days)

MIN WIP
10.05 (windows)

MIN CYCLE TIME
0.84 (Days) | **6.70** (Hours)

PUSH WIP
16.66 (windows)

PUSH CYCLE TIME
1.39 (Days) | **11.11** (Hours)

Based on CONWIP Level of 0 (windows)

THROUGHPUT
1.30 (windows/Day)

CYCLE TIME
5.00 (Hours)

WIP LEVEL
1.00 (windows)

BOTTLENECK UTILIZATION
3.85 %

Cycle Time Analysis ▲

	CONWIP			PUSH								
Product Flow	WIP (Units)	Throughput (Units/Day)	Cycle Time (Days)	WIP (Predicted) (Units)	Throughput (Units/Day)	Cycle Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)
Inspection of caulking 1	1.00	1.30	0.77	16.66	12.00	1.39	9.02	5.00	4.02	0.00	0.00	0.00

	CONWIP		PUSH																
Item	Cycle Time (Hours)	Cycle Time SD (Hours)	Cycle Time (Days)	Cycle Time SD (Hours)	On Time Delivery (%)	Planned Lead Time (Days)	Replenish. Time (Days)	Cycle Time = (Hours)	Raw Process Time + (Hours)	Queue Time + (Hours)	Batch Time + (Hours)	Move Time + (Hours)	Shift Diff. Time (Hours)	Raw Process Time (%)	Queue Time (%)	Batch Time (%)	Move Time (%)	Shift Diff. Time (%)
EIFS, windows and caulking 1 inspected	0.00	5.11	1.39	9.23	100.00	30.00	1.39	9.02	5.00	4.02	0.00	0.00	0.00	55.41	44.59	0.00	0.00	0.00

Process Center	Number of Machines	PC Util (%)	SCVa Batches	SCVe Batches	Mean Time 1 Batch (Hours)	Queue Time (Hours)	Queue Time Std Dev (Hours)	WIP
PC-Caulking inspection	1	35.50	0.66	2.40	2.50	2.01	5.46	16.66