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MASTER

Planning and control of inbound operations at a distribution center
the role of information integration and station flexibility

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Planning and Control of Inbound Operations at a Distribution Center

The Role of Information Integration and Station Flexibility

by

E.J.N. (Elke) Mares

Eindhoven, September 2018

by

Planning and Control of Inbound Operations at a Distribution Center

The Role of Information Integration and Station Flexibility

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In partial fulfilment of the requirements for the degree of

Master of Science
in Operations Management and Logistics

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TU/e. School of Industrial Engineering.

Series Master Theses Operations Management and Logistics

Subject headings: Inbound operations planning, order assignment problem, information integration, station flexibility, simulation

Preface

I present to you a copy of the dissertation “Planning and Control of Inbound Operations at a Distribution Center: The Role of Information Integration and Station Flexibility”. It has been written in order to fulfill the graduation requirements of the study program Operations Management and Logistics at the faculty of Industrial Engineering and Management Sciences from the Eindhoven University of Technology (TU/e).

My research demonstrates how to improve and innovate the Inbound process according to information integration. In addition, it provides insights to the key importance of the Inbound process and how to redesign in terms of flexibility, throughput time and on-time performance.

I would like to thank my supervisors Karen de Wolde and Roger L’Ortye for this great opportunity. Especially Karen, who offered me guidance in the company and supported me along the entire process. In addition, my special gratitude goes to the Inbound department, in particular Claudia Weckseler, Jurre Hendriks and Ilona Kaczorowski who were always willing to help. I would also like to thank my supervisors from the TU/e, Rob Broekmeulen and Tugce Martagan, for their knowledge, guidance and helpful feedback.

At last, I would like to thank my family and friends for their support. Not only during this graduation project, but during my entire study. Special gratitude goes to my fellow student Mila de Win for walking the path together and being my friend. Last but certainly not least, I would like to thank Jim Hoenen for his unconditional support and love.

Elke Mares

(Eindhoven, August 2018)

Abstract

This Master thesis analyzes the Inbound department of the distribution center of a multinational healthcare company. A case study has been performed to identify problems that influence the performance of the operations. By means of a literature and simulation study, the main research question can be answered: “*How can the current Inbound process be redesigned, so that throughput time is improved?”* The thesis provides insights in the value of information availability when creating operation schedules. An algorithm is formulated which includes aspects as shortest processing time, urgency and idleness. Research has been done on how to improve the system flexibility and its effects on performances. Recommendations about the integration of these redesign opportunities are made based on requirements and implementation plans.

Management Summary

This thesis report is written in cooperation with a multinational healthcare company. The research is conducted at the Inbound department of a Distribution Center in EMEA (Europe, Middle East and Africa).

Problem Statement

The main goal of the research is to perform a detailed analysis on the Inbound department of the research company. The research is triggered by too little slack in flexibility and a too high Work-In-Process inventory level. Therefore, the main objective is to reduce the average throughput time of the operations in the Inbound department. The scope of the research includes Inbound as well as its suppliers. The operational systems and the overlapping Supply Chain department have also been placed in scope. This results in the following main research question: *"How can the current Inbound process be redesigned, such that throughput time is improved?"*

This question is divided into three research questions. At first, the as-is situation of the current Inbound process is analyzed. The procedures of planning and controlling the department are described, as well as the key performance indicators resulting from this analysis. Secondly, it is investigated how this current scenario could be redesigned such that the throughput time and the supply chain integration are improved. This should create a more efficient flow such that more flexibility in the planning is established. Thirdly, improvement opportunities are identified and designed to be tested by simulation study. The results of this study are compared so that recommendations can be made, which should improve the current situation according to the objectives and concludes the research.

The research is performed according to the model of Mitroff et al. (1977). With the help of data analyses, semi-structured interviews and a literature review, the four phases (problem situation, conceptual model, scientific model and solution) can be conducted. By designing a simulation model of the real-life situation, the proposed improvement opportunities can be tested in order to draw accurate conclusions. Both for the research company as for academic literature, this research indicates the missing link in Supply Chain Management: a successful Inbound Management. (Lavin, 2014) It delivers insights in the effect of advanced shipping information on Inbound planning.

Detailed Analysis

The company's current process is researched in detail such that the main causes can be found for the proposed problem. The analysis is divided into four categories: business process, information and technology, planning and control, and performance. The business process contains two main steps: receipt and booking of the shipments. With the help of work stations, Inbound processes its shipments according to a First-In-First-Out policy. The planning of these operations is mainly based on experience and the little information that is known in advance. This lack of information and implementation of a planning system results in an inefficient planning. It can be concluded that by improving transparency along the supply chain and developing a planning tool or concept, improvement opportunities rise for the Inbound planning process. The current performance of the research company is described in its key performance indicators. The lead time targets are nearly met, which indicates the need of reducing the throughput times. This is confirmed by benchmarking the performances to other situations, of which can be concluded that there are large improvement opportunities regarding the throughput time.

Design Model

To simulate the research scope, a design is created with the objective to minimize throughput time and WIP-inventory. Some constraints are defined to assure feasible results.

- Inbound is open 11 hours a day, 5 days a week, 50 weeks a year
- Ample workforce to cover stations
- No preemption and one job at one station a time
- Products are categorized into different groups
- Orders cannot be rejected and arrive at full hours
- Parallel stations are identical for processing times

The design investigates the effects on the performance of three parameters: the level of information availability about shipment arrivals and workload, the flexibility level of the work stations and the change in pull/push ratio. These parameters are implemented in an algorithm that determines the assignment of orders to work stations. Depending on the analyzed scenario, the algorithm considers the shortest processing time policy in combination with the urgency of over-due shipments and/or the look-ahead policy. The flexibility parameter can be adjusted to limited or full. When there is limited flexibility, an order can only be processed at two possible stations. In case of information availability, the in-transit shipments are considered up to a maximum number of hours in advance. For the change in the ratio, the pull share is increased which results in a decrease of arrival variance. In total, there are eight redesign scenarios illustrated in Table 1.

TABLE 1 DESIGN MATRIX BASED ON 2^K FACTORIAL DESIGN

Scenario	Factor 1: Information Availability	Factor 2: Flexibility	Factor 3: Pull/Push Ratio	Name
1	–	–	–	$(NI \& LF)^-$
2	+	–	–	$(PI \& LF)^-$
3	–	+	–	$(NI \& FF)^-$
4	+	+	–	$(PI \& FF)^-$
5	–	–	+	$(NI \& LF)^+$
6	+	–	+	$(PI \& LF)^+$
7	–	+	+	$(NI \& FF)^+$
8	+	+	+	$(PI \& FF)^+$

To compare the different scenarios to each other and the current situation, the key performance indicators are measured. These include the average throughput time of the shipments, the on-time performances and the Work-In-Process inventory. A design of experiments, validation and verification analyses of the simulation study are performed in order to obtain accurate and reliable results.

Results

Three redesign alternatives are discussed which have been tested over four different scenarios: increasing the flexibility of the stations, the information availability for planning the Inbound operations and changing the queuing policy based on an assignment algorithm. Table 2 shows the comparisons of the current situation to following four scenarios.

Table 2 Comparison of Simulation Results of all Scenarios versus the Current Situation

Scenario	**Performance Indicators**			
	Throughput Time (hours)	*On-time Performance* *β = 24 hours*	*On-time performance* *β = 48 hours*	*WIP-inventory* *(shipments)*
1 (NI & LF)¯	-17%	-2%	-1%	-21%
2 (PI & LF)¯	-22%	2%	0%	-28%
3 (NI & FF)¯	-33%	11%	2%	-45%
4 (PI & FF)¯	-40%	12%	1%	-50%

All redesign scenarios are based on the assignment algorithm that include the SPT-rules as well as urgency and idle time aspects. In comparison to the current situation, which follows a First-In-First-Out policy, this algorithm performs significantly better. The increasement of the flexibility level of the work stations reduces the average throughput time and WIP, and improves the 24- and 48-hour on-time performance. This effect is higher under the use of the look-ahead algorithm in case of information availability. The overall results of the implementation of information integration causes the average throughput time and WIP-inventory level to reduce. A combination of increasing flexibility and information integration would result in the best improvement. Especially when considered in the throughput time. For the change of pull/push ratio, it can be concluded that by decreasing the arrival variance, large improvement opportunities occur over all performance indicators.

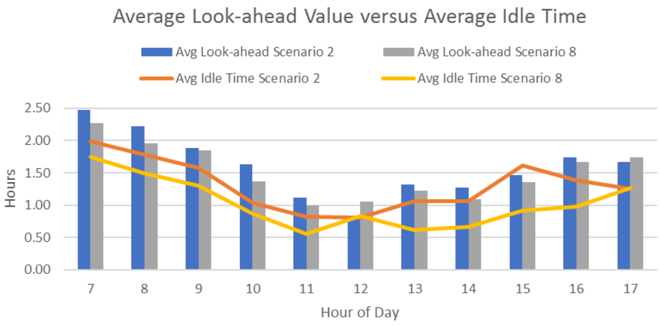

Figure 1 Average Look-ahead Value versus Average Idle Time for Scenario 4 and 8

The frequency and time frame of looking ahead in the assignment algorithm depend on both the processing times of the shipments as the occurring trends in the shipment arrivals. Figure 1 shows that during loaded working hours, the average look-ahead value is smaller compared to the less loaded hours. Especially at the start and end of a day, the arrival trend is smaller than during the middle of the day. This means that during these less loaded hours, the algorithm looks further ahead on average. When arrival variance is decreased, the look-ahead is more often used while the average look-ahead value is smaller than the normal pull/push ratio.

By simulating the addition of flexibility links, a business case has been illustrated. The current flexibility level has been used as base level including the implementation of the assignment algorithm without look-ahead policy. Results show that with the addition of each link, improvements in throughput time, on-time performances and WIP-level are being achieved. The costs per addition is 7.2 fte’s, but can be shared by implementations of links at the same stations.

Implementation and Recommendations

The simulation results lead to a to-be situation of which redesign recommendations can be made. The implementation of these redesign opportunities should be aligned with running projects at the research company in order to achieve an as best as possible performance. The following recommendations can be concluded from this research report:

- Improve the integration between Enterprise Resource Planning system and operational system to provide accurate data
- Implement a new operational system that provides tooling for planning. These could be based on requirements set in this report
- Implement a system for information integration, e.g. Electronical Data Interchange system, which provides information about in-transit shipments and purchase orders based on defined requirements. Noted, it is key a proper connection to the Enterprise Resource Planning System should be maintained
- Implement the assignment algorithm into the planning system to improve the performance. Once information integration is in place, extend it to the look-ahead principle
- Increase current flexibility level by adding links between stations and product groups. A tradeoff between costs and improvement results should be made
- Increase the share of pull shipments in the pull/push ratio since this stabilizes the work flow and will reduce the average throughput time

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1 Introduction

This chapter introduces the research project. The investigated company is introduced in section 1.1, section 1.2 describes the structure of the remaining report.

1.1 Introduction to the Company

Due to confidentiality reasons, the name of the research company and confidential information cannot be shared. From now on, the company of research will be called company Vita. Also, some axes are not shown to protect the information. Vita is an organization which delivers innovative services and solutions to the healthcare industry. The multinational has customers in over 100 countries. As indication, Figure 2 shows the distribution of its net sales per region. Vita's goal is to contribute in the transformation of healthcare as a trusted partner through meaningful innovation and by expanding global access to therapies. Vita has net sales of over €20 billion and ratio of current assets to current liabilities of 1.7 to 1.0. This indicates that Vita is a continuously growing and healthy company with its priorities at globalization, therapy innovation and economic value. Due to the fact that Vita operates in the healthcare industry, product and service quality and reliability are extremely important. Therefore, the patient will always be put first in performing activities.

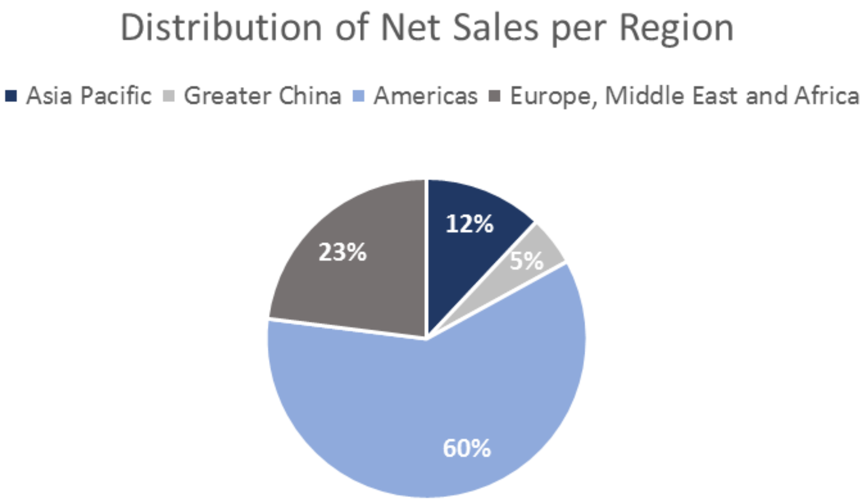

FIGURE 2 DISTRIBUTION OF NET SALES PER REGION

This master thesis has been conducted in the Distribution Center (DC) that serves customers around Europe, the Middle East and Africa (EMEA). The products of Vita are transferred to the DC before they are being sent to the customers. DC's overall process flow is illustrated in Figure 3. As stated, this process starts by receiving products from the suppliers at the Inbound department. The products are either stored in the warehouse until Outbound picks them for customer orders or some value-added services are performed. In this particular case, the service is provided and they are stored in the warehouse or sent directly to the Outbound department. After that, the products are transported to the customer. The DC also deals with reverse logistics, which includes operations around customer returns. The Reverse department is responsible for performing the correct remaining operations of both product and customer. This research will conduct (innovative) improvements for the Inbound process, looking at it from an IT perspective. Therefore, both Inbound and IT-departments are closely involved in this master thesis.

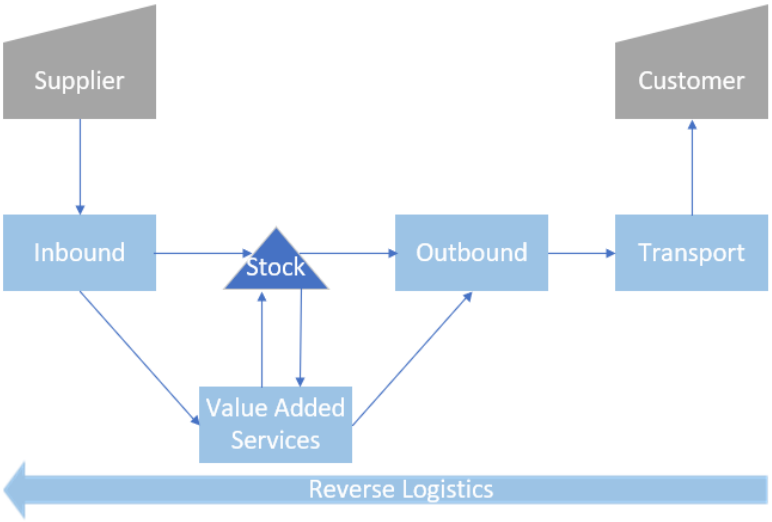

FIGURE 3 PROCESS FLOW OF THE DC

1.2 Outline of the Report

There are nine chapters in total, including this first chapter which contains the introduction of the research. The second chapter describes the problem with the research questions as guidelines for the remaining of the report. Each following chapter contributes in answering one or more research (sub)-questions. Chapter 3 includes a detailed analysis of the research company. A literature review on the topics of this research: information exchange and order assignment will be described in chapter 4. The fifth chapter provides a conceptual design, which is translated into a detailed design in chapter 6. The simulation results are being discussed in chapter 7 based on the key performance indicators. The implementation of the results for the research company is described in chapter 8 and lastly in chapter 9, conclusions and recommendations of the report are summarized.

2 Problem Statement

This chapter provides a detailed description of the problem statement. In section 2.1, the problem description can be found. The research scope is then elaborated in section 2.2., which states the research questions with its sub-questions in 2.3. The relevance of the topic is described in section 2.4 and concludes in the methodology explanation of 2.5.

2.1 Problem Description

The goal of this research is to analyze the Inbound process at Vita. In order to improve the process, the throughput time should be reduced. Possible improvement strategies are researched to reduce throughput time. This research is applicable to any distribution company looking for managing service levels through improvements in Inbound systems. The emphasis of this thesis will lie on the receiving process of Inbound and its planning and control aspects. Also, the main process flow is investigated in order to stabilize and reduce inefficiencies.

The process flow should be stabilized such that a more flexible planning can be achieved. By striving for better planning conditions and an efficient use of resources, a reduced throughput time can be realized. By creating more flexibility in terms of slack, process variabilities can be compensated. Slack is a time-window within a process that activities can be delayed which does not impact the performance. The problem description is summarized into one statement:

"The current Inbound process needs to be improved in terms of throughput time by dealing with inefficient process steps and a lack of transparency in the receiving process."

2.2 Research Scope

As can be seen in Figure 4, the DC-process consists of different sub-processes. In this research, the supplier side of both intercompany and third-party vendors, and Inbound are included. The end of the defined research area lies at the start of the warehousing process. In particular, the put-away into the warehouse is included in some parts of the analysis, but the warehouse management operations itself are not part of the scope. The Outbound and shipping processes are also not included in the research area.

The Supply Chain (SC) department, which acts as overlapping control unit, is included in the research. Only the parts of SC which are linked to the Inbound activities are covered. Finally, the SAP-system used for the entire process and the Closed Loop Tool (CLT) used for Inbound is covered in the scope of the research. The CLT is an internal system used at Vita which traces shipments from receiving till booking. All other departments and systems are not relevant for this research and therefore left out of scope.

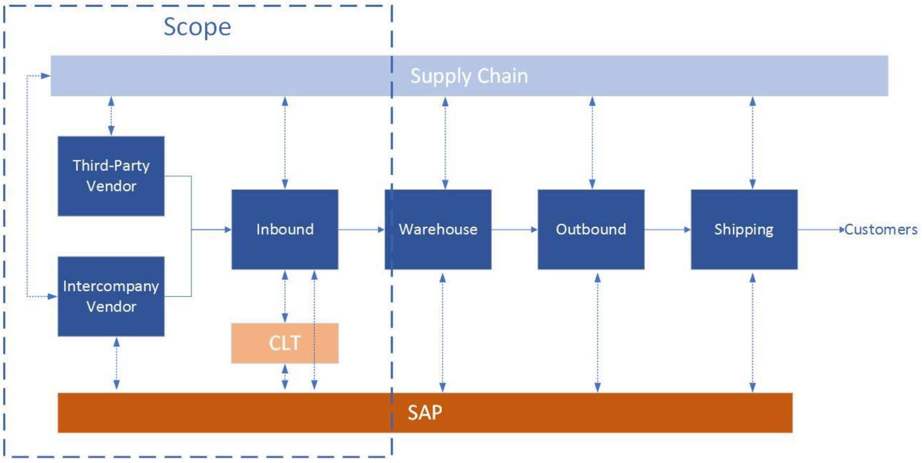

FIGURE 4 SCOPE OF THE RESEARCH

2.3 Research Questions

To deal with the problem situation, this research is performed. The goal of the report is to answer the following research question:

"How can the current Inbound process be redesigned, such that throughput time is improved?"

By redesigning the process, a more efficient flow should be created and defined service targets should be met. This should result in a more integrated supply chain and provide more flexibility in the planning. The requirements for a planning tool are drafted and a concept model is developed. By simulating the redesign alternatives, different scenarios can be evaluated. To achieve this, the following sub questions need to be answered.

1. *What does the internal Inbound process look like, and how is it currently planned and controlled?*
    a. What is the "as-is" situation of the current Inbound process of the Distribution Center?
    b. How is the current process planned and controlled?
    c. What are the Key Performance Indicators and how does Inbound perform regarding these KPIs?
2. *How can the current process be improved such that throughput time and supply chain integration are improved?*
    a. What are the key aspects and needs of an adequate planning and control tool in academic studies?
    b. Which improvements can be redesigned in the process in order to decrease the throughput time and create slack in the planning?
    c. Which integrated planning and control tool can be developed and what are its specific requirements for Vita's Inbound process?
3. *How can the process be redesigned such that the planning and control concept achieves more supply chain transparency and throughput time reduction?*
    a. What are the performances of the redesign alternatives in terms of the KPIs when using simulation studies?
    b. What is the "to-be" situation for the receiving process of Vita? And what are the gaps between the "as-is" and the "to-be" scenario?
    c. How could the redesigned process be implemented at Vita?

2.4 Topic Relevance

With greater regularity, the importance of reductions in cycle, throughput, design and setup times are highlighted by companies. High speed is not always related to better use of times. In addition, eliminating process wastes and delays are indicated as improvement factors for throughput times and customer services. Various techniques that include creativity, specialized skills, capital investments and behavioral changes should be applied to obtain significant improvement. Time is acquiring in importance as critical resource. As part of a competitive strategy, the company needs to effectively deploy its organizational resources to achieve advantage in an increasingly intense competitive environment. (Tersine & Hummingbird, 1995)

Tompkins and Smith (1998) indicate that a problematical receiving process can create as much problems in a warehouse as a poor order picking or shipping process. Therefore, it is key to design the receiving process as efficient and effective as possible and not only focus on the warehousing and outbound activities in a logistics process. This study contributes to highlighting the importance of the goods receiving process in reducing its throughput time. Known literature about this topic is researched and combined with a company case study.

Ideally, the entire Inbound process – including transport from supplier to put-away into the warehouse – is visible and managed in one system. Currently, there is no standard language or system set for exchanging information along the supply chain. Therefore, it is considered as a challenge to integrate suppliers with the Inbound department. This integration depends on high-quality data which is, even with the most powerful information technologies, still hard to obtain. The issues of sharing information in the supply chain lie with confidentiality and trust. Overall, the missing link in Supply Chain Management is indicated: a successful Inbound Management. (Lavin, 2014)

2.5 Methodology

The research is conducted in four phases according to the existing research model of Mitroff et al. (1977). The approach is illustrated in Figure 5. The report analyzes Vita's current design of the Inbound process in the DC. A research plan is developed based on an existing research model of Mitroff et al. (1977) and a problem statement is described. The problem is investigated by matters of an extensive literature review that helps finding possible solutions and investigating the topic of interest. (Mares, 2018) Redesign alternatives of the current process are proposed and analyzed with the goal of improving lead times, handling costs and efficiency. These alternatives are based on the requirements of a planning tool that helps Inbound with planning their daily operations. A mathematical model is designed to illustrate and evaluate the performance of these alternatives. This design is translated into a simulation model. After performing a simulation study, conclusions and recommendations are made on process improvement which results in an implementation plan to advise Vita in accepting the redesigned process flow.

In conclusion, the deliverables for Vita are an extensive study of their Inbound process, requirements about the advanced shipping information as input for the planning, requirements of the concept of the planning tool itself, and recommendations on the redesigns and how to implement them. The master thesis should contribute to the literature in elaborating on the topic of supply chain integration and advanced shipping information in the critical aspects of the Inbound process flow and giving a case study for providers of technological solutions in healthcare.

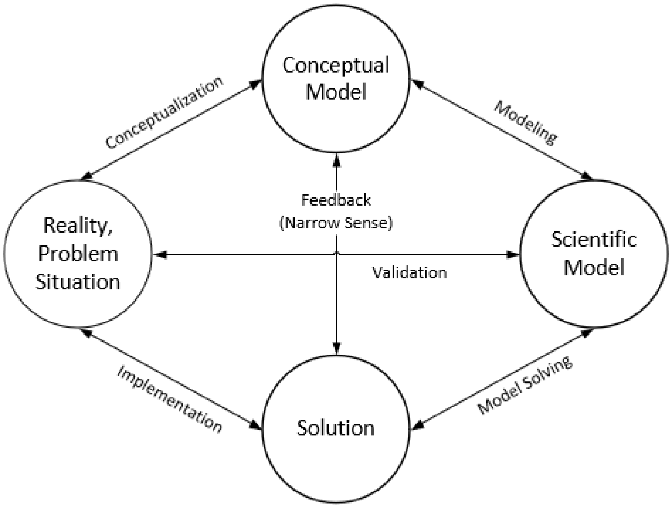

FIGURE 5 RESEARCH METHOD OF MITTROFF ET AL. (1977)

In order to retrieve information, semi-structured interviews are held with employees of various departments of the DC. A semi-structured interview consists of several guiding and open questions to make sure the interview covers all material. In addition, a mathematical tool is designed to simulate the effects on the performance indicators when redesigning the current process. A scenario-analysis of multiple scenarios is performed such that trade-off can be made between different variables. The information needed for this tool is retrieved via SAP, the internal CLT and stop watch time studies. The two information systems keep track of all data regarding shipments, orders and issues. At the time the systems were not able to deliver the right and accurate information, stop watch time studies are used to fulfill the needed information.

3 Detailed Analysis

This chapter provides a detailed analysis of Vita's current situation, which results in answers to the first two sub-question: "*What is the "as-is" situation of the current Inbound process of the Distribution Center?*" and "*How is the current process planned and controlled?*" These answers are described in sections 3.1, 3.2 and 3.3, which respectively explain the topics of Business Process, Information and Technology, and Planning and Control. The answer on sub-question 1c, *"What are the Key Performance Indicators and how does Inbound perform regarding these KPIs?",* is described in section 3.4. Concluding remarks that summarize chapter 3 can be found in 3.5.

3.1 Business Process

The sub-chapter Business Process describes the underlying process of the scope. The section is divided into the Distribution Center Process and the Inbound Process.

3.1.1 Distribution Center Process

The Distribution Center consists of three major production units. Based on the mapping process of Suh (1990), the DC-process is illustrated in Figure 6. A production unit (PU) can be explained as a subsystem that executes a sequence of processes to deliver the PU-end items. The first PU is Inbound; this department is responsible for receiving the products that are send to the DC and booking them into the system so they can be stored in the warehouse. Inbound deals with the put-away of the items into the correct storage location. The second PU is the Outbound department. The customer orders are picked from the warehouse and prepared to be sent to the customer. The last PU is the Transport department. The activities concerning the transportation of the products to the customers are outsourced to an external company which is located in-house the DC.

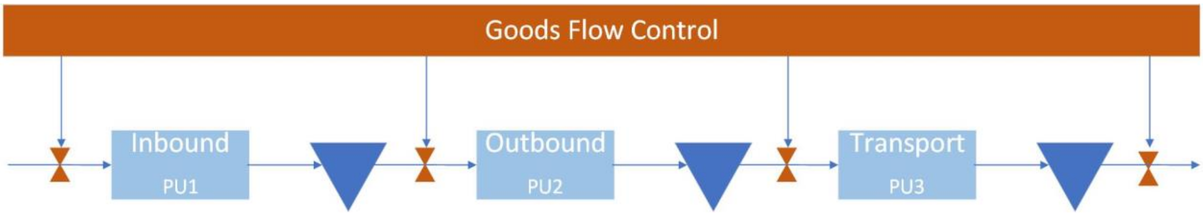

FIGURE 6 DC LOGISTICS PROCESS

The Goods Flow Control (GFC) serves as a coordinator between the different PUs. It handles the orders and receives information about the inventory levels in the different stock points. In this specific case, the GFC is named the Supply Chain department. The department is responsible for purchase and customer orders. It will send out purchase orders to suppliers whenever inventory needs to be replenished. Customer orders also flow through the GFC, which can be accepted, delayed or declined. This is why the SC-department has contact with suppliers and customers daily. In order to handle the replenishment and order acceptance, the department carries the task of inventory management and lead time analysis. The latter means that SC keeps track of the lead time performance and confirms them to the customers. For this research, the emphasis lies on the Inbound process or PU1 and therefore, the Outbound and Transport processes are not further elaborated.

3.1.2 Inbound Process

This section explains the different process steps in Production Unit 1. The overall process is illustrated in Figure 7. In addition, the throughput time indicates the time between the moment the shipments arrive at the DC until the products are booked into the system. The put-away into the warehouse is not considered in the throughput time since the internal system does not include this specific data.

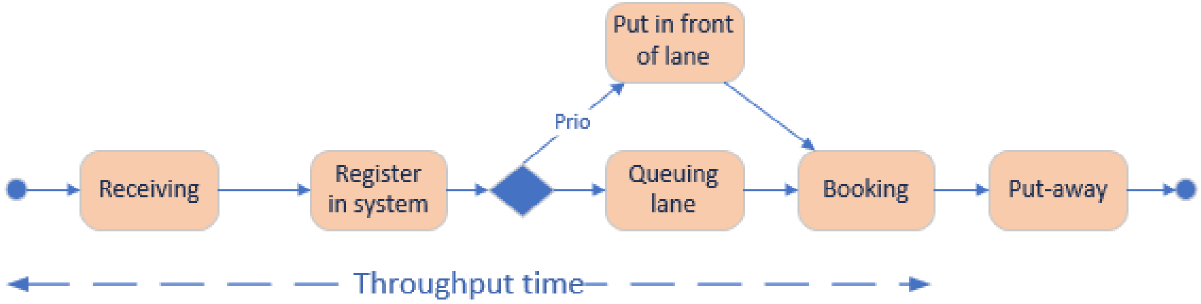

FIGURE 7 INBOUND PROCESS FLOW

3.1.2.1 Receiving

The receiving activity at the Inbound department is the first step of the process. Trucks arrive at the DC dock where the delivery note is checked and signed. After receipt, the load will be unloaded in the Inbound area. Loads can be consolidated shipments of multiple suppliers which consist of pallets and/or case packs. Products on pallets can either be sorted or unsorted per product type, while each case pack can include multiple item types. It is key that the receiving employees check and differentiate the pallets. Via the delivery note, the employees can see which products should be included in the pallets and/or case packs. The check of products is based on completeness of the shipment, quality, the use of qualified pallets, priority and distinguishable packaging. Once everything is checked, the shipments are registered into the Closed Loop Tool. After completion, they are placed in a queue in front of their assigned work station. The booking process start here.

3.1.2.2 Booking

The product booking makes sure that products are available for Outbound and that the system knows where they have been stored. The process is performed in work stations to which the products are assigned based on their type and storage location. Each cell is designed in such a way it can process a specific type of products in an efficient way to ensure the products are booked close to or in good connection to their storage place. The work stations are black boxes in this research. They have a fixed throughput time which is correlated to the amount of issues and the productivity of the work stations, which is discussed later on in this report. The more issues occur during booking process, the longer the throughput time. An issue is a problem that occurs during the booking process which prevents the process from continuing.

An operator of a work station replenishes the station from the lane according to the First-In-First-Out principle. A lane is a physical queue for the shipments in front of the work stations. This is not the case when there are priority shipments. These shipments are transferred to the front of the lanes by the receiving operators. Then, the booking employees are warned to ensure the priority products are handled as soon as possible. The products are booked into the system at the work station and are ready for put-away into the warehouse. After being put-away, all booked products are stored in the warehouse area according to their storage strategy.

3.2 Information and Technology

In order to execute and plan the process in an efficient way, information and technology integration is needed. In particular by sharing and receiving the right information and implementing a fitting technology, the process performance can be improved. Key is to invest in IT resources and in IT-capabilities. (Bharadwaj, 2000) Every day, shipments arrive at Inbound and a process to book them into the warehouse is started. In order to plan these shipments arrivals and the corresponding workload, it is necessary to have information about their arrival. The process itself has to be supported by an information system that updates the information along the process flow.

3.2.1 Supply Chain

All the products can be categorized into product types which are handled at Supply Chain as separate business unit. The planners of Supply Chain set a target for the inventory per product type for the different DCs in EMEA. These targets should ensure that 95% to 97%, different per BU, of the customer orders can be delivered from stock. When these targets are set they are entered in the SAP-system. An automatic system in SAP will send purchase orders to the suppliers when stock needs replenishment. The suppliers will send the purchase orders while being produced (if Make-to-Order) or when they have the products in stock (if Make-to-Stock). The suppliers occasionally have over- or underproduction. In that case, the products are send to the DCs according to the share of their order with respect to the total. This system of automatic replenishment can be manually influenced by the planners when they indicate an insufficient stock or backorders. Although purchase orders are send out to the suppliers, the delivery of the products is push based, and Inbound and Supply Chain have no influence on when they arrive at the DC.

When suppliers send their orders to the DCs, they share a tracking number and an invoice. With this tracking number, the shipment can be traced and an expected or actual delivery date is given. The exact content of the shipment can be determined by the invoice. Not all suppliers enter this tracking or invoice number into SAP. Some of them send the tracking number by e-mail to the planners. This would require a lot of extra work to cover the shipments into SAP. Since the supplier knows this information when the shipment is being send, it should be available at Inbound for planning purposes. Unfortunately, a great amount of information is missing or not available in the system. Therefore it is not possible for Supply Chain or Inbound to have an accurate overview of the arriving shipments with their content and arrival date.

3.2.2 Inbound

The DC receives products every day from various suppliers via various transporters. As pictured in Figure 8, there are two kinds of supplying parties: intercompany and third-party. Intercompany vendors are suppliers that are owned by Vita. The products are fabricated in their own Manufacturing Centers and can be shipped either by airplane and truck or solely by truck. The shipments that are flown by airplane are being transported to the carrier hub. After that, they can be transported by a truck to the DC. Other kind of products that are transported by truck are sent straight from the Manufacturing Centers to the DC. The third-party suppliers are transported by truck directly to the DC.

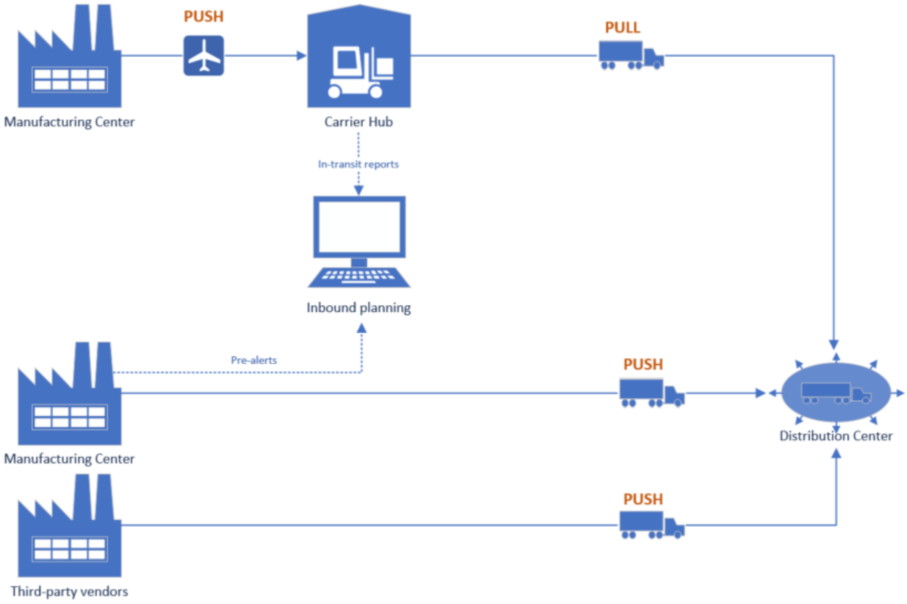

FIGURE 8 INFORMATION FLOW PER KIND OF SUPPLIER

As shown in Figure 8, there is an information flow between the carrier hub and Inbound. Every day an in-transit report of the products in the carrier hub is made. These products can be directed to the DC which creates a pull flow. The other information flow is between the Manufacturing Center and Inbound. Some of the Manufacturing Centers owned by Vita are sending pre-alerts about the shipments by e-mail or via SAP. This pre-alert is likely to contain a planned arrival date or the content of the shipment. There is no strict format for these advanced shipping notifications (ASN). The third-party suppliers have no information flow regarding shipments. Just like the third-party shipments, the direct shipments from supplier (solely by truck) have a push flow, on which the Inbound planners have no influence.

3.3 Planning and Control

In section 3.3, the current planning and control methods are discussed. The process of scheduling operations at the Inbound department of Vita is analyzed and its availability of data and resources is described. Finally, the variability of the arrival and process streams are examined.

3.3.1 Inbound Planning

A daily Inbound planning is made according to available shipment information for the coming day. Arriving shipments which are known in advance can be planned. For this planning, two aspects are taken into consideration by the Inbound planner: WIP-stock and warehouse space. All shipments that are still in queue are indicated as work-in-process (WIP) stock. These shipments need to be finished the next day before new shipments are processed. When the WIP is too high, the planner can choose to order less or no shipments at all from the carrier hub. The planner still keeps in mind that these delayed shipments cannot wait too long, because they are needed in the warehouse and the stock in the carrier hub has its limitations. Another factor is the amount of free space in the warehouse for the corresponding products. When there is none to limited space to cover the new shipments, the planner can decide to delay the plannable shipments.

Although some of the shipments can be planned, a large amount of the shipment arrivals is still unforeseen. As can be seen in Figure 9, shipments can be classified into two categories. For one, shipments can be pull based and thus plannable, which means that information is known in advance. Otherwise, shipments can be push based, which means that the suppliers determine when and what they want to send. Although this is based on a purchase order placed by Supply Chain, planners have no influence on the exact content and shipments' time of arrival. Figure 9 shows that of all shipments of the first three quarters of Fiscal Year 18[1], 34% is pull based and 66% is push based.

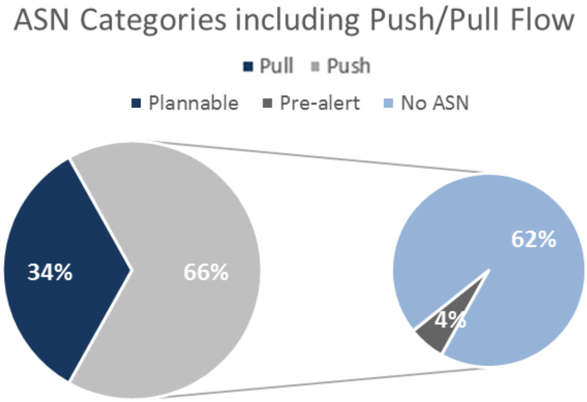

FIGURE 9 DIVISION OF SHIPMENTS INTO ASN-CATEGORIES INCLUDING PUSH OR PULL FLOW

The push category can also be divided into two different categories: pre-alert and no notification. The first category receives information about the content of the shipment in form of invoice numbers and/or the arrival date of the shipment. The other category does not provide any ASN about content or arrival of the shipment at all. This category is the hardest to deal with. Figure 9 shows that on average 62% of all shipments has no notice in advance and 4% receives a pre-alert.

3.3.2 Data Availability

A good planning is based on advance shipment notifications as well as the ratio between push and pull flow. When information is (partly) unavailable, it is hard to create a planning concerning truck arrivals and employees. Due to insufficient information about the push flow, the pull flow cannot be planned. With the current pull-push ratio, the pull-flow will not cover the uncertainty of the push-flow. In particular, this means that the peaks in the shipment arrivals cannot be stabilized due to insufficient influence on the arriving shipments. This results in conflicting timeslots, non-maximized utilization of employees and long waiting times at the docks. By striving for more information and a more pull-based environment, a better and more transparent planning condition can be achieved. It can reduce waiting and throughput times, and improved utilization of work stations.

2.3.3 Resource Availability

Another important aspect of the planning process is the number of labor hours. The work force is based on the number of full- and part-time employees, which is a defined number of hours per week. Most employees are willing to adapt their hours to the shipment scheduling. This means that sometimes employees start earlier or swap their part-time days. Inbound does not use flex-employees, which can be hired temporarily to reduce the work load. This is because they experienced the process is too complex to learn in such short notice. In cases of emergency, the Inbound department asks other departments for extra employees which will extend the work force. Each month, the management determines the number of hours needed. Due to the in-house employment

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[1] Fiscal Year 2018 ranges from 01-05-2017 to 29-04-2018. The first three quarters range from 01-05-2017 to 04-02-2018. When analyzing data, a range from 01-05-2017 to 31-01-2018 is used. The fourth quarter is not considered since the project started before this quarter started. All other data observations analyzed in this thesis are based on the same time frame.

agency, there is a possibility to extend the work force to a number of hours that cannot be covered by regular base. The extension of employees is only performed at the beginning of each month, not during.

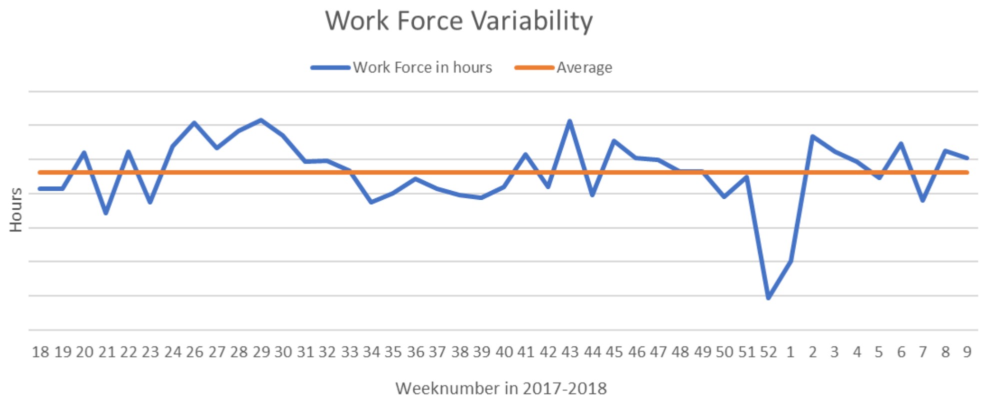

FIGURE 10 WORK FORCE VARIABILITY[2]

Figure 10 shows the variability in work force. As can be seen, week 25 is not included in the graph due to an SAP outage. Therefore, that particular set of data is not representative for the analysis. An average line is shown in orange to indicate the variability. During week 52 and 1, two outlying observations can be set. Just like week 33 to 40, this is a popular period for holidays and the work force will be lower than on average. In conclusion, there is not much flexibility in the work force planning. In fact, the work force can be seen as a given with little room for extension.

3.3.4 Variability

There are several sources that cause variabilities in the Inbound process. Two kinds of variability can be distinguished: arrival and process.

3.3.4.1 Arrival

Some upstream activities can be considered as sources for Inbound arrival variability. These include procurement, supplier lead-time and transport. Procurement includes the ordering procedures of replenishing the warehouse. Products are often ordered via an automated ordering policy in SAP in response to low inventory levels. The variability can be translated into the upstream partners according to the Bullwhip effect, which is the amplification of variation moving upstream the supply chain. (Balasubramanian, Whitman, Ramachandran, & Sheelavant, 2002)

In addition, the time it takes suppliers to deliver goods to the DC after receiving a purchase order is stated as the supplier lead time. Even if Vita's own process is completely stabilized, the variability in supplier's deliveries can have a negative influence. One particular part of this supplier lead time is the time it takes for goods to be transported to the DC. Although the responsibility lies with the supplier, they are also dependent on the transport carriers. The accuracy and reliability of these transporters have influence on the variability in the Inbound arrival process. An overview of the arriving shipments per workday per hour is illustrated in Figure 23 Appendix B.

3.3.4.2 Process

Variability can also occur within the Inbound process. Certain factors like packaging and product mixes have influence on the amount of labor it takes to flow through the Inbound process. How much time

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[2] The y-axis of this figure is not available due to confidentiality reasons.

it takes to flow through the process differs per product type. When a shipment consists of different product types or unique single items, a sorting step needs to be executed which results in more effort. For example, bulk items (a large number of similar products) will be processed faster than a set of unique items.

Some items that are being received at the DC experience quality issues. In this case, the amount of labor can be much higher than was expected on forehand. The productivity rate of the employees is dependent on the workload and the experience of each individual. It can differ day by day which results in variances along the road. Overall, the differences in the amount of labor results in variabilities along the process.

3.4 Performance

The current performance of the Inbound process will be analyzed in this section. The key performance indicators for the process are productivity, throughput time and on-time performance. Benchmarking is done to compare Vita's KPIs.

3.4.1 Productivity

Management forecasts the expected number of lines processed by Inbound every month. A delivery line contains all similar goods that are part of a shipment. The weekly forecasts are compared to the actual number of lines, which indicate the accuracy of the high-level planning. Figure 11 shows the forecasted versus the actual number of lines per week. It can be concluded that this high-level planning is simulating the actual situation well. The low-level, or daily floor, planning, is covered by this weekly high-level planning. It is more difficult to plan lines on a daily base. The weekly planning does not have to deal with tracking information, shipment arrivals and space issues.

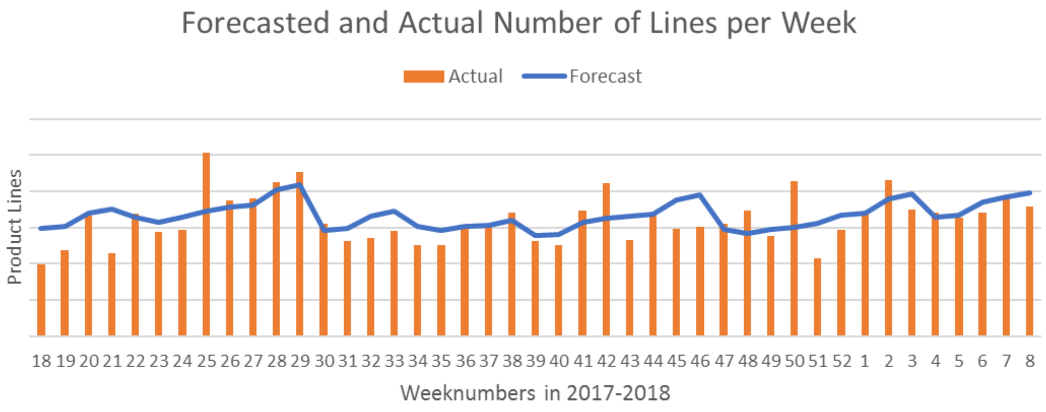

FIGURE 11 FORECASTED AND ACTUAL NUMBER OF LINES PER WEEK[3]

These line forecasts are used to determine the productivity target and number of required working hours to meet this target. The productivity target is the average number of product lines per working hour. Whenever the target is not met by regular frequency, management starts an examination into the causes of this discrepancy. The actual average productivity is measured and compared to the target every day. Figure 12 shows the actual productivity versus the set target per week. A trendline is also added which indicates the productivity growth. It can be concluded that the productivity matches the set target. The target should be updated when considering the growing trend.

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[3] The y-axis of this figure is not available due to confidentiality reasons.

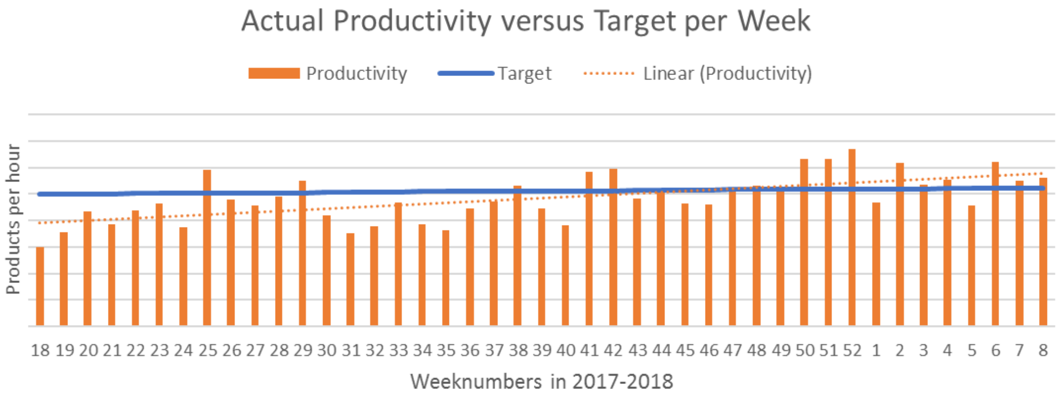

Figure 12 Actual Productivity versus Target per Week[4]

3.4.2 Throughput Time

The throughput time of the Inbound process is an important KPI for Vita. For Inbound, it measures the time it takes receiving the product until booking it into the IT-system. The CLT tracks these times such that data can be analyzed. For Vita, the mean throughput time of a shipment is set at 30.10 hours. When all occurring issues are left out of scope, the throughput time would be 17.93 hours. In the next section, the performance of the throughput time is further elaborated.

A regression analysis is done to examine the variables that could influence the throughput time. The y-variable is the throughput time in minutes and the x-variables are the number of case packs, the number of pallets, whether the shipment has priority and whether an issue occurred during the process. The results of the regression analysis can be found in Table 15 Appendix C. A significant positive influence of a variable is indicated with a positive coefficient and a P-value larger than 0.05. In particular, throughput time increases when this kind of variables are present. Whether there is a space issue has a significant positive effect on the throughput time. A coefficient of 8003.84 indicates that when a space issue occurs, the throughput time will increase significantly. The occurrence of other issues has, alike but not as large as the space issue, this influence. The number of case packs only has a small positive influence. In addition, the number of pallets has 1.72 time more effect $\left(\frac{101.82}{68.87} = \frac{coefficient\ of\ pallets}{coefficient\ of\ case\ packs}\right)$ on the throughput time than the case packs. 1.72 is used to determine the weight of a shipment consisting of pallets or case packs. Whether the shipment has a label priority is not significantly (P-value of 0.83) related to the throughput time.

To gain more insight in the throughput time, one specific part is analyzed: the lane or queue waiting time. After products are received, they are placed in the lane waiting to be booked. The average fraction of the throughput time of which the product is waiting is 79%. This means that for a 24-hours throughput time, the product awaits 21 hours in the lane. This same percentage is measured without the shipments that contain an issue. In this case, 86% of the throughput time consists of waiting time in the lane on average. This indicates that there are improvement opportunities in reducing the throughput time within this non-value-added activity. It can also indicate that the current workload and the work force are not in balance. This can be caused by performing too many handling steps, which indicates an inefficient process design, or by a lack in work force.

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[4] The y-axis of this figure is not available due to confidentiality reasons.

3.4.3 On-time Performance

Inbound has predefined lead time targets which it wants to meet every day. Their lead time is the time between receiving and confirmation of the booking process. The targets are set by the management and can be divided into two categories: case pack and pallet shipments. For case packs, the target is set on 75% of the shipments to be processed within 24 hours and 100% within 48 hours. When a shipment consists of pallets, the target is set on 100% that has to be processed within 48 hours. In order to see whether these targets are met, the throughput times are categorized into below or equal to 24 hours, between 24 hours and 48 hours and performances which take longer than 48 hours.

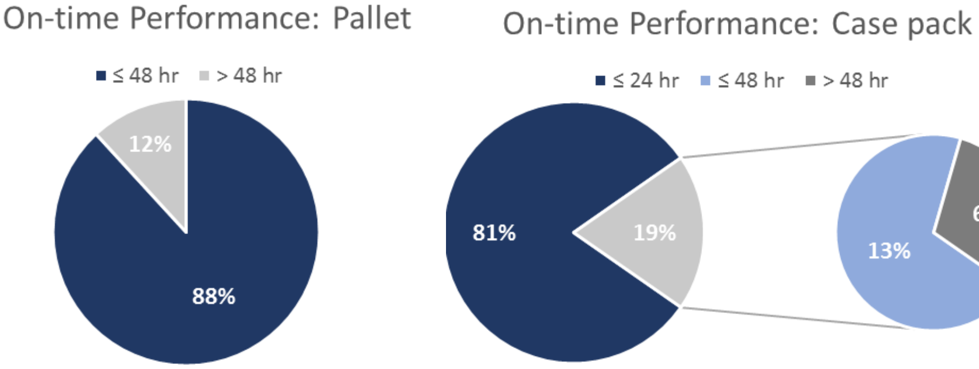

FIGURE 13 ON-TIME PERFORMANCE PALLET AND CASE PACK

The on-time performance indicates the number of times the throughput time does not meet the lead time targets. In Figure 13, the on-time performances are given regarding to the set lead times of Vita. For case pack shipments, 81% of all shipments is booked within 24 hours after receiving. The other 19% can be split into 13% which take between 24 hours and 48 hours and 6% which take longer than 48 hours. For the pallet shipments, 88% is booked within 48 hours. On average, the predefined target of 24 hours is just met, while the target of 48 hours is not met at all. A small amount (12% for pallets and 6% for case packs) of the shipments take more than 48 hours. It can thus be concluded that lead time should be reduced in order to fulfill the defined targets.

3.4.4 Benchmarking

In order to classify Vita to other competitive practices, benchmarking is being processed. This is a process of studying the competitive industry, comparing performances and indicate successes and shortcoming. To compare the performance of Vita in more detail, a master thesis of an equivalent process is used. Similar to this research project, Boeve (2016) focusses on the Inbound process of receiving, checking and put-away orders. The main difference lies within the type of the product. Boeve describes a company that processes plastic pipes, while Vita has healthcare products which have to be of high quality and reliability. This is why, Vita experiences more inspections and cautious processes.

When considering the thesis of Boeve (2016), the average throughput time is 14.42 hours. It indicates the mismatch between the capacity to perform the Inbound process and number of products that need to be processed, which results in a too long dock to stock time. A similar case is going on at Vita. Vita has a throughput time of 30.10 hours. When shipments with issues are being eliminated from the data, this average throughput time decreases to 19.49 hours. The on-time performances are not completely met according to the defined lead time targets and the ratio between waiting time and total throughput time is 86% without considering the issues. This does indicate why long throughput time results in their long waiting times.

The difference between the throughput time of the benchmark case and Vita is circa 16 hours with issues and 5 hours without issues. Part of this large difference can be explained by the different kind of industry. Healthcare industry needs to be inspected more to ensure a continuously high quality. The benchmark case is a smaller scaled company than Delta with less receiving shipments each day. That being said, the difference indicates large improvements regarding the throughput time in the company Vita.

3.5 Conclusion

Sub-question 1a is answered in this chapter by analyzing the current “as-if” situation of the Inbound process. The business process is divided into two main steps: receiving and booking. The current use of information and technology along the Supply Chain and Inbound department is considered. Supply Chain creates purchase orders that lead to replenishment of the warehouse. These replenishments arrive at the Inbound department as incoming shipments. The information about these shipments is (partly) unavailable which leads to planning problems.

While answering sub-question 1b, the current planning and control process is analyzed. Various problematic areas are discovered concerning this topic. The Inbound planning is currently based on experiences of the planners and information of pull shipments received via Excel files. In order to balance the use of resources, a reliable and accurate planning is needed. This reliability and accuracy can be achieved by improving the available information about shipment arrivals and the ability to influence the pull/push ratio of shipments. Time-consuming receipts should be shifted to off-peak hours such that the work load is spread evenly throughout the work day. (Tompkins, White, Bozer, & Tanchoco, 2010) The research does not include the effect of changing the pull/push ratio since this is a cross-functional problem which needs large input from the Supply Chain department to include the suppliers and transporters. The current method of planning Inbound is performed manually without the use of any information system. By improving transparency along the supply chain and developing a planning tool or concept, improvement opportunities rise in the Inbound planning process.

For sub-question 1c, several performance indicators of the Inbound process are analyzed. The lead times are nearly to not met according to the targets set by Vita. The throughput time along the Inbound process should be reduced. The benchmarking section indicates many possible improvements regarding the throughput time at Vita. At first, the number of issues that occur during the process have a negative effect on the throughput time. By solving these issues in earlier stages of the process and preferably preventing them, the throughput time can be improved and the interruptions of the process flow can be reduced. Secondly, the share of the total throughput time the products are waiting indicates that the throughput time can be reduced significantly by improving the wastes and inefficiencies in the Inbound process. The current productivity matches the target set by management. A growing trend indicates that targets should be analyzed and updated. In conclusion, the supply chain analysis highlights the improvement opportunities in Vita’s Inbound process. Throughput time should be improved by reducing movements along the process, streamlining data at receiving and planning Inbound activities more efficiently.

4 Literature Review

In this chapter, sub-question 2a will be answered: "*What are the key aspects and needs of an adequate planning and control tool in academic studies?*". Goal is to find possible solutions for the research problem in academic literature. As stated before, the Inbound process is an under-valued topic and a missing link within successful Supply Chain Management. In order to improve the Inbound process in terms of the research's most important performance indicator, literature is investigated into possible improvements.

After costs, quality and reliability, flexibility is gaining more and more importance as performance indicator. By creating flexibility in operational systems, process uncertainties can be reduced. These uncertainties occur in form of timing and frequency of arrivals, processing times and capacities. Reducing uncertainties and increasing flexibility are often-investigated topics. Some solution directions found in literature are discussed in this research. At first, the importance of information exchange is described in section 4.1. Secondly, the methodology of order assignment and its contribution to a flexible system are examined in section 4.2.

4.1 Information Exchange

Holmström and Aavikko (1994) state that the coordination of supplier deliveries in terms of frequency, timing and lateness is one of the key problems in the Inbound process. It is crucial to define appropriate delivery agreements, give suppliers constructive feedback on their performance and quality, and create collaborations between Inbound and its upstream Supply Chain partners. This indicates the importance of Supply Chain Integration along the partners in the chain. (Holmström & Aavikko, 1994) For planning purposes at the Inbound department, status information of the incoming shipments is needed. The availability of this information is highly dependent on the suppliers of the orders. Within academic literature, information exchange is an often-investigated problem. Prajogo and Olhager (2012) state that companies do not only need to improve the internal operations, but also focus on this integration between suppliers and customers. They indicate that by improving the logistics integration, various problems such as the Bullwhip effect will be reduced. (Balasubramanian, Whitman, Ramachandran, & Sheelavant, 2002)

Zhou and Benton (2007) indicate that information sharing between suppliers and customer enhance supply chain performance such as a more adequate planning. The idea arises that transparency along the chain is created to reduce variations. (Zhou & Benton, 2007) By receiving information about arriving orders in advance, Inbound can plan its operations in a more efficient way by taking these orders into account in the schedule. In a comparable research, Larbi et al. (2011) examined three different situations of information sharing: scheduling under no information, partial information and full information. This information includes the order and content of incoming trucks. In the case of no information, the trucks just arrive randomly without any notice in advance. Under full information, the department knows when and what to expect at every moment in time. When information is limited, this means that for the next Z[5] trucks, the content and arrival moment is known. The case of full information is not realistic since variations occur in each process and a deterministic situation is not reasonable. Yet, it can give a good indication of the feasibility of the system and a lower bound for the performance indicator.

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[5] Z indicates a number of trucks that is looked ahead to. It is an integer greater than or equal to zero.

Although the research of Larbi et al. (2011) is based on cross-docking operations, some of its findings can be used for this research as well. They represent the idea that scheduling of operations can be performed in smaller time horizons. Instead of daily schedules, they indicate generation of scheduling for several hours, repeated multiple times a day. This reduces the complexity of the problem which can result in more efficient solutions. When more information is available during the planning horizon, it can be updated and included in planning decisions. A more interesting finding of Larbi et al. (2011) is the fact that partial information with a specific number for *Z*, has almost as good results as the full information scenario. This indicates that creating a planning horizon with enough information about the incoming arrivals would be sufficient to achieve an efficient and adequate planning.

4.2 Order Assignment

The assignment of orders to machines determines the route the orders take through the process. In the next two sections, two determents of this routing are being discussed: flexibility of system and assignment according to algorithms.

4.2.1 Flexibility of the System

Flexibility can be defined as “the ability to change or react with little penalty in time, effort, cost or performance.” (Upton, 1994, p. 73) A flexible operational system is formed by machines, labor and material handling flexibility. An important aspect of those three items is the process routing. This indicates the sequence of activities during a process which leads to the final product. In process routing, the following topics are relevant: priority, scheduling and allocation rules. These rules define the decisions about the route that a product takes along the process. (Bertrand, 2003)

In their research, Jordan and Graves (1995) indicate the importance of flexibility in manufacturing systems as competitive advantage in market responsiveness. The research answers two important questions: *How much flexibility is needed?* and *How to add it to an existing set of plants?* They state that this flexibility is determined by decisions about process routing. The allocation of products to machines can have a strong influence in terms of flexibility and costs. Therefore, a trade-off between flexibility and its costs must be made.

Consider a system that has ten product groups and ten machines. In the stated research, the allocation of products to plants are tested according to different scenarios. They have started with low flexibility, which means that each product can only be processed at one machine. Next, they have added links between products and machines to investigate the effect of having extra flexibility. This lead into the examination of the effects of having one or multiple chains with the same amount of links. A chain is a group of products and plants that is (in)directly connected in terms of allocation decisions.

The results indicate that the more flexibility or links are added, the more sales is expected. Most interestingly when limited flexibility is well configured, it can achieve almost the same benefits as full flexibility. After adding the tenth link, circa 95% of the sales and utilization benefits of full flexibility is gained. This effect is strengthened by building a system with as many numbers of plants and products per chain, the longest chain, as possible.

Jordan and Graves (1995) find three main rules for improving a system’s flexibility.

1. Equalizing the number of plants to which each product in the chain is assigned to.
2. Equalizing the number of products to which each plant in the chain is assigned to.

3. Creating a chain that includes as many plants and products as possible, preferably one chain for the entire system.

In case of parallel machines, scheduling is used to balance the workload over these identical machines. The idea is that *n* jobs are assigned to *m* parallel machines. How these jobs are being assigned is dependent on the strategy determined by the department. The strategy should help removing bottlenecks from the system. The main goals are to achieve efficient utilization of all work stations to minimize WIP-inventory and to smooth operations.

4.2.2 Assignment Algorithm with Information Availability

This research examines the assignment of orders to stations when information about incoming orders is available. Fleischmann et al. (2004) performed a comparable study which covers a dynamic vehicle routing problem with the integration of online traffic information. The customer orders are of dynamic behavior of which information becomes available during the planning process. This paper describes a single order at once, no pre-emption model that deals with minimizing delays and costs. Various planning horizons are considered in which the planning is updated accordingly to available information. Fleischmann et al. (2004) conclude that the assignment algorithm, which re-plans every time an event occurs, outperforms the other algorithms. When a machine is done executing the current order, a new order is assigned to it according to the updated planning schedule. This schedule is updated whenever new information becomes available. The latest completion time of the orders in execution is therefore considered to be the planning horizon.

The planning framework provides a method to calculate a solution for this dynamic vehicle routing problem. Based on the dynamic travel time information, shortest paths are calculated dynamically. Then, the assignment algorithm is used to determine which orders are assigned to which machines such that corresponding costs are minimized. By updating information at every occurring event, future decisions are revised up till the moment they are actually made. This creates a high flexibility in decision making which improves the process' performance. (Fleischmann, Gnutzmann, & Sandvoß, 2004)

5 Conceptual Design

Chapter 5 describes a conceptual design for the research. The goal is to develop a model that can schedule the Inbound activities according to the characteristics of Vita. This chapter also provides an answer to sub-question 2b: "*Which improvements can be redesigned in the process in order to decrease the throughput time and create slack in the planning?*". Section 5.1 describes the model scope which results in the objectives in 5.2. An overview of the design constraints is given in section 5.3 which are translated in design parameters that result in alternative model scenarios in 5.4. In addition, the decisions are categorized into the three hierarchical levels. A summary of the conceptual model is given is 5.5 with the alternative scenarios that are used in the detailed design.

5.1 Model Scope

In order to generalize the research, the conceptual model is defined based on scientific literature. The general Inbound process is similar for several industries. This logistics process is related to receiving, storing and distributing inputs into the warehouse. Examples of such activities are Inbound transportation, incoming inspection, materials handling, warehousing, inventory control and reverse logistics. (van Weele, 2010) Inbound is the starting point of the material flow in the goods receiving process in a Distribution Center, which consists of 6 steps. (ten Hompel & Schmidt, 2007)

1. Notification of goods receipt and delivery date
2. Goods acceptance
3. Goods receipt
4. Incoming inspection
5. Building of loading units
6. Put-away

In order to deal with the stated problem situation, a scope for the research model is being identified. The conceptual model includes the goods receipt and the building of loading units. These two steps are the main tasks of the Inbound department and can be represented as production stations. To investigate the improvement opportunities, the goods acceptance and the corresponding notification are considered as partially included in scope. For some redesigns, these process steps will be examined and covered. The other steps, incoming inspection and put-away, are not considered in the model. In Figure 14, the scope of the conceptual model is illustrated in green.

All arriving shipments are assumed to be in good condition. Therefore, no defect items will occur during the simulation. However a 0% failure rate will not occur in a realistic situation, the failure of items is not relevant to this model. Since this research investigates the Inbound process design and the availability of shipping information, the redesign opportunities have no direct effect on the failure rate. Therefore, the occurrence of failure is left out of scope.

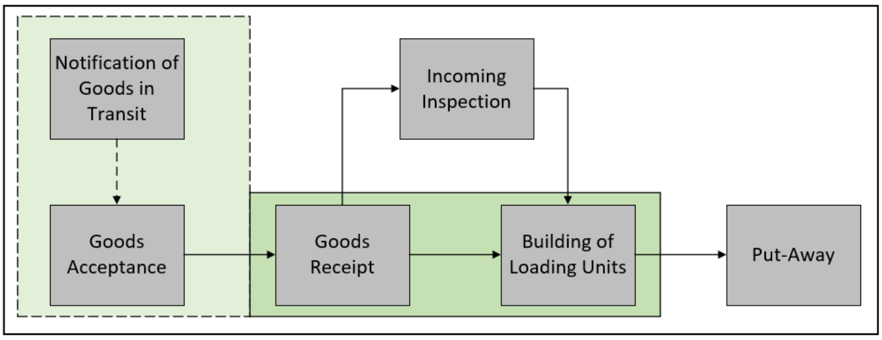

FIGURE 14 SCOPE OF CONCEPTUAL MODEL

5.2 Objectives

The main objective of the model is to minimize the throughput time of processing products at the Inbound department. Meaning, the time it takes for incoming orders to be received until they are booked at Inbound should be reduced by improving the current situation. This affects the on-time performance directly, which indicates the fraction of orders that is processed within defined target. A WIP-inventory is created by waiting orders before busy stations. It is important to realize that the WIP-inventory serves as a flow controlling parameter. By setting the inventory to a predefined level, a constant workflow can be created such that utilization can be optimized. Since orders should not be rejected or influenced, this is not the case for this research model. The goal is set to minimizing the WIP-inventory level without losing a buffer for the work flow.

5.3 Design Constraints

To meet the set objectives, the model should be created in a way that it represents the reality as close as possible. However, there are some existing design constraints that influence the model. These are strict design limits that must be met in order to achieve a feasible and acceptable result. The design constraints are as followed.

5.3.1 Design Horizon

The Inbound department is assumed to be open for five days a week, from Monday until Friday. The weekends are left out of the model and one work week consists of five days. Each day, the department is open for 11 hours per day, from 7:00 till 18:00. The model will consider the results per working hour and day which leads to a time unit of hours.

5.3.2 Rejection of Orders

No incoming orders or arriving shipments can be rejected. Even if the orders are going to be overdue, the shipment must be processed and accomplished. All orders that arrive at the system are accepted and should leave the system after being completely processed.

5.3.3 Workforce

The workforce is assumed to be known in advance. When illness occurs, there are other employees available to cover the shifts. There should be an ample workforce to support the predefined hours to make sure the stations are working during these hours.

5.3.4 Product Groups

Since it is not possible to simulate each individual job, classes will be created to classify the different types of products. This means that each arriving shipment or job will be classified into a category. Each category has its own process characteristics, such as processing time and level of station flexibility. The categories are products with similar process features so they can be treated in the same way.

5.3.5 Work Stations

As stated in the scope, the goods receipt and the building of loading units are considered in this model. The operations performed in these activities can be considered as work stations. There is one work station that performs the goods receipt, called stage 1, and *n* stations for the building of loading units, called stage 2. In front of the stages, queues are formed for waiting products to be staged. This indicates that there is a WIP-inventory which should be minimized according to the objective of the model. For the *n* parallel stations in stage 2, the processing times are assumed to be identical per product type. This means that the processing times of stage 2 are not dependent on the type of station.

The work station can only process one job at a time. This basically means that a station can only manufacture one unit and one shipment can only be processed at one station a time. In addition, a model without preemption is assumed. Once a job has started its process at a station, it will run to completion with all its assigned stations.

5.3.6 Order Arrival

The arrival of orders is defined in units of shipments. This means that no distinction is made between case packs and pallets. In the calculations of the processing times, adjustments are made to ensure service times can be defined per shipment. All shipments that arrive are assumed to be known at the start of every hour. This means that orders will only arrive at full hours and no incoming order can occur during working hours.

5.4 Design Parameters

The described objectives of the research should be achieved by planning the resources and order efficiently along the Inbound process. Therefore, some key aspects are designed such that throughput time and WIP-inventory can be reduced. Firstly, the information availability serves as input for the planning. Secondly, it is important to consider the process flow design. Alternative ways the products flow through the process, the allocation methods and the system's flexibility can improve the set objectives. In the following sections, the design parameters are explained. These are then classified into Antony's pyramid. (Anthony, 1965)

5.4.1 Information Availability

The Inbound process should be planned in such a way orders can be processed as efficient as possible at the stations. Therefore, information is needed to determine which orders are processed at what time, on which machine and in which sequence. This information consists of two parts: information concerning in-transit orders and information about orders that have already arrived at Inbound. For the first category, it is important to know when orders will arrive and how much workload they will contain. In addition, the time this information is needed in advance is a parameter that differs per situation. Based on the processing times of orders, it can be determined how long in advance information about arriving orders is needed. For the second category, which are orders that have already arrived, information about the expected workload is required. This expected workload contributes in planning the assignment of orders to the stations.

As described in the literature study, information availability about in-transit shipments can be classified into three possible scenarios: scheduling under no information, partial information and full information. The application of the three information flows in this research model are discussed in next sections.

5.4.1.1 Full Information

The availability of all information would result in a deterministic problem. All information about arrived and not yet arrived shipments is available. This means that the arrival times and processing times are known and thus deterministic. The assignment of orders in flexible scheduling problems with identical parallel machines is a broadly examined topic in literature. The shortest processing time rule is well-known to be best performing when considering throughput time as performance indicator. (Bertrand, Wortmann, & Wijngaard, 1990) (Montazeri & Van Wassenhove, 1990) Ouazene et al. (2014) examined a method of assigning a job to the machine with the smallest workload, also referred to as WINQ. The workload of a machine is calculated by taking the sum of the processing times of all assigned jobs. A list of all unassigned jobs is used to select the following job. The first job from the list that is allocated next can be determined by using a scheduling rule. (Ouazene, Yalaoui, Chehade, & Yalaoui, 2014)

Choi and Malstrom (1988) state that a combination of the Shortest Processing Time (SPT) rule and WINQ performs best when considering throughput time as performance indicator. This means that after determining the machine with the lowest workload in queue, a job will be chosen from the unassigned jobs list by means of a SPT-principle. (Choi & Malstrom, 1988) This study investigates a dynamic flexible job shop scheduling problem. Other than a general flexible job shop scheduling problem, the job releases occur dynamically during the process. This creates a situation of idleness of stations in case of a low utilization of the stations. In Vita's case, it can be concluded that there is enough WIP-inventory to achieve a high utilization. Therefore, the effect of the order releases can be ignored. This means that the SPT-rule in combination with the WINQ policy can be used to model this deterministic scheduling problem.

5.4.1.2 No Information

In contrary to the previous situation, this situation assumes that there is no in-transit information available. This means that only information is accessible concerning orders that are inside the system. In this case, it is assumed that orders arrive according to a fitted distribution based on experimental data. The service times of the shipments that have arrived have to be approximated by a goodness-of-fit test. Therefore, planning is based on approximations and not on real-time data. Since no information is available, the planning follows certain routing rules that would suit the set objectives.

In literature, the sequence in which jobs are chosen to be processed next, can be referred to as priority rules. A lot of research is done in this area to determine the best scheduling rule. The most common used rule is the First-In-First-Out (FIFO) rule. It processes jobs according to when they arrive in the system. When throughput time is set as performance indicator, the Shortest Processing Time rule is performing best. Overall, the SPT-rule will outperform other priority rules. (Montazeri & Van Wassenhove, 1990) (Eilon & Cotterill, 1968) In addition, Eilon and Cotterill (1968) state that an extension of the SPT-rule performs better than the basic SPT-rule. The idea is that the SPT-sequence rule is modified with a float F, which is calculated as followed.

EQUATION 1 FLOAT F OF SPT-RULE

$$F = (t_d - t) - t'_e - U$$

$$\begin{aligned} &with \\ &\qquad t_d - t = time\ available\ until\ due\ date \\ &\qquad t'_e = estimated\ time\ for\ outstanding\ operations\ on\ the\ job \\ &\qquad U = a\ control\ parameter\ to\ allow\ for\ delays\ in\ the\ system \end{aligned}$$

Two queues are formed. The first queue consists of all jobs with $F \leq 0$, and the second queue covers the jobs with $F > 0$. The first queue then gets priority over the second queue since these are more urgent orders. Each individual queue follows a SPT-policy. This scheduling rule, named SPT/float, takes due dates into account to reduce delays for very long jobs. Besides, more flexibility is created due to the control parameter U.

5.4.1.3 Partial Information

As discussed in the literature study, the availability of a certain horizon of information would achieve an almost-as-good situation as the availability of all information. This is a more realistic situation for the research scope. It means that for an upcoming planning horizon, information about the arriving shipments is to be known. This information consists of two parts: arrival time and workload. Instead of knowing information about the orders that have arrived, there is information available about orders yet to come. This creates a situation in which shipments can be planned without having even arrived yet. Whenever a new event occurs, which would be the arrival of new orders, new information or a station that becomes idle, a sequence of planning runs is performed to update the current plan with new information. Then a decision on the very next action is made while further actions are planned but not yet communicated. Due to the myopic character, the situation strives for maximum flexibility. In other words, the planning looks ahead to shipments which are to be arrived and updates the planning according to the in-transit information. The research of Fleischmann et al. (2004) is consulted to build such a look-ahead algorithm.

The overall goal of the algorithm is to assign orders to stations in the most costs and time efficient matter. Based on a certain horizon of planning, there will be determined which order will be processed next at each station. Then, whenever a station becomes idle, the planning is updated with a decision based on all available information and an order is chosen to be processed next. Since this decision is based on all information, it is possible a not yet arrived order is being chosen. A trade-off is made between waiting for that order to arrive, which results in an idle station, or creating a sub-optimal performance and delaying that order. This trade-off is translated into costs, which is the objective of the assignment algorithm. The designed planning algorithm is illustrated in Figure 15. (Fleischmann, Gnutzmann, & Sandvoß, 2004)

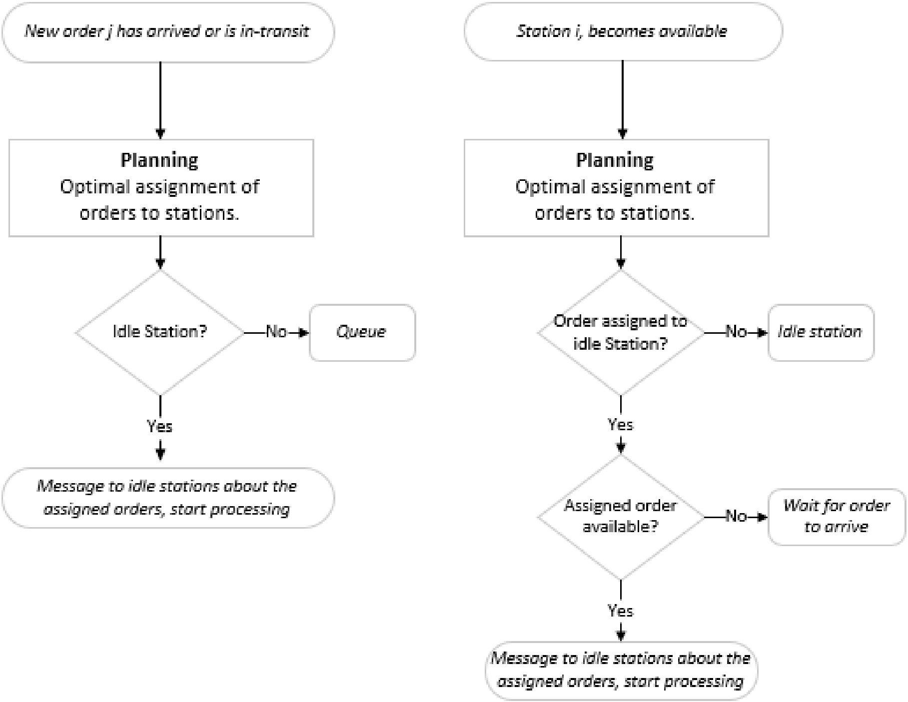

FIGURE 15 PLANNING PROCEDURE WITH APPLIED ASSIGNMENT ALGORITHM

It starts with an event trigger: either an arrival of new orders or new information, or a completion of an order on a station. In both cases, a planning update is performed to ensure all (new) information is covered. After this, a myopic planning is made with the assignment of a next order at each station. At the time a new order arrives, a check will be executed verifying whether the station is idle or unavailable. If the station is idle, it will process the assigned new order. In case of unavailability, the order will be placed in the queue. Since there is only one queue in front of stage 2, there is no assignment decision made yet. The loop of the completion of an order, checks after planning which order has been assigned next. At this point, two possibilities exist: the order has either arrived already or it is still in-transit. In the first case, the order is processed next at the station. In the latter case, the station stays idle until the assigned order arrives.

One of the main risks concerning this assignment problem is the uncertainty in arrivals and the process of the orders. Forecasted values are being used to plan the process and an error will occur due to its dynamic character. Therefore, unwanted events will happen such as unplanned arrivals or unplanned end times of stations. This can influence the planning in terms of creating delays. It is key to update the planning algorithm each time an event occurs to provide the flexibility which deals with this uncertainty.

In addition to the assignment algorithm, information can also be of value while planning operations on a higher level. Information availability on push shipments one or more days in advance makes the pull shipments planning more efficient. This results in a reduction of the arrival variance while the amount of shipments does not change on average. Changing the ratio between pull and push shipments can thus lead to a more evenly spread arrival process which will result in a decreased and stabilized WIP flow. Ultimately, this results in a reduced throughput time but the question arises on how this would influence the use of the look-ahead algorithm.

5.4.2 System Flexibility

The design of the process flow has great influence on the set objectives. One of the most used aspects to create a more efficient process, is increasing the flexibility of the system. Jordan and Graves (1995) indicate that increasing flexibility has a positive influence on the system's performance. This can be achieved by training employees with specific skills and design the stations in such a way more types of products can be processed at one station.

As discussed in the literature, three different scenarios for station flexibility exist: full, limited and no flexibility. First option states that the system can be fully flexible. In this case, the stations of stage 2 are identical and there is one common queue created in front of them. It would be logical to use a common queue because the assignment decision is postponed to the last moment before processing. Then the flexibility increases to deal with uncertainties and variations in the process. Since flexibility is performed over a maximum level, the queue follows the WINQ principle. The parallel stations are identical such that no skill allocation differences occur. When information is available in advance, the decision could be made to wait for more profitable incoming shipments. Due to the fully flexible system, this is less interesting than the next case which introduces limited flexibility. Here, the surplus value of advance information is added when the skills allocation becomes more limited.

Secondly, the limited flexibility in this research indicates that each product type can be processed on two different stations. It is discussable whether to use a common queue or separate queues per station of stage 2. Questionable is how permanent the allocation to the queues is. Is it possible to switch a product to another queue in case of new information? According to Newell (1982), long-term approximations will be the same for a common queue or separate queues. Even if the jobs are not switching queues, new arrivals will choose the shortest queue which leads to spreading workload over all stations. The only difference between common or separate queues on long-term, is the order of service. To increase flexibility, one common queue will be used.

In the third case, low flexibility, it makes no sense to use common queues. The allocation of the shipments is already determined since each product has only one assigned station. The question to ask is the sequence of each queue. Currently, there is already a situation of limited flexibility at Inbound and the goal is to increase its flexibility. For this research, the implementation of low flexibility would downgrade the performance. Therefore, this scenario is left out of scope.

5.4.3 Hierarchical Decision Making

The redesign decisions can be classified into three categories: strategic, tactical and operational. This is shown in Figure 16. The higher the decision level, the more risk and uncertainty is involved. Besides, the three levels correspond to the three levels of management: high, middle and low. The strategic decisions are being made at top-level, tactical at middle and operational at lower management level. The considered decisions described in this chapter are classified into one of these three levels. (Anthony, 1965)

FIGURE 16 HIERARCHICAL DECISION-MAKING PYRAMID (ANTHONY, 1965)

Decisions made on strategic level are based on the enterprises common goals. It mostly includes long-term implications on the business with high risks and uncertainties. For this case, the acquisition and implementation of an Information Technology system is a high-level decision. Due to large investments in costs and time, the high-level management is being involved. The effects an IT system has on information availability are large. Redesigning the layout of the Inbound department is decided on strategic level. As stated, this is a time and cost-consuming investment. The cross-functional change of the pull/push ratio can be seen as a strategic decision. Not just multiple internal departments like Inbound and Supply Chain are involved, but also the external suppliers. Most likely, decisions about starting a project with this ratio are led by a higher management level.

The tactical level is based on medium-term decisions with less risks and uncertainties and at this level the design parameters are included. The decisions regarding the information availability depend on tactical decisions made. These decisions include the length of the planning horizon and the content of the information used for planning. Secondly, the skill allocation per station and the design of the work stations are decisions on tactical level. The decisions result in the determination of a work method and influence the order assignment to the stations. Meaning, it indicates the flexibility of the stations. The training of employees and changing the division of skills over the station is determined at tactical level. This decision has a large influence on how stations are utilized and on performances in terms of inventory level and throughput time. The determination of mutual or separate queues in front of the work stations is a tactical decision. It is important to consider that these decision parameters are dependent on decisions made at a higher level.

Finally, the operational level characterizes decisions that involve low-risk and routine decisions with shorter time-frames. The most important decision made at operational level in this conceptual design is the allocation of jobs to stations. Based on specific rules or assignment algorithms, the jobs are assigned of the queue to a station. This allocation depends on decisions made at strategic and tactical levels. The planning concerning the employees and resources has to be determined. At this point, decisions about the working hours of the stations and manpower are made. It needs to be scheduled in such a way operational efficiency and productivity is achieved. Changing these schedules has a large influence on performance but needs small investments.

5.5 Conceptual Design Summary

Overall Objectives

- Minimizing throughput time of the Inbound process
- Minimizing WIP-inventory

Scope

- Notification of Goods In-Transit
- Goods Acceptance
- Goods Receipt
- Building of Loading Units
- Queues in front of stations

Constraints

- Inbound is open 11 hours a day, 5 days a week, 50 weeks a year
- Ample workforce to cover the stations
- No preemption
- One job at one station a time
- Products are categorized into different groups
- Orders cannot be rejected and arrive at full hours
- Parallel stations are identical for processing times

Design Parameters

- Information availability about arrivals and workload
- Flexibility level of work stations

6 Detailed Design

The goal of the detailed design is to translate the conceptual design into a mathematical model that can be simulated. This simulation model is used for providing insights in the redesign opportunities rather than aiming for a precise simulation with exact results. Goal is to prove that redesigning would improve the current situation. Therefore, sub-question 2c, *"Which integrated planning and control tool can be developed and what are its specific requirements for the Inbound process of Vita?"*, can be answered by describing how the redesigns can be applied to the model. Section 6.1 gives an overview of the model and the mathematical details of this model are then being discussed in 6.2. The calculations of the key performance indicators are described in section 6.3, while the experimental set-up is explained in 6.4.

6.1 Model Overview

As discussed in the previous chapter, the overall characteristics of a receiving process in an Inbound department are similar for various industries. The main entities of this research model can be seen in Figure 17, starting with the arrival of the shipments at the Inbound floor. Each time shipments arrive, they will enter the queue for the receipt process (station 1). When the registration is finished, the shipments enter the second queue. Then, the shipment needs to be assigned to one of the work stations (station 2 till 6). The stations perform a set of activities like sorting, consolidating and booking to make sure the products are ready to be put-away into the warehouse. To model this situation, some model parameters have to be determined. From analysis, it is clear that the second stage is the bottleneck of the system and this is why the key research steps are based on stage 2 of the system.

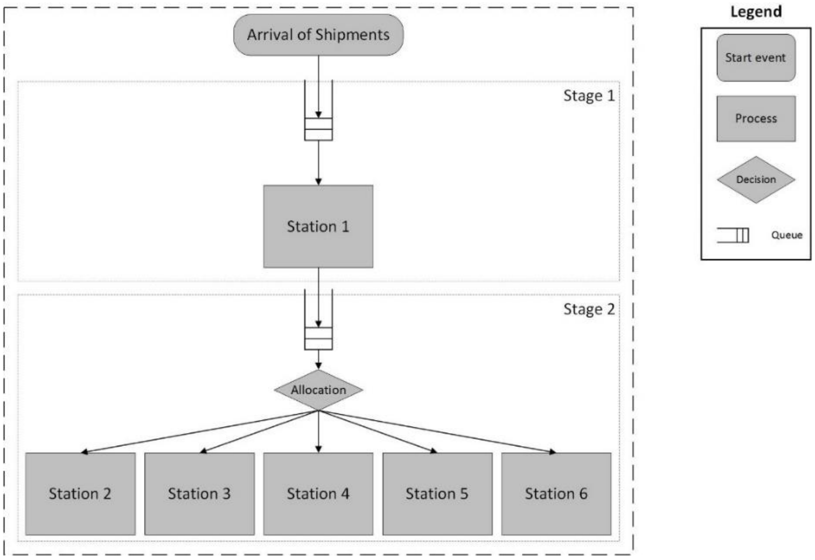

FIGURE 17 CONCEPTUAL MODEL

6.2 Mathematical Model

The following mathematical model is being used as a base for the simulation model and is based on the assignment algorithm of Fleischmann et al. (2004). This section includes the explanation of the cost determination, assignment algorithm, look-ahead principle and station flexibility. An overview of the used model notations are displayed in Appendix D.

6.2.1 Cost Determination

The objective of the mathematical model is to minimize the costs. Costs regarding the assignment of order j (c_j) need to be determined. All shipments j considered in the planning are included in set J. In addition, the stations of stage 2 are defined by set I. Three different aspects are being considered in the costs formula: urgency, processing and idle time.

6.2.1.1 Processing Time

As stated by Fleischmann (2004), the processing time should be included in costs determinations. By adding these costs, the SPT-rule is enabled in the algorithm. The SPT-rule has the highest performance when objective is set to minimizing throughput time. The costs are calculated as in Equation 2.

EQUATION 2 COSTS DETERMINATION OF PROCESSING TIME

$$c_j^p = c_{processing} * E[PT_j] \qquad \forall\, j \in J$$

$$with$$

$$c_j^p: costs\ of\ processing\ order\ j$$

$$c_{processing}: costs\ of\ processing\ per\ minute\ on\ a\ station\ in\ stage\ 2$$

$$E[PT_j]: expected\ processing\ time\ in\ minutes\ of\ order\ j\ in\ stage\ 2$$

6.2.1.2 Urgency

The second aspect that determines the costs of an assignment are the urgency costs. The main idea is that more urgent orders are less desired to be postponed. Therefore, the costs of processing an over-due order are negative since the objective is to minimize costs and this order cannot be postponed any longer. These negative costs are allocated to ensure postponement is excluded. A quadratic function is being used to determine the time until the due date to indicate the importance of over-due orders. Parameter c_{urgent} indicates that if the order is more than circa $\sqrt{c_{urgent}}$ hours away from its due date, there is no hurry in processing the shipment and it can be postponed. Therefore, costs are assigned that are going to infinity. For the simulation, these costs are equal to c_{urgent}^4 and multiplied with the quadratic function of the time until the due date is reached. In any other cases, the urgency costs are dependent on a quadratic function of the slack time until the order reaches its due date. The formulas of the urgency costs can be found in Equation 3.

EQUATION 3 COSTS DETERMINATION OF URGENCY

$$c_j^u = \begin{cases} -c_{urgent} * \left(DD - ST_j\right)^2 & if\ ST_j > DD \\ c_{urgent}^4 * \left(DD - ST_j\right)^2 & if\ \left(DD - ST_j\right)^2 > c_{urgent} \\ c_{urgent} * \left(DD - ST_j\right)^2 & if\ otherwise \end{cases} \qquad \forall\, j \in J$$

$$with$$

$$c_j^u: costs\ of\ delaying\ an\ order\ based\ on\ over-due\ time\ of\ order\ j$$

$$ST_j: time\ in\ minutes\ that\ order\ j\ is\ in\ the\ system$$

$$DD: defined\ due\ date\ in\ minutes\ for\ all\ orders$$

$$c_{urgent}: parameter\ to\ indicate\ the\ importance\ of\ urgency$$

6.2.1.3 Idle Time

The third aspect of the costs determination is the idle time. A trade-off should be made between planning a sub-optimal order or waiting for an optimal order to arrive. Meaning that idle costs need to be calculated such that the costs of leaving a station idle can be determined. The formula to calculate the idle costs are described in Equation 4. The expected arrival time for each order at stage 2 can be calculated by means of an approximation of a G/G/1 queue. Calculations can be found in Appendix E. It should be noted that when the order has already arrived at stage 2, the expected arrival time is smaller than or equal to the current time. This gives an idle time of 0.

EQUATION 4 COSTS DETERMINATION OF IDLE TIME

$$c_j^d = c_{idle} * \left(\left(E[AT_j] - t_{current}\right)^+\right)^2$$
$$with$$
$$x^+ = \max(x, 0)$$
$$c_j^d: costs\ of\ idle\ time\ by\ waiting\ on\ order\ j\ on\ station\ i$$
$$c_{idle}: costs\ of\ station\ being\ idle\ per\ minute$$
$$E\left[AT_j\right]: expected\ arrival\ time\ of\ order\ j\ at\ stage\ 2$$
$$t_{current}: current\ time$$

6.2.2 Assignment Algorithm

Based on the costs determined in section 6.2.1, the assignment algorithm can be described. As stated before, the objective function is to minimize costs. The costs function can be stated as followed.

EQUATION 5 COSTS FUNCTION

$$c_j = c_j^p + c_j^u + c_j^d$$

The costs are calculated by adding the three aspects together. Order assignment based on these costs is a more detailed version of the discussed SPT/float-priority rule. Just like the calculations of the float, the time until an order is over-due in combination with the processing time is being used. However, the assignment algorithm also deals with not yet arrived orders and the idle time while waiting. The costs are minimized by assigning the order j to station i with the lowest costs.

EQUATION 6 OBJECTIVE FUNCTION OF ASSIGNMENT ALGORITHM

$$min \sum_{i=1}^{m} \sum_{j=1}^{n} c_j * x_{ij}$$
$$with$$
$$station\ i \in I = \{1, \dots, m\}\ of\ stage\ 2$$
$$order\ j \in J = \{1, \dots, n\}$$

There are some constraints in this assignment algorithm to ensure the model is feasible. Constraint (1) indicates that all shipments are assigned to one and only one of the stations at stage 2. In addition, constraint 2 ensures that every station of stage 2 is assigned to one single shipment. Constraint (3) states that x_{ij} is a binary variable that only can have value 0 or 1.

EQUATION 7 CONSTRAINTS OF ASSIGNMENT ALGORITHM

$$Subject\ to$$
$$\sum_{i=1}^{m} x_{ij} = 1 \qquad \forall j \in J \qquad (1)$$
$$\sum_{j=1}^{n} x_{ij} = 1 \qquad \forall i \in I \qquad (2)$$
$$x_{ij} \in \{0,1\} \qquad (3)$$

In case of a tie-break between two or more possible stations, the station with the least flexibility will be selected. Low flexibility indicates a lower amount of processed orders. The higher the flexibility of a station, the greater the possibility that the next order can be produced at this particular station. Therefore, it makes sense to choose the lowest level of flexibility whenever this opportunity arises. When the least flexibility rule also results in a tie, the shipment will be assigned to the station in lexicographical order (sequence of 1 to 5). Another possibility would be to choose the station that has been idle for the longest time, in order to better spread the workload. However, the choice has been made to follow this lexicographical sequence to provide an (or more) efficient station(s) so that eventually a station can be closed early. When this would be the case, this station can perform other operational tasks.

6.2.3 Look-ahead Principle

In the different scenarios, the information availability can have two different values: partial or none. In case of no information availability, the planning is made based on arrived orders. When information is available, it is important to know how long in advance this information will be available. Therefore, the parameter look-ahead is created which indicates the maximum number of hours in advance of which shipment information is known. This information includes their arrival day and time and their specific product category. This product category can be used to know at which station of stage 2 the products can be processed and their expected service time on both stage 1 and 2. The data around stage 1 is not very helpful, since all shipment have the same characteristics at stage 1.

The main idea behind this principle is to look ahead for shipments that have not arrived yet. This is why a trade-off is made between processing a sub-optimal order immediately or waiting for a more optimal order to arrive and leaving the station idle for that time being. This trade-off is considered in the costs calculations of previous sections. By setting the goal to costs minimization, the most optimal trade-off choices are made.

6.2.4 Station Flexibility

The station flexibility indicates the amount of order types that can be processed at each station. One product category contains shipments that have the same characteristics in station flexibility and processing time. This is described in detail in section 6.4.2.1.

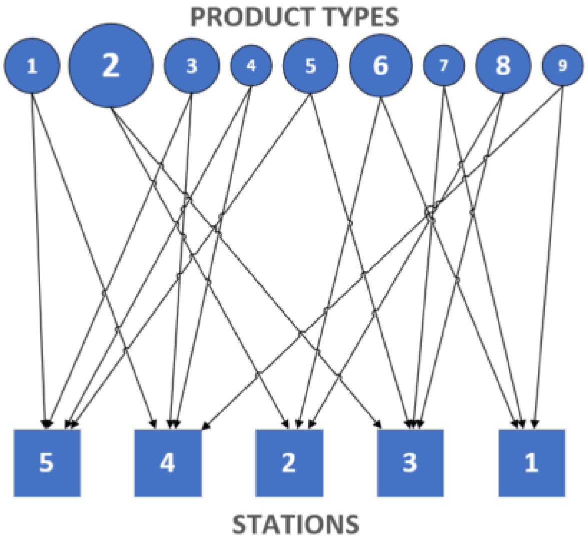

FIGURE 18 LIMITED STATION FLEXIBILITY APPLIED ON RESEARCH CASE

As stated, there are two different kind of station flexibility researched in the model: limited and full. In the full flexibility case, each product category can be processed at each station. When the model assumes limited flexibility, this can be illustrated as performed in Figure 18. Based on the flexibility and chaining principles of Jordan and Graves (1995), the assignment of the categories to the stations is done in such a way that the workload is equally divided amongst the work stations. The assignment is based on arrival frequency and expected workload of the different product types. A visualization of these differences is displayed in Figure 18. The calculations of this assignment are discussed in Appendix F.

6.3 Key Performance Indicators

To measure the performance and to compare different results of the model, key performance indicators are determined.

6.3.1 Throughput Time

The throughput time of the system is measured at first. With great regularity, the importance of reductions in throughput times are highlighted by companies. (Tersine & Hummingbird, 1995) Regarding shipments, the time it takes from arrival till booking is being determined. This time is an overall indicator of the system's performance. When simulating different scenarios, the throughput time can be of great use while comparing results. The throughput time can be calculated by subtracting the time shipment p arrived at the queue of stage 1 from the time that the process at stage 2 ends for shipment p. Although the Inbound department is opened for 11 hours per day, the throughput time is measured continuously for 24 hours per day. This means that in non-opening hours, time just passes by without orders being processed. The results can now be compared to real-time scenarios which are also measured over the entire day. However, weekends are not included since the company is closed these two days.

EQUATION 8 THROUGHPUT TIME

$$TPT_j = End\ Time\ Stage\ 2 - Arrival\ Time\ at\ Queue\ Stage\ 1$$
$$with\ shipment\ j \in P, and\ P = \{all\ finished\ shipments\}$$

$$avgTPT = \sum_{j=1}^{n} TPT_j / n$$
$$with\ shipment\ j \in \{1, \dots n\}, and\ which\ are\ all\ n\ finished\ shipments\ at\ moment\ t$$

6.3.2 On-Time Performance

The on-time performance gives an indication of which fraction of shipments was processed within the defined target β. These targets are defined by the owner of the system. The on-time performance is then calculated based on the throughput times. This target indicates the maximum throughput time for all shipments. The on-time performance can be calculated with guidance of the following formula.

EQUATION 9 ON-TIME PERFORMANCE

$$OTP_\beta = \frac{\sum_{j \in P,\ TPT_j \leq \beta} j}{\sum_{j \in P} j}$$
$$with\ \beta = defined\ maximum\ throughput\ time\ target,$$
$$and\ P = \{all\ finsished\ shipments\}$$

6.3.3 Work-In-Process Inventory

To know where a shipment is in the process, its location is updated at each time unit. This data is used to calculate the WIP-inventory at each time unit. There are two possible WIP-locations in the system after the shipment has arrived. The locations are defined in Table 3. After arrival, the shipment enter the first location Q_1. Then, Q_2 contains shipments that are processed at station 1 and that have not been allocated yet to one of the following stations. After shipments are processed at stage 2, the end of the process is reached.

TABLE 3 LOCATION MATRIX

l	Location	Explanation
1	Q_1	Queue of stage 1
2	Q_2	Queue of stage 2

All shipments that are in queue can be considered as WIP-inventory. This means that every queue contains a WIP-stock. The shipments are waiting in queues to be processed, which indicates that it is a non-value adding activity. Work-In-Process Inventory is an undefined stock point between operations to reduce the down time of the machine due to a lack of work. (Johnson, 2003) Crandall and Burwell (1993) indicate that by undertaking actions to reduce the WIP-inventory, such as decreasing the queue capacity or simplify the process structure, the throughput time can be reduced. Therefore, the WIP-inventory should be measured in order to compare different scenarios. The WIP can be calculated by counting the number of shipments in the queue at a moment in time. The following equation shows how the WIP at moment t per queue is calculated. The average WIP-level over all time units is taken to compare the different scenarios.

EQUATION 10 WIP-INVENTORY

$$WIP(t) = \sum_{j \in Q_i} 1$$

$$with\ shipment\ j,$$

$$and\ Q_i\ with\ i = \{1,2\}$$

$$avgWIP = \sum_{t=1}^{a} WIP(t)/a$$

$$with\ time\ horizon = \{1, \dots, a\}$$

6.4 Experimental Set-up

The main goal of this simulation study is to compare the alternative redesigns stated in the conceptual design. In order to perform this study, a Design of Experiments needs to be described. Besides that, the simulation model should be validated and verified.

6.4.1 Design of Experiments

The Design of Experiments (DoE) is a planning of how the simulation study should be performed. According to Kelton (2016), there are multiple aspects to deal with when performing a simulation study. The most important factors are described in this section: number and length of runs and output interpretation. All three are context-dependent which means that there is no universal standard for determining the values. The following questions should be considered according to Kelton and Barton (2003).

- *What model configurations should you run?*
- *How long should the runs be?*
- *How many runs should you make?*
- *How should you interpret and analyze the output?*
- *What's the most efficient way to make the runs?*

The different configurations of the model can be determined based on the 2^k factorial design rule. (Law & Kelton, 1992) This means that with *k* input factors, each factor has two possible values, referred to as "+" and "–". The two factors applicable for this study are deeply described in the conceptual design: information availability and flexibility level. Thereby, a third factor is added which changes the pull/push ratio. The number of scenarios can be determined by calculating the factorial design (2 * 2 * 2 = 8). The design matrix, illustrated in Table 4, can be made up at this point. The "–" indicates no information for factor 1, while the "+" stands for partial available information. In case of factor 2, "–" includes limited flexibility and "+" indicates full flexibility. The change of the pull/push ratio decreases the arrival variance resulting in a more balanced arrival. Therefore, "–" indicates a decrease in variance and thus a higher pull share, while "+" includes the current situation of pull and push.

TABLE 4 DESIGN MATRIX BASED ON 2^K FACTORIAL DESIGN

Scenario	Factor 1: Information Availability	Factor 2: Flexibility	Factor 3: Pull/Push Ratio	Name
1	–	–	–	(NI & LF)$^{-}$
2	+	–	–	(PI & LF)$^{-}$
3	–	+	–	(NI & FF)$^{-}$
4	+	+	–	(PI & FF)$^{-}$
5	–	–	+	(NI & LF)$^{+}$
6	+	–	+	(PI & LF)$^{+}$
7	–	+	+	(NI & FF)$^{+}$
8	+	+	+	(PI & FF)$^{+}$

Next, Kelton and Barton (2003) state that the run length should be determined. In order to perform the simulation, a terminating condition should be defined. Since there is no grow factor included in the model, it makes no sense to perform the study for a long-run. However, the run length should be long enough to cover the warm-up period and provide accurate results. Therefore, the run is stopped after 1 year which stands for approximately 260 working days. This number is determined based on logical reasoning and trial and error while simulating. In addition, each run should be replicated a number of times to deal with variations of the simulation. Determining the number of replications is a matter of context and should provide accuracy of the output. (Kelton, 2016) Based on the level of variances in the model and replication algorithm of Hoad et al. (2007), it can be concluded that between 10 to 20 replications should lead to an accurate result. For this research, a performance of 20 replications per simulation is chosen. In order to achieve accurate results, a 95% confidence interval is provided for each simulation scenario for the throughput time. These intervals are given in Appendix J.

Three parameters need to be defined for the simulation study. At first, the look-ahead value for scenarios 2, 4, 6 and 8 is determined. Since the maximum expected processing time of an order is 295 min (4.92 hour), this value is set to five hours. It makes no sense to look ahead over more than five hours due to the SPT-character of the algorithm. For the stated scenarios, a percentage of the assignment when looking ahead a range of 0 to 5 hours is calculated. Secondly, the station flexibility can be represented into three different categories: current, full and limited. The values for the three flexibilities are illustrated in Appendix F. Finally, the costs parameters for processing (*c_p*), idle time (*c_i*) and urgency (*c_u*) need to be defined. The costs parameters are tuned for various scenarios and is being discussed in Appendix G. The final values for the parameters can be found in Table 5.

TABLE 5 VALUES OF COSTS PARAMETERS

Costs Parameter	Value
c_p	3
c_u	16
c_i	30

6.4.2 Validation

This section includes the validation of the research and answers the following question: “Are we building the right model?” The validation is analyzed in three different areas: the input data, the assumptions and the model itself.

6.4.2.1 Validation of Input Data

ARRIVAL DISTRIBUTION

The data on shipment arrivals is tested according to several distributions with help of statistical programs. No known distributions are significantly fitting the dataset. Therefore, a two-moment fit test is performed on determining which discrete distribution fits the empirical distribution best. Results of these calculations can be found in Appendix F. In conclusion, the arrival distribution can be simulated as a Negative Binomial distribution with failures R = 1.00824 and success probability P = 0.220173 for the normal pull/push ratio and R = 3.2100 and P = 0.47703 for the increased pull ratio. The arrival distribution is calculated in number of shipment arrivals per working hour. (Adan, van Eenige, & Resing, 1994) A trend is identified in the arrivals during the working hours of a day. This is illustrated in Appendix B and the normalized values are applied in the simulation model.

PROCESS DISTRIBUTION OF STAGE 1

The first stage, which includes the first station, processes all shipments in the same way. This is why one function can be used to simulate the activity of station 1. Data on the received shipments at station 1 is analyzed and tested to approach the Weibull distribution with three parameters. The test results are shown in Appendix F. The data on the processing times of stage 1 fit the Weibull distribution with scale parameter $\eta = 6.5982$, shape parameter $\beta = 1.171$ and location parameter $\gamma = 3.5191$.

PROCESS DISTRIBUTION OF STAGE 2

In order to define the processing times of stage 2, product categories need to be identified. After analyzing the data, nine categories can be determined. The products in these groups differ in both processing time distribution and station flexibility. In case of limited flexibility, each category can be processed at two kinds of station. Each category has its own processing time distribution. The processing times are fitting a Negative Binomial distribution with the following parameters. The calculation can be found in Appendix F. The processing time parameters, the fractions of the categories over the arrivals and the station flexibility are shown in Table 6.

Table 6 Product Categories With Distribution Parameters, Fractions and Flexibility

Category	R	P	Avg PT	Fraction	Station				
					1	*2*	*3*	*4*	*5*
1	63.8488	0.2112	239	9.69%	0	0	0	1	1
2	2.2096	0.0399	54	32.36%	0	1	1	0	0
3	2.7536	0.0435	61	9.69%	0	0	0	1	1
4	1.9572	0.0228	84	4.59%	0	0	0	1	1
5	4.9822	0.1690	25	9.69%	0	0	1	0	1
6	1.3842	0.0115	119	14.24%	1	1	0	0	0
7	5.4121	0.0181	295	4.78%	1	0	1	0	0
8	4.544E03	0.9954	21	9.69%	0	1	1	0	0
9	2.8165	0.0359	76	5.27%	1	0	0	1	0

6.4.2.2 Validation of Assumptions

To ensure reliability of the model, it is important to validate its assumptions. The model assumes no preemption, which means that the process cannot be interrupted once it has started. The goal of this assumption is to finish a process at all time when it has been started at a particular station. If an order is allocated to a station, but has not started yet, it is possible to re-schedule the sequence at the station. This aligns with the principle of workflow at Vita. Once a shipment has entered a work station, it has to be finished and be cleared of the work station before any other shipment can enter. Only in case problems or issues occur, the order can be stopped. However, since the failure rate is not considered in this model, no issues will occur during the process. This leads to a complete no-preemption situation. In turn, the none occurring failures assumption can be validated by the fact that the issues are not covered in this research model. This would be an interesting subject for further analysis of the Inbound department of Vita.

The model assumes that only one order at a time can be processed at one station. This means that a shipment cannot be split and a station cannot be over used for multiple instances. The model choice aligns with the real-life situation at Vita. Another assumption based on Vita's data is the categorization of the products into nine different groups. These groups have their own processing times, arrival frequency and station flexibility and are specific for the research case. However, the input can be adjusted when these groups would possibly change in future. The processing times of the groups are similar for each station of stage 2 since these are identical. This can be explained by creating work stations with similar layout and equally trained skill levels for each employee.

The incoming shipments can only arrive at the top of the hour. Due to model choices, it is not possible to receive shipments during the hour. The expected arriving orders for the upcoming hour will thus be available at the top of that hour. In addition, no incoming orders are rejected since all products that arrive must be processed. It is only possible to receive and process orders during the opening hours of Inbound. The model simulates for 11 hours per day, for 5 days a week. However, the non-openings hours are covered in the performance indicators, such as throughput time. Besides that, the due dates are based on a 24-hours per day calculation. The model distinguishes these two timings well such that accurate results can be concluded.

6.4.2.3 Validation of Model

The model needs to be validated in such a way its accuracy can be tested. A simple case of the simulation model is created. This model is being compared to known results of analytical models. For this model, a M/G/5 system is chosen. It is defined by a Poisson arrival process with rate λ and general distributed service times with mean μ. This includes five identical and parallel servers. There is one queue in front of the 5 stations that treats the orders according to a FIFO-policy whenever a server is becoming empty. The queue is assumed to be infinite, which is also the case for this model. An order cannot be rejected, so there has to be enough space to receive all incoming orders. The results of the simulation can then be compared to the calculations of analytical formulas. These formulas are based on the approximations of a M/G/5 queuing system. The calculations can be found in Appendix H. As can be seen in Table 7, the average time and number of jobs in the system are calculated according to the simulation model and analytical formulas. When comparing the results, it can be concluded that the simulation approaches the analytical results closely and the model represents the situation accurately. This validation serves as a base for further extensions of the model and the research scope.

TABLE 7 ANALYTICAL VERSUS SIMULATION RESULTS

	Analytical Results	**Simulation Results**
Average Time Spent in System W	1.6 hours	1.6 hours
Average Jobs in System L	5.8 jobs	5.9 jobs

6.4.3 Verification

In order to verify the model, it is compared to the results of Vita's performance indicators. The goal of the verification is to confirm whether the implementation of the conceptual model is correctly performed. More specific, the specifications and assumptions of the model are being tested. It has been verified that an error free code is implemented in Matlab with correct implemented input-output relations. (Sargent, 2011) Some data comparisons can show that the simulation is a verified approximation of the reality.

The current situation of flexibility is applied to the model making sure the real situation can be simulated. The queuing rule is set to the default value of FIFO. This means that the shipments which arrive first, are served first. Then, according to the DoE, a simulation has been run for 20 replications. The results are shown in Appendix I. In the following table, a comparison of the real situation and simulated situation is shown. Since the simulation does not consider the difference between pallets and case packs, the performance indicators are averaged over both. The on-time performance is recalculated leaving out issues since these are not covered in the research scope. As can be seen in Table 8, the simulation approaches the real situation very well.

TABLE 8 REAL DATA VERSUS SIMULATION OF CURRENT SITUATION

	Real Situation	**Simulation**
Average Throughput Time	17.93 hours	18.04 hours
On-Time Performance $\beta = 24$ hours	82%	80%
On-Time Performance $\beta = 48$ hours	96%	98%

7 Results

In this chapter, the results of the simulation study of the mathematical model are being discussed. It provides an answer to sub-question 3b: “*What are the performances of the redesign alternatives in terms of the KPIs when using simulation studies?”*. An overview of all results of the study is provided in form of tables and numbers in section 7.1. The results for the different scenarios are being discussed and the improvements are analyzed in section 7.2. These specific results for the look-ahead scenario are being discussed in section 7.3. A business case for Vita is described in section 7.4. Finally, the most important conclusions are described in section 7.5. All detailed simulation results can be found in Appendix J.

7.1 Simulation Results

As stated in previous chapters, eight different redesign scenarios are simulated by the model. These scenarios are then being compared to the current situation. The performance indicators are the throughput time, the on-time performances for a 24- and 48-hour target and the WIP-inventory level. For scenarios 1, 3, 5 and 7, the look-ahead value is set to zero since these scenarios include a situation where no information is available. The scenarios where factor 1 equals PI (2, 4, 6 and 8) are tested with a maximum look-ahead value of five hours. In Table 9, the simulation results of the eight different scenarios and the simulated current situation are illustrated.

Table 9 Simulation Results of Scenario 1, 2, 3 and 4 Compared to the Current Situation

Scenario	**Performance Indicators**			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
Current	18.04	80%	98%	20
1 (NI & LF)$^-$	15.04	78%	97%	16
2 (PI & LF)$^-$	14.12	81%	98%	14
3 (NI & FF)$^-$	12.09	88%	99%	11
4 (PI & FF)$^-$	10.74	89%	99%	10
5 (NI & LF)$^+$	10.10	93%	100%	9
6 (PI & LF)$^+$	9.37	93%	100%	8
7 (NI & FF)$^+$	6.82	98%	100%	4
8 (PI & FF)$^+$	6.56	98%	100%	4

7.2 Comparison of Scenarios

The comparison to the current situation has been executed for each tested parameter. Table 10 provides an overview of the in- and decreases in performance indicators of the first four scenarios versus the current situation. The first conclusion that can be drawn from the comparison is the fact that the implementation of the assignment algorithm improves the results significantly. For all scenarios, a decrease in both throughput time and WIP-level is achieved when comparing them to the current situation. The assignment algorithm succeeds the general FIFO-policy as currently used. For the on-time performances, we see improvements from the second scenario onwards.

Table 10 Comparison of Simulation Results of all Scenarios versus the Current Situation

Scenario	**Performance Indicators**			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1 (NI & LF)$^{-}$	-17%	-2%	-1%	-21%
2 (PI & LF)$^{-}$	-22%	2%	0%	-28%
3 (NI & FF)$^{-}$	-33%	11%	2%	-45%
4 (PI & FF)$^{-}$	-40%	12%	1%	-50%

7.2.1 Information Availability

To draw conclusions about the information availability parameter, scenario 1 (NI & LF)$^{-}$ is compared to scenario 2 (PI & LF)$^{-}$. Scenario 1 (NI & LF)$^{-}$ includes a situation with no information availability and limited flexibility of the stations. As stated in Table 10, the throughput time decreases with 17%, and therefore improves when the scenario is being compared to the current situation. The on-time performance of both 24- and 48-hour targets are being reduced. This indicates a tradeoff between decreasing the average throughput time or improving the on-time performance. When the average throughput time is not reduced, a 100% target can never be reached. The main objective of the research is to decrease the throughput time. This is why the most important comparison indicator is the throughput time which will weight heavier than on-time performances. The WIP-level decreases by 21% for scenario 1 (NI & LF)$^{-}$. The second scenario (PI & LF)$^{-}$ indicates a situation where planning is based on a look-ahead policy with a maximum of five hours. Similar to the first scenario, the flexibility of the station is limited. A reduction in throughput time of 22% is achieved. The on-time performance percentages slightly improve when comparing them to the current situation. Lastly, the WIP-level improves with 28%. Some conclusions can be made by comparing the results of scenarios 1 and 2. Under the same conditions of flexibility, information availability gives a higher improvement for throughput time (a reduction of 6%). The on-time performances slightly improve when comparing these two scenarios.

In addition, conclusions can be made when comparing scenarios 3 (NI & FF)$^{-}$ and 4 (PI & FF)$^{-}$. Scenario 3 (NI & FF)$^{-}$ includes a situation with full station flexibility and an unavailability of information for planning purposes. Comparable to scenarios 1 and 2, a 33%-reduction in throughput time is achieved. While the on-time performance with a target of 48 hours increases with 2% to the current situation, the on-time performance of the 24-hour target is improved with 11%. Besides, the WIP-inventory decreases with 45%. The fourth scenario (PI & FF)$^{-}$ indicates a full flexibility situation under information availability of a maximum of five hours in advance. Of all redesign alternatives, this scenario improves the current situation best. The throughput time reduces by 40% in comparison to the current situation. The on-time performances of the 24-hour target improves with 12%, while the 48-hour target increases with 1%. Finally, the WIP-level decreases with 50% when it is compared to the current situation. Scenarios 3 and 4 can be compared with the same conditions of flexibility. The availability of the in-transit information creates high improvements in both WIP-inventory (-30%) as throughput time (-20%). It should be considered whether the reduction in throughput time and WIP provides more benefits than the costs for implementing a look-ahead situation.

7.2.2 Flexibility

The influence of changing the level of flexibility can be determined by comparing scenarios 1 and 3, for which the same conditions of information availability hold. It can be concluded that by implementing a higher level of flexibility, in this case limited versus full, a significantly better performance can be achieved. According to the simulation results, a throughput time reduction of 20% is obtained. Improvements on the on-time performances and WIP-inventory of respectively 13%, 3% and 30% are achieved when comparing the two scenarios. A more interesting finding is that this is contrary to the literature study hypothesis which stated that limited flexibility would result in an almost alike performance as full flexibility. It is plausible to state that for the research of Vita, more flexibility in stage 2 is beneficial for the performance of Inbound.

In addition, scenarios 2 and 4 can be compared for drawing conclusions about the flexibility effects on performance. Under the same conditions of partial information availability, an improvement of 24% in throughput time is achieved. The on-time performances increase with 10% and 1% for the 24- and 48-hour targets respectively. As the WIP-level increases by 31%, when applying full instead of limited flexibility, this aligns with the conclusion drawn in previous comparison. The overall performance of scenario 4 is better than the current situation and scenario 1, 2 and 3. Therefore, the improvement opportunities of implementing information availability in the planning are significant, as well as increasing the station flexibility.

7.2.3 Pull/Push Ratio

The change in the pull/push ratio is influencing the variance of the arrival process. The effects to performance indicators can be spotted by comparing scenarios 1, 2, 3 and 4 with respectively scenarios 5, 6, 7 and 8. For each compared scenario duo, the changes in performance indicators are illustrated in Table 11.

TABLE 11 COMPARISON OF SIMULATION RESULTS OF ALL SCENARIOS FROM CURRENT TO ADJUSTED RATIO

Scenario	**Performance Indicators**			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
NI & LF	-33%	19%	3%	-45%
PI & LF	-34%	14%	2%	-48%
NI & FF	-44%	11%	1%	-60%
PI & FF	-39%	9%	1%	-57%

All scenarios' throughput time decrease over 30%. This indicates that the main performance indicator is improved when the arrival planning contains less variance. This could be achieved by changing the pull/push ratio to a larger share of pull shipments. The WIP-inventory levels of all scenarios decrease by over 45% when comparing the regular pull/push ratio with an increased share of pull. The on-time performances increase for both targets to on average 100% for the 48-hour target. This shows that all indicators improve when increasing the pull/push ratio to a share of approximately 60% pull shipments.

7.3 Look-ahead

For scenarios 2, 4, 6 and 8, which include partial information availability, the maximum value of looking ahead for the assignment of orders to stations is set to five hours. In this chapter, the amount of times the assignment algorithm chooses to look ahead is being analyzed. Besides that, the number of hours the algorithm will look ahead is discussed. The data discussed in this chapter will be based on the simulation results of the fourth and eighth scenario.

It is important to consider that there are six different categories which analyze the look-ahead. These categories can be found in Appendix K. Besides that, the amount of look-ahead assignments which took place in each category is analyzed. As illustrated in Table 46 Appendix K, on average 88.2% of all assignments were based on orders that had already arrived at stage 2 of scenario 4, while this is 80.9% for scenario 8. When comparing scenario 4 to 8, it can be concluded that when arrival variance is decreased the look-ahead policy is used more frequently in the algorithm. This can be explained by looking at the fact that on average it is less occupied when arrivals are spread over the day. For the analysis of the look-ahead policy, it is more interesting to go deeper into the other five categories that represent looking ahead 1 to 5 hours in advance.

The division of assignments of the not yet arrived orders is illustrated in Figure 19. In case of look-ahead, the most occurring look-ahead value is 1 hour for both scenarios. A 2-hour look-ahead is also used often, while the frequency of looking ahead 3, 4 and 5 hours in advance is decreasing compared to the other values. This can be explained by the fact that the average processing time of stage 2 measured over all product categories lies around 2 hours. Due to the SPT-character of the algorithm, the values of 3, 4 and 5 hours are minimally to less used comparing them to 1 and 2 hours.

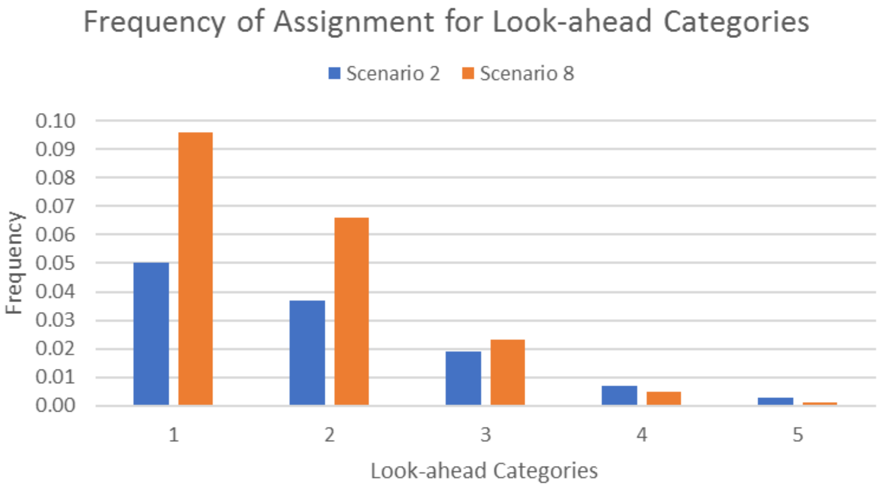

FIGURE 19 FREQUENCY OF ASSIGNMENT FOR LOOK-AHEAD CATEGORIES FOR SCENARIO 4 AND 8

When an order that has not arrived yet at stage 2 is being assigned to a station, this results in idle time at this station. In Table 47 Appendix K, the average idle times per hour and the average look-ahead values can be found. The results are displayed in Table 22. Overall, there is a clear trend visible which has peaks at the start and end of a work day. This indicates that at these moments, the assignment on average looks further ahead than it does at other moments. The average idle time is therefore directly related to the average look-ahead value. The figure shows that the eighth scenario does not look as far ahead on average as the fourth scenario. Besides, the differences between the look-ahead values per hour are less, which is caused by the fact that the WIP is more stabilized in case of a larger pull share. It can therefore also be concluded that although the eighth scenario uses the look-ahead more frequently in its assignments, scenario 4 strives to look on average further ahead.

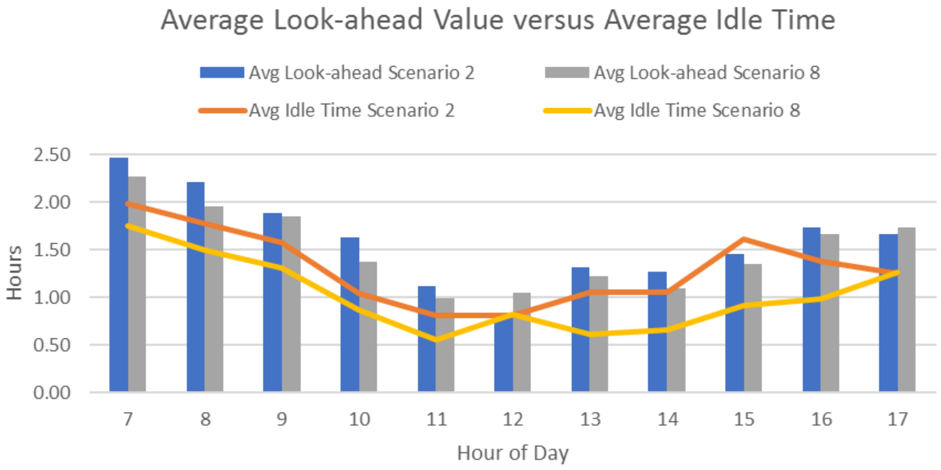

FIGURE 20 AVERAGE LOOK-AHEAD VALUE VERSUS AVERAGE IDLE TIME FOR SCENARIO 4 AND 8

When comparing the average look-ahead values per hour with the weekly arrival trend, an interesting conclusion can be drawn. The patterns in the data are in contrary to each other, as can be seen in Figure 21. In particular, when the trend of the arrival is high, which means that more shipments arrive in that hour, the average look-ahead value is low. This indicates that the workload at this particular moment in time is higher than at other moments and the algorithm assigns arrived orders first to look-ahead orders.

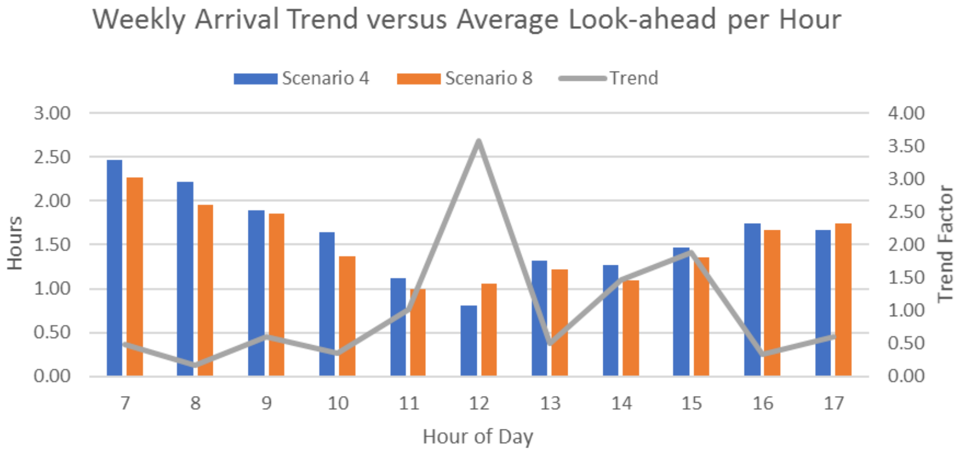

FIGURE 21 WEEKLY ARRIVAL TREND VERSUS AVERAGE LOOK-AHEAD PER HOUR FOR SCENARIO 4 AND 8

7.4 Business Case

The researched flexibility levels are set to limited or full. For Vita, the current level can be defined as a variant of limited flexibility. In order to make recommendations on how to improve this current level, a business case is executed. For this case, the proposed model in the research is used to define the improvement opportunities. Some additional assumptions have been defined to perform this case study. The goal of the study is to trade off the implementation of flexibility links against the implementation costs. A link between a station and a product group indicates a possibility to process that product group in the specific station. The assignment algorithm defined in previous chapters is used to simulate each additional link compared to the current flexibility. It is assumed that no look ahead is applied in the algorithm since this case study only includes the flexibility parameter. In addition, the arrival process based on the normal pull/push ratio is used.

To determine the sequence of adding links between product types and stations, a linear problem is used. The objective function includes a combination of the standard deviations of the frequencies and processing times of the product groups, and the averages of the distances from the stations to the storage locations. The lower the standard deviations, the more the product groups' workloads are spread along the stations. The distance for transporting the products from their stations to their storage locations is minimized as well.

A sequence of adding links is determined with help of this linear problem. The current situation has a flexibility with a total of 20 links between the 9 products groups and 5 stations. After solving the linear problem, the number of links is increased to 26. The sequence is illustrated in Table 12.

TABLE 12 SEQUENCE OF ADDITION OF LINKS IN BUSINESS CASE

Step	Addition of Link
1	Group 3 > Station 4
2	Group 3 > Station 5
3	Group 6 > Station 1
4	Group 3 > Station 3
5	Group 9 > Station 4
6	Group 9 > Station 5

Every type of product can arrive at the DC in different types of quantity and packaging. This increases the opportunity that one product category can be processed at more than one station. Vita's stations are designed in such a way that they can process a variety of product groups in a range of specific packaging and quantity characteristics in the most efficient way as possible. When adding links, this basically means that something must be adjusted in order to be able to process a specific product group at a specific station. One way is to adjust the product category at the supplier so that it can also be packaged in the way the stations prefer. Since this is the responsibility of the supplier, it is much easier for Vita to adjust something at their own site.

When a link is added, this means that a product category can be processed at a station which is not designed to do this is the most efficient way. Therefore, the process productivity of this particular product group will be lower than on its already assigned stations. Adjustments in the station layout need to be implemented to ensure that the stations are able to process a wider range of products and with the same productivity. This results in costs as well as employee time to develop and implement a well redesign plan. The training for processing this extra type of product in a station can be neglected since the employees are already trained in working methods at the station. Therefore, the new type of product can be handled in the same way.

In previous results, it has already been shown that the implementation of the assignment algorithm results in improvements in performance indicators. In order to provide an accurate overview of the effects while changing the flexibility level, the first scenario (step 0) is based on the current flexibility level when the algorithm is applied. This current level is illustrated in Appendix F. Next, the links as shown in Table 12 are added in steps. Each step provides results in terms of performance indicators. The calculations can be found in Appendix L.

Table 13 Simulation Results of Adding Links in Business Case

Step	**Performance Indicators**			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
0	15.47	79%	98%	19
1	13.41	82%	98%	14
2	13.30	84%	99%	14
3	12.94	85%	99%	14
4	11.78	88%	99%	11
5	10.95	89%	100%	10
6	10.49	90%	100%	9

The results of the simulation study for the business case are illustrated in Table 13. They are indicating a decrease of throughput time and WIP-level when links are added according to the discussed sequence. Each time a link is added, performances improve even further. Vita has to decide on trading off between the improvement effects for all performance indicators and the costs of redesigning the stations. It is highly dependent on the type of product involved in the redesign how much these costs will increase and what is needed to redesign the station layout. Many projects for developing new stations have already found place at Vita. These are comparable to the redesign in which a link is going to be added. Obviously, there is already a starting point, namely the current station, in place which results in a reduction of the normal project time by 50%. The start-up time of a new station is proven to be approximately 9 months with 2 hours work per week in a team of 8 members. Therefore, the costs of adding new links in fulltime-equivalents (fte's) can be set to $\frac{8\ employees*2\ hours\ per\ week*4\ weeks\ per\ month*9\ months*50\%}{40\ hours\ per\ week} = 7.2\ fte's$. This will be the costs per addition of a link. In case more links are added at the same time, these costs can be shared when the station which is to be designed is alike. Besides, when the same product groups are added as links at the same time, their requirements can be used for both projects. For example, when steps 1 and 5 are both being applied, costs can be set to 3.6 fte's per link. The requirements for the redesign will be adjusted to both product groups, so the team members can work on both groups at the same time.

7.5 Conclusion

By comparing the eight different scenarios to the current situation and to each other, some interesting conclusions can be drawn. This concluding section supplies an answer to sub-question 3a. There are three major redesign alternatives that will be discussed: increasing the flexibility of the stations, the information availability for planning the Inbound operations and the adjustment of the pull/push ratio of incoming shipments. Changing the queuing policy based on an assignment algorithm can be considered as a fourth redesign opportunity.

All redesign scenarios contain an assignment algorithm based on SPT-rules with aspects to urgency and idle time in case of information availability. When comparing the current situation to these redesigns, it can be concluded that by implementing such queuing policy the throughput time WIP-inventory will reduce. In case of the first scenario, a trade-off between reducing the average throughput time and increasing the on-time performance should be put in order. In this bifurcation, the throughput time is of more importance since this is the main objective of the research. For all other scenarios, the on-time performances improve in comparison to the current situation.

Besides that, it can be concluded that increasing the level flexibility of the stations improves the throughput time of the operations. By increasing the number of possible product types at a station, the flexibility will increase. The average WIP-inventory will decrease and the on-time performances will increase.

The availability of information, with a maximum of five hours in advance, will improve the operations planning. A more optimal assignment situation can be created when taking not yet arrived orders into account with the assignment of orders to the stations. This is when idle time in the queuing policy is applied. It results in a decrease of throughput time and WIP-inventory and could possibly increase the orders being processed within 24 and 48 hours. In conclusion, a combination of increasing flexibility and applying information integration would result in the largest improvement, especially concerning throughput time. When information becomes available for at least one day in advance, the share of the pull shipments increases. This creates a more efficient planning which results in a reduced arrival variation. In this case, WIP-levels will reduce and stabilize while average throughput time decreases.

It can be concluded that the frequency and look-ahead time frame when assigning the orders to the stations is dependent on a few aspects. At first, the time look-ahead frame is dependent on the processing times of the yet to be assigned orders. The higher the maximum and average expected processing times, the further the algorithm strives to look ahead. Secondly, the frequency of looking ahead is related to the workload at the stations. In this research, a weekly trend exists with a larger workload during the middle of a work day. Simulation results do exile that during busy working hours, the average look-ahead value is smaller than during less loaded hours. It is therefore less preferred according to the algorithm to leave a station idle when workload is high. When the pull share in the pull/push ratio is increased, the look-ahead policy is more often used when compared to the current ratio. On average, the policy looks less further ahead since the workload is spread more equally throughout the day.

Finishing off, a business case in which the addition of flexibility links is simulated will be explained. The current flexibility level is used as base including the implementation of the assignment algorithm without look-ahead policy. Results show that with the addition of each link improvements in throughput time, on-time performances and WIP-level are achieved. The costs per link is 7.2 fte's but can be shared by implementing multiple links at the same time.

8 Implementation

Chapter 8 provides an answer to the last two sub-questions: *"What is the "to-be" situation for the receiving process of Vita and what are the gaps between the "as-is" and the "to-be" scenario?"* and *"How could the redesigned process be implemented at Vita?".* Section 8.1 describes the "to-be" situation and identifies the gaps compared to the current situation. In addition, section 8.2 gives the implementation strategy for Vita. The limitations of the design are discussed in 8.3.

8.1 To-Be Scenario

In this research, three redesign opportunities are tested by means of simulating different scenarios. The two process redesigns, information integration and Inbound planning, are discussed. An overview of the implementation of these redesigns is illustrated in Figure 22.

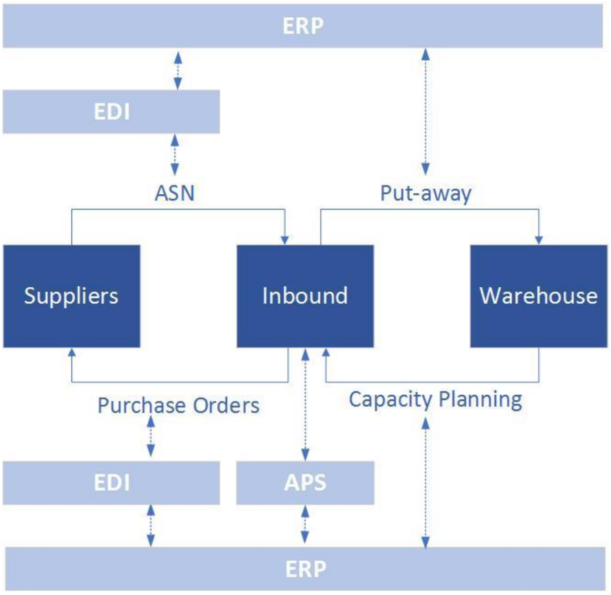

FIGURE 22 OVERVIEW OF REDESIGN IMPLEMENTATION

8.1.1 Information Integration

The value of having information about arriving shipments is examined in this research. When results turn out the be improving in terms of performance, it can be concluded that information integration would improve the Inbound process for Vita. In the research model, the main goal of having information is to improve the efficiency of the planning, which is discussed in detail in the report. Although this is an important improvement result, the availability of information could also be helpful in improving other aspects of the process which are discussed next.

When information is available in advance, the Inbound process can be set up proactively instead of reactively. The issues which are not considered in the research can be identified in an earlier state of the process. Whenever there is no space available in the warehouse while products should be booked, a space issue will occur. This could be prevented by knowing if shipments are on their way to the DC and taking actions in order to make sure space is available at the time of their arrival. In addition, missing data that could interrupt the process, can be filled in in advance when information about possible arrivals is known.

As the importance and value of having information in advance is discussed, an integration between the information provider and receiver is needed. Currently, Vita receives information of only 34% of to arrive shipments and most of the time this information is incomplete. This means that the majority of the shipment content is missing which causes that the expected workload cannot be calculated. Besides, the information which is available is sent in separate Excel files via e-mail contact. These aspects results in a non-efficient planning. The research concludes that by increasing this information as well as the pull share in the shipment ratio, large improvements can be achieved. Transferring push suppliers into pull needs strong collaboration between Inbound, Supply Chain and external suppliers. Besides, an infrastructure for integrating the operations of the supplier and vend is mandatory.

In order to provide an infrastructure for information integration, it is important to consider IT-solutions. The current enterprise resource planning system, ERP, is the base for all information flows in this process. To create a transfer of information between the supplier and Inbound, a supportive technology needs to be implemented. This technology should work similar to an Electronic Data Interchange (EDI) system. EDI is a computer-to-computer exchange between companies of business documents in a standard electronic format. The system transfers advanced shipping notices and POs between suppliers and Vita's supply chain department. It is key that this EDI-system connects to Vita's ERP system to ensure all information is available in the main system. By implementing such an information exchange system, no contact via email and Excel files attachments are in order. It is key to integrate all possible suppliers to make sure as much as possible information about arriving shipments is being provided. The content of the ASN should include an updated expected time of arrival and an invoice to be able to calculate the workload.

8.1.2 Inbound Planning

The Inbound operations planning is currently based on experience and the little-known information in advance. The information integration of previous section can create a much more efficient planning in terms of input. The planning methodology itself can be improved to increase performance. Two different aspects of the planning are discussed in this section: station flexibility and the planning system.

8.1.2.1 Station Flexibility

In order to improve the performance of the system, flexibility proves to be an important factor. By increasing flexibility of the work stations, the possible stations per product type increase. As described, this results in reduced throughput time and WIP-inventory. The Inbound department of Vita currently designed its stations in limited flexibility. When increasing this to e.g. full flexibility, a large improvement could be achieved. In order to increase this flexibility, stations have to be redesigned and employees have to be cross-trained. Although products differ in types, the process of booking them into the system should be similar in general. The improvement in throughput time and WIP-inventory should cover the costs of investing in this redesign.

While one way of improvement is achieved by increasing the flexibility, it should also be considered to improve the used method applied to the current flexibility. The limited flexibility of the current scenario is not used to its full potential. At this time, only one station per product type is being used. As noticed during this study, when this flexibility level increases a better performance can be achieved. In particular, when Inbound uses its flexibility it can improve the situation without redesigning the current flexibility and training its employees. A possible way to improve the use of the flexibility is the implementation of an advanced planning and scheduling (APS) system, which is discussed in the next section.

The business case provides improvement opportunities for adding links between stations and product groups. As improvement results and costs are discussed, it would be highly recommendable to redesign the stations such that achieve increased flexibility. Which stations are to be redesigned is discussed in the business case. When enough budget is available for implementing multiple links at the same time, it is more beneficial to share costs.

8.1.2.2 Planning System

Vita's Inbound department lacks in an optimal operations planning system. This research indicates improvement opportunities when implementing an assignment algorithm for the shipments and stations allocation. Instead of using the FIFO-policy, an algorithm based on SPT, and urgency is suggested. The look-ahead assignment can be applied whenever information is available about in-transit shipments. In this case, the idle time undergoes a trade-off with a more optimal solution. The implementation of a better planning algorithm improves throughput time and WIP-inventory.

In case of a look-ahead algorithm, the shipments should be known before they have arrived by means of an ASN. The research suggests that receiving this information several hours in advance is key. The ASN should include the expected arrival time and date and its content. The arrival time will provide an indication of how long the station will be idle which the algorithm uses for cost calculations. The expected workload has to be determined based on the shipment content. This is the case for both arrived as in-transit shipments (when using look-ahead). Rather than planning operations discretely for the next day, the planning is updated continuously during the day. This means that a more flexible system is created by using up-to-date and as much as possible available information.

The algorithm should be built into a system that plans the daily operations. Next to creating schedules for shipment arrivals and planning daily operations, the system should provide calculations concerning employee and warehouse capacity. By implementing such a system, future issues can be prevented and a clear process overview is provided. The advanced planning and scheduling system makes these improvements possible should be connected to the ERP system of Vita. The ERP system provides the input and will be updated with information from this APS-system.

While the look-ahead policy only keeps track of in-transit shipments for several hours in advance, high-level planning can also benefit from information availability. Another implementation improvement would be to increase pull shipments in the pull/push ratio. When more information becomes available in an earlier stage of the process, a better planning of shipment arrivals can be achieved on daily/weekly level. This results in less variance in the arrival process and due to Bullwhip effects also adapts the rest of the process. Overall, it creates a more stabilized WIP-flow, improved throughput times and on-time performances. Therefore, the look-ahead policy in the assignment algorithm is strived to be used more often, but with a lower averaged value of the number of hours it looks ahead.

8.2 Implementation Strategy

Currently, a project is in progress concerning a new system for the operations of the Inbound department, referred to as the *Inbound Optimization Project*. Besides that, a project has recently started about the information integration in Vita's ERP system, referred to as *End-to-end Visibility Project*. These two projects are aligning the outcome of the research closely. When the *Inbound Optimization Project* is kicked off, a requirements document will be written concerning a new Inbound system. This research could provide evidence and input for specific aspects of the system. The improvements of the Inbound planning should be implemented in this new system as well, ensuring a more optimal performance. In particular, when management chooses for implementing an assignment algorithm rather than the FIFO-policy, the calculations of the algorithm should be implemented into the requirements. The *End-to-end Visibility Project* provides the infrastructure needed to implement the information integration into the planning. Without a connection between EDI and APS-system, the look-ahead assignment cannot be implemented. Therefore, these projects need to be aligned as much as possible to be able to design it company-broad.

The operational planning should be translated into an APS-system which is able to fulfill the requirements stated in the next section. The implementation process of a new system at Vita is as followed. The logistics department performs a detailed analysis about the occurred problem. In case this problem leads to the need of a new system, a document is written with all the specific requirements. This document is delivered to the IT-department which performs an analysis of the IT-capabilities and costs. Then, in case this proves to be a feasible solution and management approves, the new system is developed and implemented with help of the logistics team that provided the requirements document.

8.3 Requirements

In this section the specific requirements for the possible redesigns are described. Starting with the requirements for a system that deals with information exchange and then the requirements of the planning system are described.

8.3.1 Information Exchange (EDI)

The requirements for the information exchange system are:

- The system must be able to receive information about the arriving shipments.
- The system must be able to send Purchase Orders to suppliers.
- The information of the arrivals must contain expected time and date of arrival and content regarding to the format of an invoice.
- Information should be updated along the time the shipment is in-transit such that actual data can be used for analysis.
- The system should be able to retrieve information from and update this information to the ERP system.

8.3.2 Planning System

The requirements for the Inbound planning system are:

- The system should be able to retrieve the information it needs as an input for the planning. This information includes:
    - Arrival information of in-transit shipments
    - Content of arrived or in-transit shipments
    - Current WIP-inventory and all concerned information
    - Employee capacity in terms of station working hours
- The system should be able to calculate the expected processing times for each shipment based on the shipment's content. These calculations should be based on historical data and should be updated very frequently.
- The system should be able to calculate the processing, urgency and idle costs.

- The system should be able to look ahead to in-transit shipments that have not yet arrived and involve these shipments into planning the assignment of orders to stations.
- The system should be able to provide a clear planning on daily base to ensure an optimal performance. This planning should contain:
    - Assignment of next order at each station
    - Possibility to manually adjust the planning in case of issues or priority changes
    - Possibility to report the performance of the Inbound department in terms of the stated KPI's

8.4 Limitations

This research is scoped in order to achieve feasible results within the time frame of the thesis period. Therefore, there are some limitations concerning the research that could be improved in future research. Some of these limitations were inevitable due to characteristics of the research company.

The current Inbound system, the Closed Loop Tool, is an efficient operational tool. Unfortunately, the required data for this research was partly unavailable in the system. This could be explained by the gap that exists between the CLT and the ERP. Therefore, the manual stop watch tests were performed. Since there is already a new system development in progress, this annotation about the lack in data should be included in the requirements. In particular, the data of the CLT is based on manual actions by the operators in order to time stamp the operations. The data has also been measured on shipment level which is makes it less accurate and traceable.

Secondly, the model contains some constraints that could be seen as limitations of the research. The shipments are analyzed as one unit with no distinction between pallets and case packs. This has no further consequences for the level of detail in the results. All shipments are categorized into nine product types, which are based on data to enclose a real-life situation that has been simulated as close as possible. Although this differentiation could have been more sophisticated and detailed, these categories made it possible to simulate the situation. It is also more applicable for other companies or situations if the simulation model was not built in detail around this single case study. Lastly, the model assumes that the employee capacity is no constraint. In real-life, the department has to deal with restricted capacity for the work stations. This adjustment should be covered in real-life implementation but has no further consequences to the research results.

9 Conclusions and Recommendations

In section 9.1, the conclusions of the research are summarized. Section 9.2 provides the recommendations for Vita, finishing up with the suggestions for further research which can be found in section 9.3.

9.1 Conclusions

In this section, the answers to the research questions are provided. Based on these answers, the main research question can be answered as well.

1. *What does the internal Inbound process look like and how is it currently planned and controlled?*

The Inbound process at Vita includes two main stages important for this research: the shipment receipt and booking stages. The planning of the operations at these stages is mainly done based on experience and insights of the Inbound planners. No information system is used to plan daily operations. The information available of shipment arrivals is scarce. Therefore, the planners use a FIFO-policy to assign the orders to the stations. This results in a performance of a 30.10 hours (17.93 hours when leaving out issues) throughput time and an on-time performance of 88% with a 48-hour target for pallets. The on-time performance for case packs is at 81% for the 24-hour target and at 94% for the 48-hour target.

2. *How can the current process be improved such that throughput time and supply chain integration are improved?*

The improvement opportunities of the Inbound process are studied by means of a simulation study. Therefore, a conceptual design is developed which is translated into a detailed design. Based on a literature review, the two design parameters, system flexibility and information availability, have been chosen. For each parameter two different values are examined. The flexibility of the stations can either be limited or full, while the information can be partially available or unavailable. These four scenarios are tested by the simulation model which is based on an assignment algorithm. The algorithm determines the optimal assignment of orders to station such that costs are minimized. The main objective of the simulation study is to minimize both throughput time and WIP-inventory.

3. *How can the process be redesigned such that the planning and control concept achieves more supply chain transparency and throughput time reduction?*

From the simulation results, it can be concluded that both the design parameters can lead to improvement. The implementation of the assignment algorithm leads to a reduction of the average throughput time and WIP-inventory. When the flexibility of the stations increases, an even larger reduction of both can be achieved. The same case holds for the implementation of the look-ahead in the algorithm. When shipment information is available at a maximum of five hours in advance, for the specific case of Vita, both discussed KPI's can be reduced. This maximum value depends on the workload of the shipments and the trend in shipment arrivals. It can be recommended that a system should be developed for planning daily Inbound operations. This system should be able to implement an assignment algorithm, similar to the one used in this research. Next to that, improvement opportunities can be found in increasing the system flexibility and implementing an integration system for increasing information availability. For these systems, the thesis provides a requirement description list that should be connected to existing Inbound-IT projects. By increasing the share of the pull shipments in the pull/push ratio, a more stabilized WIP-flow and a reduced arrival variance can be achieved. The overall performances will then improve since operations can be planned more efficiently and spread along the day.

How can the current Inbound process be redesigned, such that throughput time is improved?

In conclusion, this thesis examines and suggests three different redesign opportunities for improvement in the Inbound process. First, the assignment should be based on an algorithm that deals with the urgency as well as the processing time of orders. Secondly, Inbound should strive for an as high as possible flexibility of the system. Lastly, the availability of information can improve the performance by making it possible to plan orders in-transit.

9.2 Recommendations

Based on the conclusions of the results, some recommendations for Vita are made.

- The current Inbound tool is supportive on operational level, but for reporting and data motives it does not perform sufficiently. This depends on the integration of the system with the ERP system. This should be improved to provide accurate data.

- Aligned with running projects, a new system should be developed to monitor the Inbound operations. This system should contain a platform for planning daily operations concerning the assignment of shipments to stations, such that planning is based on data instead of instincts and routines. Supplementary requirements for this system are stated in this thesis that can serve as an input and provide evidence for the projects. The current and possibly increased flexibility can be used to its full potential when a planning system is integrated in future.

- An infrastructure should be developed, e.g. an EDI-system, to ensure information about in-transit shipments becomes available. This system should be connected to the ERP system such that this information can be used for analyses and planning purposes.

- The assignment algorithm stated in previous recommendations should improve the planning policy based on processing time and over-due time. Once the information integration has been implemented and in-transit shipments are visible in the system, this algorithm can be extended according to the look-ahead principle.

- The current level of flexibility should be improved by adding links between stations and product groups. Management needs to discuss the tradeoff between the costs in fte's of adding those links and the improvements results of the throughput time in particular.

- The current pull/push ratio should be investigated and the share of pull shipments should be increased. This stabilizes the work flow and will decrease both average throughput time and WIP-inventories. The cross-functional process needs to be aligned with the supplier and Supply Chain which can be supported by the infrastructure provided in previous recommendations.

9.3 Future Research

Based on the scope and limitations of the research, some future research directions can be provided. As stated in the detailed analysis of Vita, there are other aspects that influence the operations of the Inbound department. This research investigates the improvement opportunities of information integration and the planning system of Inbound. Other aspects that were shortly discussed are the amount of issues that interrupt the process and on how to change the pull/push ratio of the shipments to Vita's benefits. Each of these two factors could become research projects on their own. Therefore, in order to improve the Inbound department other than proposed matters, it would be recommended to analyze these two factors as well.

The on-time performances of the 24- and 48-hour were measured and simulated for all scenarios in this research. However, since it was not the main objective, it had rather a descriptive function. The OTP for both targets were already relatively high, which can indicate that the targets have to be redefined. The benchmarking section also indicates that improvement is needed to keep up with competitive performances. Therefore, a project could be started on decreasing the OTP's, instead of decreasing the average throughput time. This would decrease variations in results rather than decreasing overall throughput time.

Another interesting topic for further research would be the integration of capacity constraints. In contrary to the sufficient capacity assumption, real-life situations have to deal with illness, unexpected events and capacity restrictions. By adding this to the research situation, a closer approximation of reality is created and even stronger recommendations can be concluded. It would help gaining insight in how to deal with this missing capacity. An application of this situation would be the implementation of warehouse capacity into the planning system, which results in possibly solving future space issues.

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Appendix A Abbreviations

APS	Advanced Planning & Scheduling
ASN	Advanced Shipping Notification
CLT	Closed Loop Tool
DC	Distribution Center
DoE	Design of Experiments
EDI	Electronical Data Interchange
EMEA	Europe, the Middle East and Africa
ERP	Enterprise Resource Planning
FF	Full Flexibility
FIFO	First-In-First-Out
Fte	Fulltime-equivalent
GFC	Goods Flow Control
IT	Information Technology
LF	Limited Flexibility
NI	No information Availability
PI	Partial Information Availability
PU	Production Unit
SC	Supply Chain
SPT	Shortest Processing Time
WIP	Work-In-Process

Appendix B Shipment Arrivals

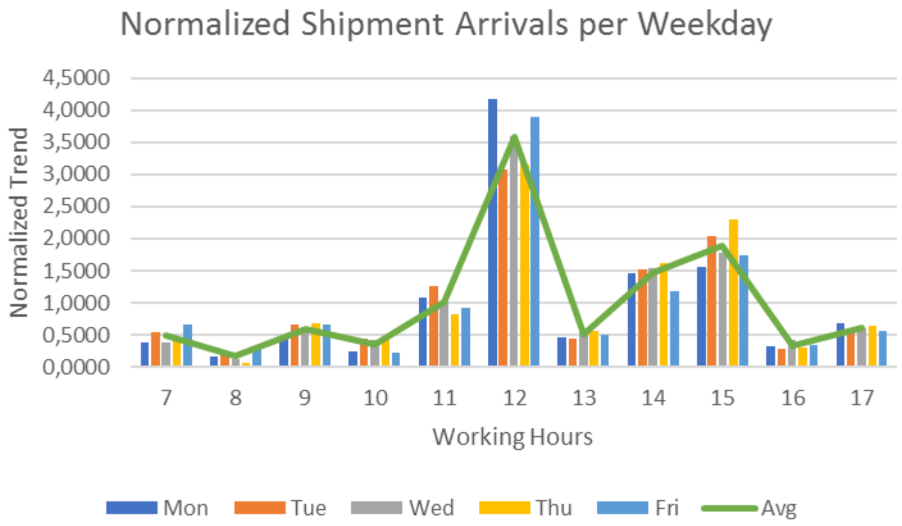

FIGURE 23 SHIPMENT ARRIVALS PER WEEKDAY PER HOUR

The trend of the shipment arrivals can be identified per hour. As can be seen, a large peak is occurring in the middle of the day. These values are normalized so that they can be used in the simulation to apply the trend to the data distribution. The normalized values averaged over all workdays are as followed.

TABLE 14 NORMALIZED VALUES OF ARRIVAL TREND

Working hour	Normalized Trend
7	0.4863
8	0.1712
9	0.5999
10	0.3478
11	1.0136
12	3.5851
13	0.5015
14	1.4644
15	1.8861
16	0.3343
17	0.6098

Appendix C Regression Analysis

When the P-value is lower than 0.05, the relation between the two variables is significant. These significant relations are highlighted in green in Table 15.

TABLE 15 RESULTS OF THE REGRESSION ANALYSIS OF THE THROUGHPUT TIME

	Coefficients	Standard Error	t Stat	P-value
Intercept	854.3667	71.9066	11.8816	2.8730E-32
Number of Case packs	68.8687	17.1467	4.0164	5.9662E-05
Number of Pallets	101.8229	13.0152	7.8234	5.8481E-15
Priority	- 62.0862	291.1309	- 0.2133	0.8311
Issue (yes or no)	1554.0181	116.1914	13.3746	2.4648E-40
Space issue	8003.8445	375.7278	21.3022	8.2900E-98

Appendix D Model Notations

TABLE 16 OVERVIEW WITH NOTATION OF MODEL PARAMETERS

Symbol	Explanation
	Indices
j	Shipment or Order
i	Station
t	Time in working hours
h	Working hours per day {1,…,11}
c	Product group
p	Processing
u	Urgency
d	Idle
	Parameters
$c_{processing}$	Costs of processing per minute on a station in stage 2
$E[PT_j]$	Expected processing time in minutes of order j in stage 2
c_{urgent}	Parameter to indicate the importance of urgency
DD	Defined due date in minutes for all orders
c_{idle}	Costs of a station being idle per minute
$t_{current}$	Current time
$lookAhead$	Value that indicates how many hours the algorithm looks ahead at most to orders that are going to arrive
β	The maximum throughput time for x percent of all finished shipments
	Decision Variables
x_{ij}	Binary variable that has value 1 if order j is assigned to station i, and 0 if this is not the case
	Variables
c_j^p	Costs of processing order j
c_j^u	Costs of delaying an order based on over-due time of order j
ST_j	Time in minutes that order j is in the system
c_j^d	Costs of idle time by waiting on order j
$E[AT_j]$	Expected arrival time of order j at stage 2
c_j	Costs of assigning order j
TPT_j	The throughput time of one shipment j
$avgTPT$	The average throughput time of all finished shipments
OTP_β	The on-time performance percentage for a set goal β, with $\beta = \{24, 48\}$
$WIP(t)$	The WIP-inventory level in the system at moment t
$avgWIP$	The average WIP-inventory over entire time horizon

Appendix E Approximations of G/G/1 Queue

Following calculations are based on the lecture notes of Gosavi which describe the queuing formulas of a G/G/1 queue. Since the first stage of the simulation model can be treated as a G/G/1 queue, the expected waiting time in the queue can be calculated. Gosavi states that the mean waiting time in queue can be approximated by the following formula.

Equation 11 Calculation of Expected Waiting Time in Queue for G/G/1 Queue (Gosavi, n.d.)

$$L_q \approx \frac{\rho^2 * (1 + C_s^2) * (C_a^2 + \rho^2 * C_s^2)}{2 * (1 - \rho) * (1 + \rho^2 * C_s^2)}$$

$$W_q = {}^{L_q}\!/_{\lambda}$$

$$W = W_q + 1/\mu$$

$$with$$

$$\rho = {}^{\lambda}\!/_{\mu} \qquad C_a^2 = \frac{\sigma_a^2}{(1/\lambda)^2} \qquad C_s^2 = \frac{\sigma_s^2}{(1/\mu)^2}$$

When using the input data of the simulation model, the formulas of Equation 11 can be used. The results are illustrated in the following table. As a result, the expected time in the system, W, can be used to calculate the expected arrival time at Stage 2, $E[AT_j]$.

Table 17 Results of Approximation Formulas of M/M/1 Queue

Variable	Value	Variable	Value
λ	3.6465	C_a^2	1.2532
μ	5.8334	C_s^2	0.0139
ρ	0.6251	L_q	0.6615 orders
σ_a	4.0821	W_q	10.8837 min
σ_s	0.6873	W	21.1693 min

Appendix F Input Validation

ARRIVAL DISTRIBUTION

In order to model the arrival distribution, the arrival times are analyzed. Firstly, the outliers are identified by means of the boxplot method. Potential outliers are detected by creating an upper bound based on 1.5 times the interquartile range. These data points are then considered to be removed. (Walfish, 2006) After analyzing the potential outliers, it can be concluded that the points can be left out. They concern very small shipments which can be consolidated into one shipment.

Secondly, the data is tested according to several known distributions with the help of statistical programs. None known distribution fit the data set. To simulate the arrival process, an Empirical distribution is used. This step function represents the probabilities that the value resulting from the distribution is equal to a certain value. The results of the calculation of the Empirical arrival function are as followed.

Table 18 Statistics of Empirical Function of Arrival Process

Statistics	
N	639
Min	0
Max	13
μ	2.9280
σ	3.1871

Table 19 PDF and CDF of Empirical Function of Arrival Process

x	Frequency	PDF	CDF	x	Frequency	PDF	CDF
0	167	0.2613	0.2613	7	22	0.0344	0.8905
1	117	0.1831	0.4444	8	17	0.0266	0.9171
2	85	0.1330	0.5775	9	15	0.0235	0.9405
3	72	0.1127	0.6901	10	9	0.0141	0.9546
4	47	0.0736	0.7637	11	13	0.0203	0.9750
5	30	0.0469	0.8106	12	10	0.0156	0.9906
6	29	0.0454	0.8560	13	6	0.0094	1.0000

This empirical distribution is fitted according to its first two moments. Adan et al. (1994) describes a method to fit discrete data to known distributions based on the mean and coefficient of variation. By means of the two-moment fit, the empirical distribution is fitted as a Negative Binomial distribution with mean 2.9820 and a coefficient of variation of 1.088497. By matters of a *disfit* function in Matlab, the parameters for the Negative Binomial distribution can be calculated. The number of failures R is equal to 1.00824 and the success probability is 0.256141. A comparison of the probability and cumulative density functions of the data and the Negative Binomial fit is illustrated in Figure 24 and Figure 25.

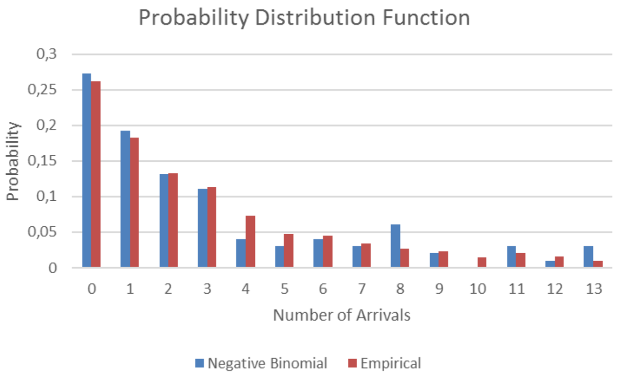

FIGURE 24 PROBABILITY DISTRIBUTION FUNCTION

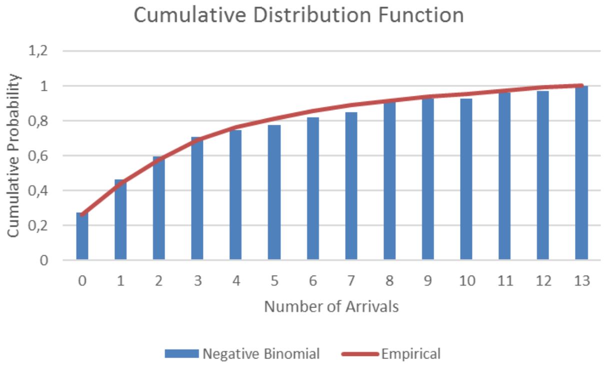

FIGURE 25 CUMULATIVE DISTRIBUTION FUNCTION

The pull/push scenario is used to simulate the results of changing the arrival process. A reduction of the arrival variance is simulated in order to predict performance improvements when adjusting the pull/push ratio of the shipments. The scenarios of an increased pull share are represented by reducing the arrival variance without changing the average number of shipments arriving per hour. The negative binomial distribution, fitted in previous paragraphs, is still used as arrival distribution. By reducing this variance, the arrivals will be smoothed along the work day without changing the average amount. This simulates a scenario of having more plannable arrivals on higher level than the daily assignment problem. As an example for simulating this scenario, the same average number of arriving shipments per hour of 2.9280 and a different standard deviation of 1.9976 is used. This number is based on a change of the fraction of pull shipments from 34% to approximately 60%.

PROCESS DISTRIBUTION OF STAGE 1

The data of the process times for the first stage is analyzed with the help of statistical programs. The goal is to fit a known distribution to the data such that this approximation can be used when simulating the model. The results of the goodness of fit test were best for the Gamma distribution with three parameters (scale η = 6.5982, shape β = 1.171 and location γ = 3.5191). The null hypothesis for the tests state that the data fits this distribution. As can be seen in Table 20, all tests accept the null hypothesis. Therefore, the data can be approached by a Gamma three parameter distribution. A histogram of the data with the corresponding Weibull distribution is illustrated in Figure 26.

TABLE 20 RESULTS OF THREE GOODNESS OF FIT TEST FOR STAGE 1

Kolmogorov-Smirnov					
Sample Size	102				
Statistic	0.0556				
P-Value	0.8937				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.1062	0.1211	0.1347	0.1503	0.1613
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	102				
Statistic	0.34851				
A	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No

Chi-Squared					
Deg. of freedom	6				
Statistic	4.5738				
P-Value	0.5995				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	8.5581	10.6450	12.5920	15.0330	16.8120
Reject?	No	No	No	No	No

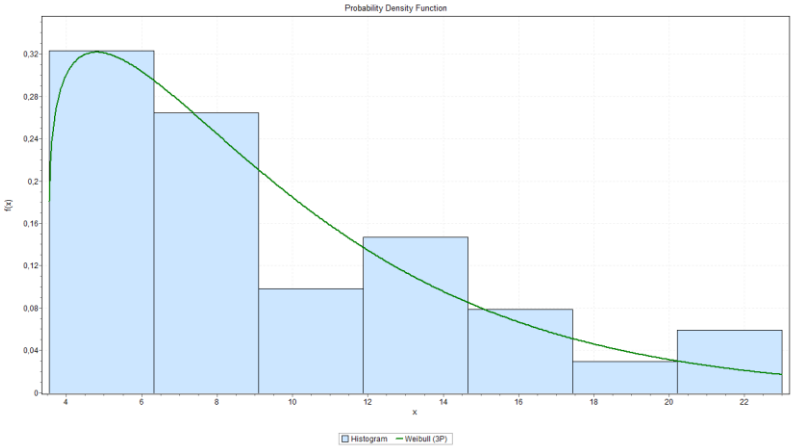

FIGURE 26 PDF OF STAGE 1 WITH WEIBULL DISTRIBUTION

PROCESS DISTRIBUTION OF STAGE 2

The processing times of the Inbound process of Vita are analyzed such that it can be simulated. Outliers are again identified by means of the boxplot method and the 1.5 interquartile range rule. These data points are then considered to be removed when feasible reason is present. (Walfish, 2006) Then, the data is tested according to several known distributions with the help of statistical programs. None known distribution fitted the data set. By analyzing the data, nine product categories can be identified based on product characteristics. Their processing times and station flexibility is similar such that they can be treated in the same way. The processing times of the nine categories are then fitted separately with the two-moment fit approximation of discrete distributions. The processing time at stage 2 is considered as discrete since the simulation is only supported by round minutes. The statistics information of the product groups is shown in Table 21. (Adan, van Eenige, & Resing, 1994)

TABLE 21 STATISTICS OF THE PROCESSING TIMES OF STAGE 2

Category	Avg	St. Dev	C_x	C_x^2	a	k
1	239	47.3762	0.1982	0.0393	0.0351	28
2	54	35.6048	0.6593	0.4347	0.4162	2
3	61	44.8453	0.7352	0.5405	0.5241	1
4	84	77.5145	0.9228	0.8515	0.8396	1
5	25	11.9024	0.4761	0.2267	0.1867	5
6	119	117.2710	0.9855	0.9712	0.9627	1
7	295	142.2474	0.4822	0.2325	0.2291	4
8	21	4.8591	0.2314	0.0535	0.0059	168
9	76	50.4249	0.6635	0.4402	0.4271	2

All processing times of stage 2 fit a Negative Binomial distribution according to the two-moment fit. Again, the *disfit* function in Matlab is used to estimate the parameters of the distributions. Besides, the average processing times for each product category is calculated to use as prediction for the workload. These are illustrated in Table 21.

STATION FLEXIBILITY

There are three different input matrices used for the station flexibility. The case of full flexibility is illustrated in Table 22, limited flexibility in Table 23 and the flexibility of the current situation in

Table 24. The rows indicate the nine different categories, while the columns show the five stations of stage 2.

TABLE 22 FLEXIBILITY OF STATIONS IN CASE OF FULL FLEXIBILITY

Category	Station				
	1	*2*	*3*	*4*	*5*
1	1	1	1	1	1
2	1	1	1	1	1
3	1	1	1	1	1
4	1	1	1	1	1
5	1	1	1	1	1
6	1	1	1	1	1
7	1	1	1	1	1
8	1	1	1	1	1
9	1	1	1	1	1

TABLE 23 FLEXIBILITY OF STATIONS IN CASE OF LIMITED FLEXIBILITY

Category	Station				
	1	*2*	*3*	*4*	*5*
1	0	0	0	1	1
2	0	1	1	0	0
3	0	0	0	1	1
4	0	0	0	1	1
5	0	0	1	0	1
6	1	1	0	0	0
7	1	0	1	0	0
8	0	1	1	0	0
9	1	0	0	1	0

TABLE 24 FLEXIBILITY OF STATIONS OF CURRENT SITUATION

Category	Station				
	1	*2*	*3*	*4*	*5*
1	1	0	0	1	1
2	0	1	1	0	1
3	0	1	0	0	0
4	0	1	0	1	0
5	1	1	0	0	1
6	0	1	1	0	0
7	1	1	1	1	0
8	1	0	0	0	0
9	0	1	0	0	0

In the case of limited flexibility an optimal solution is found such that each category can be processed at two stations. The objective of this allocation is to minimize the workload among the stations. Therefore, calculations were based on the arrival frequency and expected workload in processing time. A solver solution is obtained by setting the sum of assignments per product type to stations to two. The assignment variables are binary to ensure the only choices to choose between is assigning it to the station (1) or not (0). After solving the linear problem, an optimal solution with a minimum value for the standard deviation of the sum of the calculated workloads per station is calculated. In particular, it is a measurement for the spread of the workload amongst the stations. The optimal limited flexibility for this particular research is illustrated in Table 23 and the calculations can be found in Table 25.

TABLE 25 CALCULATIONS OF OPTIMAL LIMITED FLEXIBILITY

Category	Frequency	Processing Time (minutes)	1	2	3	4	5
1	0.10	239	0.00	0.00	0.00	23.11	23.11
2	0.32	54	0.00	17.22	17.22	0.00	0.00
3	0.10	61	0.00	0.00	0.00	5.86	5.86
4	0.05	84	0.00	0.00	0.00	3.85	3.85
5	0.10	25	0.00	0.00	2.37	0.00	2.37
6	0.14	119	16.93	16.93	0.00	0.00	0.00
7	0.05	295	14.08	0.00	14.08	0.00	0.00
8	0.10	21	0.00	2.02	2.02	0.00	0.00
9	0.05	76	3.99	0.00	0.00	3.99	0.00
		Sum of Calculated Workload	**34.99**	**36.17**	**35.69**	**36.81**	**35.20**

Appendix G Cost Parameters Test

In order to get an accurate result from the algorithm, it is key to set the costs parameters correctly. The value for the processing time *c_p*, the urgency *c_u* and the idle time *c_i* had to be defined. Since a lot of different values and combinations are tested, not all tests are illustrated. To give an indication into the test results, some scenarios are given in this appendix.

In order to analyze whether the used method to shape the parameters is valid and the three parameters are not correlated, an analysis is performed. The correlation coefficients of the relation of the costs parameters with each other and with the throughput time is calculated. The results are showed in Table 26. As can be seen, there are no significant correlations between the costs parameters. And therefore, the used method is valid.

TABLE 26 CORRELATION ANALYSIS WITH SPEARMAN RHO VALUE AND P-VALUE (SIGNIFICANT WHEN < 0.05)

	c_p	**c_u**	**c_i**
c_u	0.000		
	1.000		
c_i	- 0.022	0.000	
	0.909	1.000	
Throughput	0.013	0.236	- 0.249
Time	0.944	0.210	0.185

For the first and third scenario, the *c_i* is not important since they do not consider any look-ahead. Therefore, the parameters were first set for these scenarios. Firstly, *c_i* was set to zero while the other two parameters were tested. Secondly, *c_u* was set to zero such that a SPT-policy is created for the third scenario. Results of this analysis can be found in Table 27. All KPI's were tested, but the most important, the throughput time, is shown to compare the parameters.

TABLE 27 RESULTS OF PARAMETER TEST OF C_P

c_p	***c_u***	***c_i***	**Throughput Time** (hours)
1	0	0	15.65
2	0	0	15.45
3	**0**	**0**	**14.87**
4	0	0	15.40
5	0	0	15.81

As can be seen, the throughput time is not varying very much for the different values of *c_p*. Therefore, the parameter is set to three, and the other parameters are adapted to this value. Next, the parameter *c_u* is tested such that a version of the SPT/float-policy is created. Again, different values for this parameter are tested which can be found in Table 28.

TABLE 28 RESULTS OF PARAMETER TEST OF C_U

c_p	***c_u***	***c_i***	**Throughput Time** (hours)
3	1	0	14.20
3	4	0	13.68
3	9	0	12.66
3	**16**	**0**	**12.24**

3	25	0	17.99
3	36	0	16.62
3	49	0	16.76

The above table shows that a value of 16 is best for *c_u*. According to the costs function, this indicates that orders that have more than four hours until their due date can preferably be delayed. Finally, the *c_i* parameter is tested for scenario 4. The result can be found in Table 29.

Table 29 Results of Parameter Test of c_i

c_p	***c_u***	***c_i***	**Throughput Time (hours)**
3	16	10	12.08
3	16	20	14.21
3	**16**	**30**	**8.93**
3	16	50	9.59
3	16	70	11.61
3	16	80	13.52

As can be seen, a value of approximately 30 for *c_i* performs best. Therefore, for all scenarios the following values will be used: 3 for *c_p*, 16 for *c_u* and 30 for *c_i*.

Appendix H Model Validation

The validation of the model is done according to the queuing formulas examined by Lee and Longton (1957). They state that the steady state waiting time of a M/G/K system can be approximately determined with the help of the expected waiting time of a M/M/K system. The following formulas apply for this approximation.

EQUATION 12 APPROXIMATION OF M/G/K QUEUING SYSTEM (GUPTA, HARCHOL-BALTER, DAI, & ZWART, 2010)

$$W_q^{M/G/K} \approx \left(\frac{1+C^2}{2}\right) * W_q^{M/M/K}$$

$$W_q^{A/B/c} = waiting\ time\ in\ queue\ for\ an\ A/B/c\ queuing\ system$$

$$C^2 = \frac{\sigma^2}{(1/\mu)^2} = squared\ coefficient\ of\ variation\ of\ the\ service\ time\ distribution$$

$$\mathrm{c} = \text{number of stations}$$

$$\text{With steady state assumption: } \rho = \frac{\lambda}{c * \mu} < 1$$

EQUATION 13 APPROXIMATION OF THE M/M/K QUEUING SYSTEM

$$\boldsymbol{For\ the\ M/M/K\ queue}$$

$$P_0 = 1 \Big/ \left[\sum_{m=0}^{c-1} \frac{(c*\rho)^m}{m!} + \frac{(c*\rho)^c}{c!\,(c-\rho)}\right]$$

$$L_q = \frac{P_0 * \left({}^{\lambda}/_{\mu}\right)^c}{c! * (1-\rho)^2}$$

$$According\ to\ Little's\ Law$$

$$W_q = {}^{L_q}/_{\lambda} \qquad W = W_q + {}^{1}/_{\mu} \qquad L = \lambda * \mathrm{W}$$

$$W_q = average\ time\ spent\ in\ queue$$
$$L_q = average\ number\ of\ customers\ in\ queue$$
$$W = average\ time\ spent\ in\ system$$
$$L = average\ number\ of\ customers\ in\ system$$

For the simple version of the simulation model, the following input parameters are used. The arrival time distribution is set to Poisson with arrival rate λ. The service times of the five stations are Gamma distributed with shape parameter scale α and scale parameter β. In addition, the analytical results are based on a Poisson distribution with rate λ and an exponential service time with mean μ. The results for the M/G/5 queue are approximated with the squared coefficient of variation of the service time.

TABLE 30 INPUT PARAMETERS OF THE SIMPLE SIMULATION MODEL

Parameter	Value
Arrival Time Distribution	Poisson with $\lambda = 3.6853$ arrivals per hour
Service Time Distribution	Gamma with $\alpha = 1.21$ and $\beta = 45.4546$ With $\mu = 1.0909$ services per hour And $\sigma = 0.9091$
Number of servers	$c = 5$

As can be seen in Table 31, the average time and number of jobs can be calculated for both analytical and simulation situations. Then, both situations can be compared. The results show that the simulation approach closely approaches the analytical results and that the model thus represents the situation accurately.

TABLE 31 ANALYTICAL VERSUS SIMULATION RESULTS

	Analytical Results	Simulation Results
Average Time Spent in System W	1.6 hours	1.6 hours
Average Jobs in System L	5.8 jobs	5.9 jobs

Appendix I Verification

The results of the simulation of the current situation are illustrated in Table 32. There are 20 replications with each measuring the throughput time, both 24 and 48 hours on-time performance and the WIP-inventory. The average values of the runs are stated in the verification description.

Table 32 Results of Simulation of Current Situation per Run

Run	**Performance Indicators**			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1	17.52	91%	97%	21
2	19.57	62%	94%	23
3	13.73	75%	98%	12
4	14.98	87%	100%	14
5	23.66	63%	83%	29
6	15.40	83%	100%	16
7	16.97	82%	100%	19
8	19.62	80%	99%	22
9	19.50	69%	99%	22
10	18.35	92%	99%	19
11	16.09	89%	100%	16
12	20.59	82%	100%	25
13	15.58	88%	100%	16
14	17.52	68%	96%	21
15	15.20	83%	100%	15
16	19.03	87%	97%	23
17	15.95	86%	98%	16
18	18.84	86%	100%	19
19	23.32	70%	99%	29
20	19.34	71%	100%	22
Avg	18.04	80%	98%	20

Appendix J Simulation Results

SCENARIO 1 – NO INFORMATION & LIMITED FLEXIBILITY & NORMAL PULL/PUSH RATIO

In the first scenario, the situation is researched with no information availability and limited flexibility in the stations. The results per run can be found in Table 33.

TABLE 33 SIMULATION RESULTS OF SCENARIO 1 (NI & LF)$^{-}$ PER RUN

Run	Performance Indicators			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1	13.60	98%	78%	12
2	21.21	98%	77%	24
3	14.75	99%	80%	15
4	13.50	99%	75%	13
5	9.36	98%	80%	8
6	14.15	100%	91%	16
7	16.39	86%	81%	17
8	14.40	97%	70%	14
9	13.11	98%	81%	12
10	19.85	99%	88%	22
11	9.08	83%	56%	7
12	11.18	100%	92%	10
13	21.31	99%	85%	26
14	10.58	100%	86%	9
15	25.37	97%	72%	30
16	13.72	98%	83%	14
17	10.13	98%	74%	9
18	11.00	99%	82%	10
19	20.17	99%	85%	23
20	18.01	92%	71%	20
Avg	15.04	97%	79%	16

SCENARIO 2 – PARTIAL INFORMATION & LIMITED FLEXIBILITY & NORMAL PULL/PUSH RATIO

In the second scenario, the situation is researched with partial information availability and limited flexibility in the stations. The results per run can be found in Table 34. In addition, it is analyzed how many hours is looked ahead to when assigning shipments to stations. Table 35 shows the percentages of assigning for the look-ahead values 0 till 5.

TABLE 34 SIMULATION RESULTS OF SCENARIO 2 (PI & LF)$^{-}$ PER RUN

Run	Performance Indicators			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1	11.60	91%	71%	10
2	14.32	95%	74%	14

3	16.43	99%	86%	18
4	13.86	100%	87%	14
5	15.32	100%	86%	16
6	13.85	99%	81%	14
7	13.26	98%	77%	14
8	11.10	100%	91%	10
9	15.60	97%	78%	16
10	14.02	99%	74%	14
11	13.50	99%	83%	13
12	17.59	99%	81%	20
13	15.73	99%	82%	16
14	9.21	99%	88%	8
15	13.56	99%	80%	13
16	17.50	92%	73%	20
17	11.62	97%	79%	11
18	9.56	99%	82%	7
19	13.73	98%	73%	14
20	18.51	100%	88%	21
Avg	13.99	98%	81%	14

TABLE 35 PERCENTAGES OF ASSIGNMENTS OF SCENARIO 2 (PI & LF) $^{-}$

Run	Percentage of Assignments with Look-ahead value					
	0	*1*	*2*	*3*	*4*	*5*
1	90.5%	4.0%	2.4%	1.5%	0.8%	0.7%
2	91.1%	3.9%	2.5%	1.3%	0.6%	0.4%
3	88.4%	4.9%	3.3%	1.9%	0.7%	0.7%
4	85.9%	5.5%	4.1%	2.1%	1.2%	1.0%
5	90.5%	4.3%	2.7%	1.4%	0.6%	0.5%
6	90.0%	4.2%	2.6%	1.4%	1.0%	0.6%
7	90.9%	3.7%	2.7%	1.3%	0.6%	0.7%
8	88.3%	5.0%	3.0%	1.8%	1.0%	0.9%
9	91.8%	3.8%	2.1%	1.2%	0.6%	0.4%
10	91.8%	3.3%	2.4%	1.4%	0.6%	0.4%
11	88.2%	4.7%	3.2%	1.8%	1.1%	0.9%
12	89.9%	4.3%	2.8%	1.6%	0.7%	0.6%
13	90.9%	3.9%	2.5%	1.5%	0.6%	0.5%
14	86.8%	5.6%	3.3%	2.1%	1.1%	0.8%
15	89.5%	4.3%	2.8%	1.8%	0.9%	0.6%
16	90.3%	3.7%	2.7%	1.7%	0.9%	0.6%
17	89.3%	4.7%	2.8%	1.5%	0.7%	0.6%
18	87.7%	5.1%	3.7%	1.8%	1.0%	0.6%
19	89.5%	4.5%	2.8%	1.5%	0.9%	0.7%
20	88.8%	4.7%	3.1%	1.8%	0.8%	0.7%
Avg	89.5%	4.4%	2.9%	1.6%	0.8%	0.6%

SCENARIO 3 – NO INFORMATION & FULL FLEXIBILITY & NORMAL PULL/PUSH RATIO

In the third scenario. the situation is researched with no information availability and full flexibility in the stations. The results per run can be found in Table 36.

TABLE 36 SIMULATION RESULTS OF SCENARIO 3 (NI & FF) $^{-}$ PER RUN

Run	Performance Indicators			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1	12.75	100%	88%	10
2	15.16	100%	86%	16
3	17.44	98%	81%	19
4	8.84	100%	92%	8
5	10.94	100%	93%	10
6	13.26	100%	90%	13
7	9.05	100%	87%	6
8	20.28	95%	84%	23
9	7.76	99%	86%	5
10	11.35	100%	89%	8
11	9.72	100%	92%	6
12	11.08	99%	84%	8
13	12.45	100%	87%	12
14	15.27	99%	90%	16
15	11.05	100%	83%	10
16	10.83	100%	94%	10
17	10.50	100%	89%	9
18	11.30	100%	90%	11
19	11.95	100%	87%	11
20	10.77	100%	93%	6
Avg	12.09	99%	88%	11

SCENARIO 4 – PARTIAL INFORMATION & FULL FLEXIBILITY & NORMAL PULL/PUSH RATIO

In the fourth scenario, the situation is researched with partial information availability and full flexibility in the stations. The results per run can be found in Table 37. In addition, it is analyzed how many hours is looked ahead to when assigning shipments to stations. Table 38 shows the percentages of assigning for the look-ahead values 0 till 5.

TABLE 37 SIMULATION RESULTS OF SCENARIO 4 (PI & FF) $^{-}$ PER RUN

Run	Performance Indicators			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1	9.48	100%	88%	7
2	11.14	100%	95%	11
3	6.86	100%	88%	5
4	9.22	100%	99%	8

5	9.80	100%	98%	9
6	12.37	100%	95%	12
7	11.93	100%	93%	12
8	11.59	100%	89%	11
9	11.12	98%	87%	12
10	12.05	99%	87%	12
11	9.16	100%	98%	7
12	12.12	100%	92%	12
13	10.64	100%	83%	9
14	9.13	99%	76%	7
15	10.08	100%	95%	9
16	10.42	100%	92%	9
17	9.37	99%	83%	7
18	16.76	100%	93%	19
19	11.10	92%	76%	10
20	10.46	100%	85%	9
Avg	10.74	99%	89%	10

TABLE 38 PERCENTAGES OF ASSIGNMENTS OF SCENARIO 4 (PI & FF) -

Run	**Percentage of Assignments with Look-ahead value**					
	0	*1*	*2*	*3*	*4*	*5*
1	88.3%	5.2%	3.9%	1.6%	0.6%	0.2%
2	85.7%	5.8%	4.9%	2.3%	0.8%	0.3%
3	84.6%	6.2%	5.0%	2.9%	0.9%	0.2%
4	84.4%	6.9%	3.6%	2.7%	0.6%	1.9%
5	85.7%	5.9%	5.0%	2.4%	0.6%	0.3%
6	87.7%	4.7%	4.2%	2.2%	0.7%	0.3%
7	89.0%	4.5%	3.6%	1.9%	0.6%	0.2%
8	89.2%	4.4%	3.4%	1.9%	0.7%	0.2%
9	92.6%	3.0%	2.4%	1.2%	0.6%	0.2%
10	89.1%	4.8%	3.5%	1.5%	0.6%	0.3%
11	86.2%	5.9%	4.5%	2.0%	0.8%	0.5%
12	88.6%	5.0%	3.8%	1.7%	0.5%	0.2%
13	89.0%	4.5%	3.3%	2.0%	0.7%	0.3%
14	89.8%	4.3%	3.1%	1.9%	0.6%	0.1%
15	86.3%	5.7%	4.3%	2.3%	1.1%	0.2%
16	89.2%	5.3%	3.3%	1.5%	0.6%	0.1%
17	89.7%	3.9%	3.3%	2.0%	0.8%	0.2%
18	90.0%	4.7%	3.1%	1.6%	0.4%	0.2%
19	90.1%	4.1%	3.2%	1.6%	0.5%	0.3%
20	89.2%	4.5%	3.6%	1.8%	0.5%	0.3%
Avg	88.2%	5.0%	3.7%	1.9%	0.7%	0.3%

SCENARIO 5 – NO INFORMATION & LIMITED FLEXIBILITY & ADJUSTED PULL/PUSH RATIO

In the fifth scenario, the situation is researched with no information availability and limited flexibility in the stations. The results per run can be found in Table 39. The pull/push ratio has been adjusted from 34/66% to 60/40% so that arrival variance is reduced.

TABLE 39 SIMULATION RESULTS OF SCENARIO 5 (NI & LF)$^+$ PER RUN

Run	**Performance Indicators**			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1	9.95	100%	97%	8
2	10.23	100%	92%	8
3	10.72	100%	96%	10
4	8.72	100%	96%	7
5	9.34	100%	86%	7
6	11.35	99%	89%	10
7	11.06	100%	93%	10
8	8.19	100%	96%	6
9	7.99	100%	92%	6
10	9.10	100%	90%	7
11	8.37	100%	91%	6
12	9.97	100%	93%	9
13	10.01	100%	95%	9
14	16.81	99%	92%	17
15	8.13	100%	96%	6
16	13.19	100%	91%	13
17	8.67	100%	94%	7
18	9.81	100%	98%	8
19	9.18	100%	93%	7
20	11.12	100%	90%	10
Avg	10.10	100%	93%	9

SCENARIO 6 – PARTIAL INFORMATION & LIMITED FLEXIBILITY & ADJUSTED PULL/PUSH RATIO

In the sixth scenario, the situation is researched with partial information availability and limited flexibility in the stations. The results per run can be found in Table 40. In addition, it is analyzed how many hours is looked ahead to when assigning shipments to stations. Table 41 shows the percentages of assigning for the look-ahead values 0 till 5. The pull/push ratio has been adjusted from 34/66% to 60/40% so that arrival variance is reduced.

TABLE 40 SIMULATION RESULTS OF SCENARIO 6 (PI & LF)$^+$ PER RUN

Run	**Performance Indicators**			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1	7.94	99%	91%	6
2	7.75	100%	87%	6

3	8.34	100%	96%	6
4	9.72	100%	94%	8
5	9.06	100%	93%	7
6	9.29	100%	94%	8
7	8.95	100%	91%	7
8	12.73	100%	94%	12
9	9.19	100%	92%	7
10	11.81	100%	92%	11
11	9.99	100%	94%	8
12	10.47	100%	94%	9
13	11.06	100%	94%	10
14	9.11	100%	95%	7
15	8.34	99%	82%	6
16	8.19	100%	92%	6
17	9.05	100%	88%	7
18	8.46	100%	96%	6
19	8.27	100%	96%	6
20	9.57	100%	96%	8
Avg	9.37	100%	93%	8

TABLE 41 PERCENTAGES OF ASSIGNMENTS OF SCENARIO 6 (PI & LF) $^{+}$

Run	**Percentage of Assignments with Look-ahead value**					
	0	*1*	*2*	*3*	*4*	*5*
1	84.8%	7.8%	3.9%	1.8%	1.0%	0.7%
2	85.0%	7.5%	4.1%	2.0%	0.9%	0.5%
3	82.0%	8.7%	5.0%	2.2%	1.4%	0.8%
4	83.8%	8.2%	4.6%	1.9%	1.0%	0.4%
5	85.8%	7.2%	4.2%	1.6%	0.7%	0.5%
6	83.6%	8.0%	4.5%	2.3%	0.9%	0.7%
7	85.1%	7.5%	3.8%	1.9%	1.0%	0.7%
8	84.6%	7.3%	4.4%	2.0%	1.1%	0.7%
9	84.7%	7.3%	4.6%	1.9%	0.9%	0.5%
10	86.6%	6.7%	3.9%	1.6%	0.7%	0.5%
11	83.2%	8.1%	4.9%	2.3%	0.9%	0.6%
12	84.5%	7.7%	4.7%	1.7%	0.8%	0.6%
13	81.8%	9.4%	5.2%	2.2%	0.7%	0.6%
14	83.0%	8.4%	4.8%	2.2%	0.9%	0.6%
15	85.7%	6.9%	4.1%	1.9%	0.8%	0.5%
16	82.3%	8.4%	4.9%	2.5%	1.1%	0.8%
17	85.9%	7.1%	3.9%	1.8%	0.7%	0.6%
18	83.1%	8.7%	4.9%	1.7%	1.0%	0.5%
19	82.2%	8.8%	4.9%	2.4%	1.1%	0.6%
20	83.3%	7.8%	4.9%	2.6%	0.8%	0.5%
Avg	84.0%	7.9%	4.5%	2.0%	0.9%	0.6%

SCENARIO 7 – NO INFORMATION & FULL FLEXIBILITY & ADJUSTED PULL/PUSH RATIO

In the seventh scenario, the situation is researched with no information availability and full flexibility in the stations. The results per run can be found in Table 42. The pull/push ratio has been adjusted from 34/66% to 60/40% so that arrival variance is reduced.

TABLE 42 SIMULATION RESULTS OF SCENARIO 7 (NI & FF)$^{+}$ PER RUN

Run	Performance Indicators			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1	7.12	100%	99%	5
2	7.47	100%	100%	5
3	5.29	100%	100%	2
4	5.69	100%	95%	3
5	6.93	100%	97%	4
6	8.01	100%	98%	5
7	7.07	100%	91%	5
8	7.72	100%	99%	6
9	7.47	100%	97%	6
10	5.29	100%	100%	3
11	6.73	100%	98%	4
12	6.33	100%	98%	4
13	5.75	100%	96%	3
14	6.96	100%	99%	4
15	6.76	100%	100%	4
16	7.81	100%	98%	6
17	6.83	100%	97%	4
18	5.83	100%	98%	3
19	9.53	100%	98%	8
20	5.79	100%	99%	3
Avg	6.82	100%	98%	4

SCENARIO 8 – PARTIAL INFORMATION & FULL FLEXIBILITY & ADJUSTED PULL/PUSH RATIO

In the eighth scenario, the situation is researched with partial information availability and full flexibility in the stations. The results per run can be found in Table 43. In addition, it is analyzed how many hours is looked ahead to when assigning shipments to stations. Table 44 shows the percentages of assigning for the look-ahead values 0 till 5. The pull/push ratio has been adjusted from 34/66% to 60/40% so that arrival variance is reduced.

TABLE 43 SIMULATION RESULTS OF SCENARIO 8 (PI & FF)$^{+}$ PER RUN

Run	Performance Indicators			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1	6.55	100%	97%	4

2	5.95	100%	96%	4
3	6.01	100%	99%	3
4	6.20	100%	99%	5
5	7.75	100%	99%	7
6	6.95	100%	98%	4
7	5.08	100%	100%	2
8	6.87	100%	99%	4
9	6.54	100%	99%	4
10	6.14	100%	99%	3
11	6.65	100%	100%	4
12	6.84	100%	100%	4
13	6.77	100%	99%	4
14	5.15	100%	95%	2
15	7.03	100%	94%	5
16	5.75	100%	99%	3
17	7.74	100%	97%	7
18	6.72	100%	99%	4
19	7.11	100%	100%	5
20	7.33	100%	90%	7
Avg	6.56	100%	98%	4

Table 44 Percentages of Assignments of Scenario 8 (PI & FF) $^{+}$

Run	**Percentage of Assignments with Look-ahead value**					
	0	*1*	*2*	*3*	*4*	*5*
1	81.7%	9.3%	6.4%	2.1%	0.5%	0.0%
2	82.4%	8.0%	6.6%	2.4%	0.5%	0.0%
3	79.6%	10.2%	6.7%	2.7%	0.6%	0.1%
4	81.0%	9.5%	6.3%	2.5%	0.5%	0.1%
5	81.4%	9.3%	6.5%	2.1%	0.4%	0.2%
6	82.1%	9.3%	5.8%	2.2%	0.4%	0.1%
7	77.5%	11.3%	8.0%	2.4%	0.6%	0.2%
8	80.0%	9.7%	7.0%	2.6%	0.5%	0.1%
9	81.5%	9.4%	6.4%	2.2%	0.5%	0.0%
10	79.5%	10.2%	7.1%	2.4%	0.7%	0.1%
11	79.9%	10.0%	7.0%	2.4%	0.6%	0.1%
12	80.2%	10.3%	6.6%	2.4%	0.4%	0.1%
13	82.3%	8.5%	6.0%	2.4%	0.7%	0.1%
14	80.7%	10.3%	6.6%	2.0%	0.3%	0.1%
15	79.7%	10.0%	7.2%	2.5%	0.6%	0.1%
16	81.2%	9.5%	6.2%	2.3%	0.6%	0.1%
17	83.1%	8.6%	5.7%	1.9%	0.6%	0.1%
18	80.3%	9.9%	6.9%	2.2%	0.6%	0.1%
19	80.7%	9.5%	6.3%	2.7%	0.7%	0.1%
20	83.1%	8.3%	5.9%	2.1%	0.5%	0.1%
Avg	80.9%	9.6%	6.6%	2.3%	0.5%	0.1%

CONFIDENCE INTERVALS

The simulation accuracy is tested based on a 100(1-α)% interval with α = 5% and m = 20 replications. The formula used to calculate the interval is $Z \pm t\left(1-\frac{\alpha}{2}, m-1\right) * \sqrt{\frac{S^2}{m}}$. Where $S = \sum_{i=1}^{m} \frac{(Z_i - Z)^2}{m-1}$ and the t-value of the student t-distribution $t(0.975,19) = 2.093$ with 19 degrees of freedom. (Law & Kelton, 1992) Then, the confidence intervals for the average throughput times of all scenarios can be found in Table 45.

TABLE 45 CONFIDENCE INTERVALS OF THROUGHPUT TIME FOR ALL SCENARIOS

Scenario	Interval – half width	Lower Bound	Upper Bound
Current	± 3.33	14.71	21.37
1 (NI & LF)$^-$	± 3.38	11.66	18.42
2 (PI & LF)$^-$	± 3.02	10.98	17.01
3 (NI & FF)$^-$	± 4.04	8.05	16.13
4 (PI & FF)$^-$	± 1.79	8.95	12.53
5 (NI & LF)$^+$	± 1.97	8.13	12.06
6 (PI & LF)$^+$	± 0.80	8.56	10.17
7 (NI & FF)$^+$	± 0.52	6.30	7.33
8 (PI & FF)$^+$	± 0.25	6.31	6.81

Appendix K Look-ahead Results

TABLE 46 CATEGORIES OF LOOK-AHEAD AND PERCENTAGES OF FREQUENCY FOR SCENARIO 4 AND 8

Category	Description	Average Percentages of Scenario 4	Average Percentages of Scenario 8
0	Orders that have arrived at stage 2	88.2%	80.9%
1	Orders that are going to arrive within one hour, these are also orders that have arrived at stage 1 but not have been processed yet at station 1	5.0%	9.6%
2	Orders that are going to arrive between 1 and 2 hours from current time	3.7%	6.6%
3	Orders that are going to arrive between 2 and 3 hours from current time	2.9%	2.3%
4	Orders that are going to arrive between 3 and 4 hours from current time	0.7%	0.5%
5	Orders that are going to arrive between 4 and 5 hours from current time	0.3%	0.1%

TABLE 47 RESULTS OF AVERAGE LOOK-AHEAD VALUE AND IDLE TIME PER HOUR FOR SCENARIO 4 AND 8

Hour	Scenario 4		Scenario 8	
	Average Look-ahead (hours)	Average Idle Time (hours)	Average Look-ahead (hours)	Average Idle Time (hours)
7	2.47	1.99	2.27	1.75
8	2.22	1.78	1.95	1.49
9	1.89	1.58	1.85	1.31
10	1.64	1.04	1.37	0.87
11	1.12	0.82	0.99	0.55
12	0.80	0.81	1.05	0.83
13	1.31	1.06	1.22	0.61
14	1.27	1.06	1.09	0.66
15	1.46	1.62	1.36	0.92
16	1.74	1.38	1.67	0.98
17	1.66	1.25	1.74	1.27
Avg	1.60	1.31	1.51	1.02

Appendix L Business Case

This Appendix shows the simulation results for 20 replications of each step of the business case.

TABLE 48 SIMULATION RESULTS OF BUSINESS CASE FOR STEP 0

Run	Performance Indicators			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1	10.74	73%	98%	10
2	11.51	82%	99%	11
3	13.66	87%	99%	13
4	18.97	83%	100%	21
5	19.60	74%	99%	23
6	17.85	76%	99%	19
7	13.69	82%	99%	14
8	14.47	79%	99%	15
9	17.02	74%	97%	34
10	21.09	80%	97%	24
11	14.42	65%	94%	17
12	18.64	72%	100%	21
13	12.42	82%	100%	12
14	19.50	76%	91%	58
15	11.70	88%	100%	10
16	14.82	89%	100%	15
17	18.73	84%	100%	22
18	14.28	82%	100%	14
19	16.22	74%	97%	17
20	15.43	83%	100%	18
Avg	15.74	79%	98%	19

TABLE 49 SIMULATION RESULTS OF BUSINESS CASE FOR STEP 1

Run	Performance Indicators			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1	14.01	78%	81%	15
2	17.39	88%	100%	20
3	14.56	80%	100%	15
4	12.31	67%	100%	13
5	10.92	90%	100%	14
6	14.03	82%	100%	14
7	14.60	81%	100%	15
8	10.96	83%	100%	13
9	12.56	87%	100%	15
10	13.56	80%	100%	14
11	11.80	82%	100%	8

12	13.61	84%	100%	11
13	13.19	87%	100%	13
14	12.87	82%	99%	13
15	12.87	90%	100%	13
16	13.14	80%	100%	13
17	13.78	81%	100%	13
18	14.50	79%	95%	13
19	13.43	74%	96%	11
20	14.01	87%	100%	15
Avg	13.41	82%	98%	14

Table 50 Simulation Results of Business Case for Step 2

Run	**Performance Indicators**			
	Throughput Time (hours)	*On-time Performance* $\beta = 24$ *hours*	*On-time performance* $\beta = 48$ *hours*	*WIP-inventory (shipments)*
1	13.35	71%	96%	16
2	13.55	88%	100%	14
3	12.69	88%	100%	12
4	14.60	85%	98%	15
5	11.21	84%	100%	10
6	12.31	94%	100%	12
7	11.57	80%	100%	11
8	12.92	88%	99%	19
9	12.79	88%	99%	12
10	15.48	71%	97%	24
11	12.39	88%	100%	11
12	18.40	86%	99%	21
13	17.93	79%	96%	19
14	12.48	93%	100%	8
15	11.32	87%	100%	11
16	12.63	74%	93%	12
17	11.73	84%	98%	15
18	11.72	86%	100%	7
19	13.39	83%	98%	15
20	13.56	82%	100%	17
Avg	13.30	84%	99%	14

Table 51 Simulation Results of Business Case for Step 3

Run	**Performance Indicators**			
	Throughput Time (hours)	*On-time Performance* $\beta = 24$ *hours*	*On-time performance* $\beta = 48$ *hours*	*WIP-inventory (shipments)*
1	13.31	84%	100%	13
2	12.13	92%	100%	19
3	12.86	83%	99%	27

4	10.43	86%	99%	10
5	10.72	94%	100%	9
6	15.60	79%	99%	20
7	16.41	79%	100%	18
8	12.84	84%	100%	13
9	10.92	79%	97%	10
10	13.30	76%	89%	13
11	13.24	75%	95%	14
12	14.13	83%	100%	14
13	10.51	87%	99%	9
14	10.75	90%	100%	10
15	14.26	93%	100%	14
16	19.87	85%	99%	23
17	13.29	85%	99%	14
18	10.29	84%	96%	9
19	11.47	90%	100%	11
20	12.39	92%	100%	14
Avg	12.94	85%	99%	14

Table 52 Simulation Results of Business Case for Step 4

Run	**Performance Indicators**			
	Throughput Time (hours)	*On-time Performance $\beta = 24$ hours*	*On-time performance $\beta = 48$ hours*	*WIP-inventory (shipments)*
1	11.44	87%	100%	11
2	11.53	89%	100%	11
3	8.49	87%	99%	7
4	10.34	91%	99%	10
5	15.45	88%	100%	16
6	9.45	85%	98%	8
7	13.67	94%	100%	15
8	10.30	93%	100%	9
9	7.30	91%	100%	5
10	9.21	88%	98%	8
11	10.36	86%	100%	9
12	11.52	83%	100%	11
13	10.78	83%	96%	11
14	14.13	83%	100%	15
15	15.23	85%	100%	18
16	12.00	80%	99%	11
17	17.06	95%	100%	19
18	9.56	94%	100%	9
19	12.46	92%	100%	12
20	15.16	87%	100%	17
Avg	11.78	88%	99%	11

Table 53 Simulation Results of Business Case for Step 5

Run	**Performance Indicators**			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1	10.71	86%	99%	9
2	14.00	91%	100%	14
3	8.83	89%	100%	7
4	8.63	94%	100%	7
5	12.10	78%	99%	11
6	12.77	80%	98%	12
7	9.54	93%	100%	8
8	9.22	95%	100%	7
9	10.54	95%	100%	9
10	8.82	95%	100%	10
11	10.82	83%	99%	10
12	9.49	88%	100%	8
13	13.27	94%	100%	13
14	10.24	94%	100%	9
15	15.91	84%	100%	17
16	11.55	83%	100%	11
17	11.63	90%	100%	11
18	11.67	86%	99%	11
19	10.14	87%	100%	9
20	9.04	97%	100%	8
Avg	10.95	89%	100%	10

Table 54 Simulation Results of Business Case for Step 6

Run	**Performance Indicators**			
	Throughput Time (hours)	*On-time Performance β = 24 hours*	*On-time performance β = 48 hours*	*WIP-inventory (shipments)*
1	11.98	84%	100%	11
2	9.58	93%	100%	9
3	10.51	94%	100%	9
4	10.65	92%	100%	10
5	8.87	86%	100%	11
6	11.27	85%	100%	10
7	10.38	90%	100%	9
8	9.66	92%	98%	8
9	9.01	91%	100%	7
10	10.41	89%	97%	9
11	9.43	91%	100%	8
12	8.96	92%	100%	8
13	7.66	91%	100%	6
14	9.72	98%	100%	9

15	10.16	97%	100%	8
16	13.88	82%	97%	12
17	9.70	85%	100%	8
18	14.52	96%	100%	12
19	14.78	83%	96%	14
20	8.64	89%	100%	7
Avg	10.49	90%	99%	9