SIMULATION MODEL FOR OPTIMAL PRODUCTION QUANTITY DETERMINATION AND LEAD TIME REDUCTION IN MASS CUSTOMIZATION OF SINGLE PRODUCTION STAGE (CASE STUDY: PT MEGA ANDALAN KALASAN)

THESIS

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AUTHENTICITY STATEMENT

For the sake of Allah SWT, I confess this work is on my own work except for the excerpts and the summaries that each of their sources has already been cited and mentioned. If in the future my confession is proved to be wrong and dishonest resulting the violence of the legal regulation of the papers and the intellectual property rights, then I would have the will to return my degree to be drawn back to Universitas Islam Indonesia

Yogyakarta, August 2018

(Riadho Clara Shinta)

THESIS APPROVAL OF SUPERVISOR

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DEDICATION PAGE

Alhamdulillahirabbil' alamin

To my beloved mother and father
(Dra. Hj. Djannah Sriwindiyati R & Drs. Anton Karnawan)
Thank you for all of the supports and doa

To kindness supervisor, Muhammad Ridwan Andi Purnomo, ST., M.Sc., Ph.D.
Thank you for the knowledge and the provided guidance

And all of my friends, IP TI UII batch 2014 & SIMAN Laboratory Assistant

And International Program Industrial Engineering Universitas Islam Indonesia

Jazakumullah Khairan Katsira

MOTIVATION PAGE

"For each one are successive [angels] before and behind him who protect him by the decree of Allah . Indeed, Allah will not change the condition of a people until they change what is in themselves. And when Allah intends for a people ill, there is no repelling it. And there is not for them besides Him any patron."

(Qs. Ar-Rad: 11)

"*Sebaik–baik manusia diantaramu adalah yang paling banyak memberi manfaat bagi orang lain.*"

(HR. Bukhari Muslim)

Man Jadda WaJadda

Man Shabara Zhafira

Man Saara Ala Darbi Washala

PREFACE

Assalamualaikum Warahmatullahi Wabarakatuh

Alhamdulillahirabbil'alamin, gratitude and praise to Allah *Subhanahu Wata'ala* for the strength, grace, and guidance, to help the Author in completing this undergraduate thesis. *Sholawat* and gratitude from Rasulullah *Shallallahu'alaihi Wasallam* with his family and friends that we await *syafaat* in the end of the day.

The guidance, support and many helps, either directly or indirectly, from some parties involved. On this occasion, Author would like to appreciate and thank to all of the parties below:

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Author realize that this undergraduate thesis is still not perfect and still have some weaknesses so that Author really expect any criticism and suggestions from readers for the perfection of this report. Hopefully this report and information included will be useful for Author and give benefit to other parties who read this.

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ABSTRACT

In market competitive, the customer satisfaction is a key role in assessing the company power. In that case, many big companies cannot survive because they cannot adapt to the situation in satisfying the customer desire. With the globalization and pressure from customers for faster deliveries, lower prices, and higher variability in the choice of products, it is expected that manufacturing companies strive for a more efficient production. This company concern in produce hospital equipment such as bed hospital for product type of 73004, 73005, 73006 and 73010. This company has a problem in fulfilling the customer satisfaction. It means this company has longer lead time to deliver the product until 5.15 times longer before conducted mass customization. Therefore, there were several ways to solve this problem by conducted Theory of Constraint (TOC) to identify the existence of block in the components production process. This research using simulation model of Flexsim6 to make simulation based on the real manufacturing also. Besides that, there need to conduct Customer Order Decoupling Point (CODP) simulation to know the position of stock and order which has a purpose to reduce the delivery lead time to customers and increase the manufacturing efficiency by optimizing the bottleneck operation. For the lead time in simulation model development for an existing system or before CODP implementation equal to 1.5 minutes/components and lead time after CODP implementation or simulation model development for final system equal to 0.29 minutes/components. Therefore, based on the simulation model among the existing system and final system there can reduce lead time for 1.21 minutes to produce each component. The lead time improvement after conducted CODP simulation is up to 5.15 times better compared to existing lead time.

Keywords: Mass Customization, Lead Time Reduction, CODP, TOC, Simulation Model

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CHAPTER I

INTRODUCTION

1.1 Background

In market competitive, the customer satisfaction is a key role in assessing the company power. In that case, many big companies cannot survive because they cannot adapt to the situation in satisfying the customer desire. With the globalization and pressure from customers for faster deliveries, lower prices, and higher variability in the choice of products, it is expected that manufacturing companies strive for a more efficient production. Thus, there are often happened a tradeoff being made between cost and other performance objectives when efficiency is strived for (Freiheit et al., 2007). There are many ways that have been conducted for solving the problem by improving the management of supply chain management and production system.

In the production system, there was production planning and control activities in manufacturing which arranged based on customer demand. This way is one of the strategic that applied by the company to satisfy the customer. One of the outstanding results in production planning that can satisfy the customer is by improving the inventory control system, especially in Make to Stock (MTS) to Make to Order (MTO). According to Nagib et al. (2016) inventory control is the act of maintaining the inventory at a reasonable level that could fulfill customer's demand in terms of date and amount, which leads for minimizing total costs and maximizing profit.

Rafiei and Rabbani (2014) stated MTS production system is based on forecasts of product demands and production is triggered not taking into account customer orders. Hence, considerable holding costs or stock-out costs are inevitable in contexts with highly fluctuating demands. Then, according to Tadeuz and Maruf (2016) in MTO policy, the production process begins only after the orders are received from the customers. In some cases, the company used this method to reduce inventory because the production activities start when there is an incoming order. For the complexity which faced by the company about MTO system which should produce a product based on an incoming order but there will be longer delivery which causes longer lead time happened. Otherwise, in MTS system, there is shorter delivery but the company who applied this system will have inventory cost.

Hence, based on the complexity which happened in the company of MTO and MTS there are proposed a relevant design for production which is Mass Customization (MC). There are two decisions are made: (1) What customization to offer to the customer: which components of the product will be standard and which will be customized, thus where to position the product differentiation points (PDPs) and (2) How to produce a mass customized product: which processes will be made to stock (MTS) and which will be made to order (MTO), thus where to position the customer order decoupling point (CODP) (Daaboul et al., 2015). Based on Jian-hua et al. (2007) CODP means the breaking point between productions for stock based on forecast and customization that responds to customer demand. It is also the breaking point between MTS and MTO, namely, activities before CODP are driven by forecast while activities after CODP are driven by real customer order demand.

For instance, in PT Mega Andalan Kalasan (MAK) produce hospital equipment such as in this research concern in bed hospital which consists of product type of 73004 Supramak Bed-Manual, 73005 Central Lock System Supramak Bed, 73006 Economic Supramak Bed and 73010 Supramak Fowler-Sg Stainless Steel. In PT MAK, it has a problem in fulfilling the customer satisfaction. It means, this company has longer lead time to deliver the product and cannot produce the components of product type 73006 Economic Supramak Bed optimally. It caused by the components production floor there need to produce components which use the same machine. Therefore, it raising sharing machines which cause a bottleneck among machines. This research only concern in product type of 73006 Supramak Bed-Manual by considering from the highest demand and because of used as the basic components for the others product.

In PT Mega Andalan Kalasan, since the long components are produced before CODP simulation being conducted, then it will cause not optimal components production quantity for product type 73006 Supramak Bed-Manual which give an impact to the longer delivery to the next production process. According to Purnomo and Sufa (2015) the implementation of mass customization can reduce the manufacturing lead time from 43 days to 24 days or about 44.19% when producing the variety demand. Therefore, this research needs to determine the optimum components quantity and the lead time to reach the customer satisfaction by implementing CODP to solve this problem.

Therefore, there were several ways to solve this problem by conducted Theory of Constraint (TOC) to identify the existence of block in the components production process. This research uses simulation model of Flexsim6 to make simulation based on the real manufacturing. Besides that, after identifying the position of block, Customer Order Decoupling Point (CODP) simulation should be conducted to recognize the position of stock and order which has the purpose to reduce the delivery lead time to customers and increase the manufacturing efficiency by optimizing the bottleneck operation. For instance, it is required to consider the longest processing time which influences by the setup times on a bottleneck (Olhager, 2003).

Based on the identification of the problem, it can be seen that optimization in production is one of the essential and fundamental elements for an industrial manufacture in order to shorten the delivery time and minimize the inventory cost by applied Mass Customization. In Mass Customization, it is proposed an optimal position using Customer Order Decoupling Point (CODP) or by determining the amount of product which will be produced among MTO-MTS and types of product which will be stocked firstly by the company. Then it can be determined the optimal components quantity in MTO-MTS production to shorten the delivery lead time.

Therefore, based on the previous studies in the literature review, this research will analyze the implementation of a theory of constraint and customer order decoupling point in supply chain management, especially in the procurement. This research will identify the optimum components production, lead time, and lead time improvement after conducting CODP by simulation model. The method that will be used in this research is the simulation model Flexsim6. The simulation will be used to find the optimum components quantity and lead time by considering the machine, processing time, production sequence, and the longest production time.

1.2 Problem Formulation

According to the background of research, the problem formulation in this research is suggested as follows:

1. What is the optimum production quantity for the component type of 73006 Economic Supramak Bed?
2. How many times could the lead time be reduced by this model system?
3. How much is the lead time improvement after conducting CODP simulation in the production process?

1.3 Research Objectives

The objectives of this research are mentioned in the below:

1. Identifying the amount of optimum components quantity in product type of 73006 Economic Supramak Bed.
2. Identifying the gap among lead time from the existing and the proposed system.
3. Identifying the lead time improvement after conducting CODP simulation in the production process.

1.4 Scope of Problem

The scope of the problem is a limitation of a problem to keep the research inside the scope. There are some limitations as follows:

1. This research only applies the simulation for the components production which concern on product 73006 Economic Supramak Bed and will not simulate the whole company production.
2. This research will not consider the cost variables during the production of the optimum components.

1.5 Benefits of Research

Based on the purpose of the research, this paper is developed to give the contribution as follows:

1. To provide the optimum chain of MTO and MTS for the company.
2. To provide the company to minimize the lead time and accelerate the delivery time.
3. To provide the company for the optimal components production quantity in a day.
4. To increase the wide knowledge in the field of customer order decoupling point in mass customization.
5. To increase the customer satisfaction and trust that will have an impact on the increased profit.

1.6 Systematic Writing

Study writing is based on the rules of scientific writing in accordance with the systematics as follows:

1. **CHAPTER I INTRODUCTION**
   This chapter consists of background problem, formulation of the problem, research question, problem limitation of research, the objectives or purpose research, the benefits of research and systematic writing.

2. **CHAPTER II LITERATURE**
   In this chapter, there will be elaboration on the theories of reference books and journals as well as the results of previous researches related to the research problems which are used as a reference for problem solving.

3. **CHAPTER III RESEARCH METHODOLOGY**
   This chapter consists of the description of the framework or concept, line schedule of research, and the methodology in conducting the research.

4. **CHAPTER IV COLLECTION AND PROCESSING DATA**
   This chapter contains the data obtained during the research and how to analyze the data. Data processing result is displayed either in the form of tables and graphs. Processing data also include analysis of the results obtained. This section includes reference to the discussion of the results to be written in Chapter V.

5. **CHAPTER V DISCUSSION**
   This chapter presents discussion on the data processing results that have been performed, compatibility with the objectives of research so as to produce a recommendation.

6. CHAPTER VI CONCLUSION AND RECOMMENDATION

This chapter consists of conclusion the research and completed with the recommendation for the future research.

REFERENCES

APPENDIX

CHAPTER II

LITERATURE REVIEW

2.1 Inductive Study

In this decade of the production systems, there is mass customization which has a major role from the supplier to buyer markets. Usually, the manufacturer produces several products on the same production facility. During the production process, there are combining systems for Make to Order (MTO) and Make to Stock (MTS) production. In the stock production, there will be low valued, standardized products with regular demand which produced to be stocked. Compared with order product, there are high values or customized products with uncertainty demand. Thus, from this condition, there is a strategy to determine the location of Customer Order Decoupling Point (CODP) to decide the right production mode and utilize the resources efficiently.

Some researches about hybrid MTO-MTS have been conducted by Zhang et al. (2013) explained in the Journal of Production Economics about the research that develops a multiple-server queuing model of this system. It means, there are machines which dynamically switched in the machines between MTS and MTO production using a congestion-based switching policy. By applying the minimum number of machines, there are dynamic group switching systems and the algorithm that have a purpose to find out the best policy for the system. This research also concerns on how to minimize the total costs of the system by considering capacity and inventory control as the parameters which can be satisfied through the customer service constraints. In this case study, there is a primary consideration for the cost of machine capacity which adopted by a dynamic hybrid system which had a purpose to reduce the number of machines needed by the facility while staying within pre-defined customer service constraints. The dynamic system also can be remarkable solution on the of customer service among the sales channels and lower finished goods inventory levels. Therefore, it needs reparation in the customer service for MTO and MTS operations that should be performed to execute an improvement. Hence, it can lead to the decrease of the finished goods inventory levels.

In the scope of Customer Order Decoupling Point (CODP) in mass customization, it will be divided into two models which are basic model of production cost and M/M/1 extended model. In the basic model of production cost, it is discussed the production cost optimization problem of postponement system based on the various situation of CODP, while M/M/1 extended model discusses the optimize production cost of the postponement system. This research has a purpose to determine the optimize cost for each production mode. There are four types of production modes which implemented in this research which are Make to Stock (MTS), Make to Order (MTO), Assemble to Order (ATO), and Engineering to Order (ETO). In the production modes, there are inventory location and the postponed production system which consider the manufacturing cost, semi-finished inventory cost and customer waiting cost which caused by procrastinating delivery.

To ensure the validity of the optimal location of CODP in each production mode, Matlab simulation is used. Therefore, it can be concluded that in CODP location with $r=1$ should be MTS, by the characteristics that all the production process is mass production with economic scale, when $r \leq 0.6$, it should be ATO in terms of mass production process that is longer than the customization process and exits some economics scales, for $r \leq 0.3$, it is classified as MTO with characteristics that mass production process is shorter than the customization process and the last is when $r = 0$, it classifies as ETO with the characteristics of mass production process is shorter than the customization process. Furthermore, the holding cost of processing product, investment cost caused by redesigning the postponed production can be the future research (Qin and Geng, 2013).

One of electronics companies uses the principles of mass customization to gain the high improvements in the efficiency and performance. American Power Conversion (APC) engaged in selling, designs, production, delivery and install the large complex infrastructure systems for data centers and components for these systems. In the concept of mass customization which concerns on a module-based product range and the use of product configuration systems for sales and order processing, the company record showed that APC has been done a mass production of the standard components and can fulfill the customer orders based on the final assembly. By implementing the concept of mass customization, it can reduce the whole delivery time for a complete system from 400 to 16 days. It influences the production cost significantly reduced. Therefore, the reason for lead time reduction because of the existence of an inventory for standard modules. However, it can prevent the high inventory cost because of stock the standard components compared with the pure make to order system (Hvam, 2006).

Beemsterboer et al. (2016) developed a discrete-time Markov Decision Process model to find out MTS inventory level, amount of MTO orders and the remaining lead time. In this case, study of hybrid MTO-MTS production planning to determine the product type will be MTS or MTO. Then, it will be a scenario for the optimal policies and to show which decisions that should be taken among the inventory level and backlog state of MTO products by considering the scheduling decisions. To give the optimal solution for Markov Decision Process, solver was used for program ‘R’. By implementing this method, there were cost savings up to 65% rather than prioritizing MTO or MTS systems in the planning methods by up to 25%. It was required an amount of stock to buffer if there are no MTO orders and to fulfill the production capacity. Besides that, if there are MTO orders, production is required as the replenishing stock. There is future research to develop this case using heuristic planning methods for hybrid production systems and doing a simulation-based approach. Then, the possibility to control the batch size of MTS products.

In mass customization, there were Product Differentiation Points (PDPs) and the position of Customer Order Decoupling Point (CODPs) which had the same benefits to reduce the cost from mass production technique and to obtain good response on customer requirements from the customization. The research by Daaboul et al. (2015) defined the best mass customization strategy by adopting a model and discrete event simulation software which called as Arena (Rockwell Automation). In this research, the scenario of PDPs and the possible position of CODPs shown in Pareto front from the integration of PDP and CODP as the decision making to determine the best mass customization strategy. This research concerns on the objective performance indicators which are revenue and cost. Then, the subjective performance indicators are reputation, ranking among the competition, service level, customer's loyalty and employee well-being. In the customer's perceived quality, it used the quality model that can be differentiated into an intrinsic attribute from the extrinsic attributes. The intrinsic attributes focused on the product and the physical composition. The result of this research was validated by the simulation and analyzed different possible positions of CODP and PDP which affect the generated value in a value network.

In Logistics Service Integrator (LSI), Liu et al. (2015) stated that there are two models of CODP decision which consist of single and multiple customer demands. The objective of this research was to consider the cost of order transferring and order waiting at CODP to minimize total cost of LSI. The model building on single service order in LSSC concept should recognize the cost of mass service before the CODP, after the CODP, and the cost of a customized order transferring at the CODP. This research did not use general linear programming models but a matrix. Through the analysis problem, it can be solved using MATLAB. For the future research, it can be emphasized more on the customers' satisfaction which reflected to the lead time constraints. The essential of customer's satisfaction is to make an accuracy.

Purnomo and Sufa (2015) explained that the variety of customer's needs and wants forced the manufacturer to be agile. The variety of product must be high and spend a short delivery time. Thus, this situation forces the company to combine among the order based and stock-based with high flexibility and short manufacturing lead time using mass customization concept. Then, the analysis result should be simulated. According to this research, the company can reduce the manufacturing lead time from 43 days to 24 days or about 44.19% when producing the variety demand. In the analysis method, this research used product picture analysis to classify the basic components of every product, customized components and the required manufacturing process for the customization component. The operation process chart (OPC) was applied to find out the required data for MC analysis. For the future research, optimization algorithm can be applied to control the inventory amount and set up time before CODP manufacturing process.

In the scope of flexible manufacturing, there is an evaluation of the system performance which was conducted by Polotski et al. (2016) using a piecewise linear function of serviceable and returns inventories. Then, this research proposed about the manufacturing-remanufacturing strategy analytic using heuristics, which optimized the policies in the case of system by the numerical study based on the solution of Hamilton-Jacobi-Bellman equations as the validation way. The result of this research indicated that the manufacturing and remanufacturing activities have to be coordinated in order to meet the customer demand and optimized the system performance under integrated capacity constraint.

Other than that, Sun (2017) explained about timing games and Flexible Manufacturing System (FMS) using barbell model with continuous time and make a repetition for purchasing to identify the product differentiation and production flexibility that affected firms' timing of entry. In this research, there was the concern about the maximum differentiation in product location and minimum timing differentiation as the outcomes. The result of this research was no market failure in the product location choices but there were a lateness and the earlier entry can be classified as a more flexible production system. Otherwise, there was also lateness entry which can be classified as a less flexible production system.

Theory of constraint usually concerns on the increased restricted contribution margin, reducing inventories and operating expenses. Then profitability can be improved efficiently. In furniture firm, it only produces the same raw material and the same production processes which are a dining table, TV bench, and coffee table because this system was applied to reach the highest profitability. According to the production process, the sequence consists of cutting, edge banding, montage and quality control. Based on the calculation, it can be notified that in montage there was actual capacity exceeds theoretical capacity. Therefore, this firm cannot meet customer demands, which identified as bottleneck or capacity constraint. Then, the capacity constraint in the firm and profitability will increase 42% after the elimination of this constraint (Okutmuş et al., 2015).

Garment industry concerns in the mass customization which integrated to the custom-made goods on a mass scale with good quality, low price and high productivity. In this field, it is required to respond to the customers' demand quickly by categorizing which products that can be customized and should be accomplished in very short time. Due to the fluctuating demand of the customer, quick response is needed to maintain the market which leads to the shorter lead time. This garment industry distribution network has three tiers consist of customers, three logistics service providers, and factories. Based on these tiers, customers are categorized as end customer and the third logistic service providers and the company categorized as the upstream for manufacturers. Thus, it can be concluded that the half-finished products are produced with mass production method and keep their low cost. Besides that, the module products will be produced for customized products based on the customized data (Dong et al., 2012).

Thus, based on the previous researches, this research will conduct the analysis of mass customization among the components that should be produced first. This research will get the optimal point of components production by combining concept the Make to stock and Make to Order using Customer Order Decoupling Point (CODP) which simulated by simulation model FlexSim6 to determine the differences of lead time before and after implementing CODP.

Table 2.1 State of the Art

No	Year	Author	Title	Method										
				Markov Decision Process	**Poisson distribution**	**Barbell Model**	**Multi-server queueing model**	**Mass customization**	**MATLAB simulation**	**Arena (Rockwell) Simulation**	**Stochastic dynamic programming**	**Product Picture Analysis**	**Theory of Constraint (TOC)**	**Simulation Model Flexsim6**
1	2013	Zhe George Zhang, Ilhyung Kim, Mark Springer, Gangshu (George) Cai, Yugang Yu	Dynamic pooling of make-to-stock and make-to-order operations				✓							
2	2013	Yanhong Qin, Yuanfang Geng	Production Cost Optimization Model Based on CODP in Mass Customization		✓				✓					
3	2006	Hvam, Lars	Mass customization in the electronics industry: based on modular products and product configuration					✓						
4	2015	Bart Beemsterboer, Martin Land, Ruud Teunter	Hybrid MTO-MTS production planning: an	✓	✓									

No	Year	Author	Title	Method										
				Markov Decision Process	**Poisson distribution**	**Barbell Model**	**Multi-server queueing model**	**Mass customization**	**MATLAB simulation**	**Arena (Rockwell) Simulation**	**Stochastic dynamic programming**	**Product Picture Analysis**	**Theory of Constraint (TOC)**	**Simulation Model Flexsim6**
			explorative study											
5	2015	Joanna Daaboul, Catherine Da Cunha, Julien Le Duigou, Bos ˇtjan Novak and Alain Bernard	Differentiation and customer decoupling points: An integrated design approach for mass customization							✓				
6	2015	Weihua Liu, Yuming Mo, Yi Yang and Zi Ye	Decision model of customer order decoupling point on multiple customer demands in logistics service supply chain						✓					
7	2015	Muhammad Ridwan Andi Purnomo, Mila Faila Sufa	Simulation-based performance improvement towards mass customization in make to order repetitive company									✓		

No	Year	Author	Title	Method										
				Markov Decision Process	Poisson distribution	Barbell Model	Multi-server queueing model	Mass customization	MATLAB simulation	Arena (Rockwell) Simulation	Stochastic dynamic programming	Product Picture Analysis	Theory of Constraint (TOC)	Simulation Model Flexsim6
8	2016	Vladimir Polotski, Jean-Pierre Kenne and Ali Gharbi	Production Policy Optimization in Flexible Manufacturing - Remanufacturing Systems								✓			
9	2017	Chia-Hung Sun	Timing of entry and product location in a linear barbell model: Application to flexible manufacturing systems			✓								
10	2015	Ercüment Okutmuş, Ata Kahveci, Jekaterina Kartašova,	Using Theory of Constraints for Reaching Optimal Product Mix: An Application in The Furniture Sector										✓	
11	2012	Bo Dong, Hongmei Jia, Zheng Li, Kangcheng Dong	Implementing Mass Customization in Garment Industry					✓						

No	Year	Author	Title	Method										
				Markov Decision Process	**Poisson distribution**	**Barbell Model**	**Multi-server queueing model**	**Mass customization**	**MATLAB simulation**	**Arena (Rockwell) Simulation**	**Stochastic dynamic programming**	**Product Picture Analysis**	**Theory of Constraint (TOC)**	**Simulation Model Flexsim6**
12	2018	Riadho Clara Shinta	Simulation Model For Optimal Production Quantity Determination and Lead Time Reduction In Mass Customization Of Single Production Stage					✓					✓	✓

2.2 Deductive Study

In this deductive study, the theories related to the topic will be discussed. Thus, in this deductive study, there will be an explanation about make to order, mass customization, customer order decoupling point, lead time, supply chain management and flexsim 6 simulations.

2.2.1 Make to Order

Make to Order (MTO) systems supported by zero or small inventories, agile enough to guarantee short response times. To enhance Quick Response, buyers of custom products are increasingly encouraged to order significantly in advance of their actual needs (Federgruen and Katalan, 1999). MTO products must be manufactured before a prespecified due date and production planning and control focuses on the timing and/or sequencing of the operations. The MTO systems offer a high variety of customer specific and typically, more expensive products. The production planning focuses on order execution and the performance measures are order focused. For instance, average response time, average order delay. The competitive priority is shorter than delivery lead time. Capacity planning, order acceptance/rejection and attaining high due date adherence are the main operations issues (Soman, 2005).

2.2.2 Make to Stock

Make to Stock (MTS) systems offer a low variety of producer-specified and typically, less expensive products. The focus is on anticipating the demand (forecasting) and planning to meet the demand. The competitive priority is a higher fill rate. The main operations issues are inventory planning, lot size determination, and demand forecasting. The performance measures are product focused. For instance, line item fill rate, average inventory levels (Soman, 2005).

2.2.3 Mass Customization

Mass Customization (MC) supply chain can be categorized in the mass production and customize production. Mass customization is a process which considers on the production process and the technology which designed to fulfill products based on the customer desire and wants as the customer. Make to Order (MTO) is a flexible strategy and more responsive to the volatility of demand and product variety. At the same time, Make to Stock (MTS) has a strategy in the high capacity utilization and the short lead times. By the existence both of this advantageous strategy, there were conduct a research to determine the combination of methodology about the advantages of MTO and MTS (Köber and Heinecke, 2012).

The main focus of the mass production is the highest volume and cost-effective method in the production. Mass customization can be categorized as the flexible manufacturing systems which can determine the optimal quantity of Economic Order Quantity (EOQ). The manufacturing flexibility has three main dimensions which are:

a. The range of possible production combination
b. The cost of migration from one configuration to another
c. Necessary time for migration

According to the above dimensions, a flexible manufacturing system can decrease all of three dimensions in order to minimize the total production costs also (Matulik, 2008). Besides that, flexible manufacturing system can produce a variety of products with mass volume and economies of scale achieved by mass production but there is not possible to do a modification also (Dong et al., 2012).

2.2.4 Theory of Constraint (TOC)

Theory of constraint concerns on the weakest ring(s) in the chain which called as a bottleneck for the entire company and tries to determine the relationship of these bottlenecks. In this era, it becomes an important tool for solving root problems. TOC is based on the idea that every system has at least one bottleneck which can be defined as any kind of situation that impedes the system to reach high-performance level in terms of its purposes (Goldratt, 1990). In literature, there are several studies to understand this management philosophy in detail. In their study Watson et al. (2007) stated that to better understand the historical evaluation of TOC it can be useful to separate its evaluation into five eras consist of:

1. The optimized product technology era
2. The goal era
3. The haystack syndrome era
4. It's not luck era
5. The critical chain era

This classification is useful to see how this philosophy evolves through time and how the main point of TOC researches evolves. Theory of constraints has a wide range of implementation scale. Theory can be applied in production, logistics, supply chain, distribution, project management, accounting, research and development, sales and marketing and so on. The main aim of every company to implement TOC is to increase the profit. According to this point of view, constraints are the main obstacles at achieving companies' aims. In other words, everything which exists in the road of having more profit is considered as a constraint. Thus, if companies can handle constraints in their system and manage these constraints, they would have a continuous improvement management system thus they could achieve higher profits.

Identifying a bottleneck might be difficult in a complex production process and should be investigated with great care. Normally bottleneck identified by analyzing the operational parameter such as inspecting queue lengths, machine utilization or loading levels (Duwayri et al., 2006). One approach to identify the bottleneck machine is to measure the utilization of the machines used in the production system (Law & Kelton, 2000). The machine with the highest utilization is considered to be the bottleneck. However, the utilization of different processes might be the same, so in that case, it's hard to detect the bottleneck operation. The utilization method is also unable to determine the momentary bottleneck (Roser et al., 2002). Another frequently used method to evaluate the bottleneck operation is to measure the "queue lengths of the machines" in the production systems. In this method, either the queue length or the waiting time is determined, and the resource with the longest queue length or waiting time is considered to be the bottleneck (Lawrence and Buss, 1995).

2.2.5 Customer Order Decoupling Point (CODP)

The implementation of mass customization in the manufacturing can be a continuous process or discrete product manufacturing which can be used to determine the Customer Order Decoupling Point (CODP). CODP is the breaking point between productions for stock based on forecast and customization that respond to customer demand. It is also the breaking point between MTS and MTO, namely, activities before CODP are driven by forecast while activities after CODP are driven by real customer order demand. As to the process industry, there are two characteristics in choosing CODP: firstly, the production process of the process industry is very complex and the quantities of product differentiation points are very limited. In the discrete industry, product differentiation points may appear in each stage, but in the process industry, they are usually related to the production technology and often occur in the storage link, raw material adding the link, and so on. Secondly, more factors should be considered. The setup time in the process industry is long and the requirements for equipment production load are rather strict. In addition, the raw materials, work in process, and the finished products are often perishable goods; therefore, the storage conditions are very demanding. Thus, there are several considerations in choosing CODP in the process industry, such as production technology cost, customer service level, production utilization rate, and the requirements of work in process for storage conditions and time. To implement mass customization, there are usually partly change products or production technology, which is named as re-manufacturing (Jian-hua et al., 2007).

The different situations are related to the ability to manufacture such as Make to Order (MTO), Make to Stock (MTS), Assemble to Order (ATO), and Engineering to Order (ETO) related to the different position of CODP which can be seen in Figure 2.1.

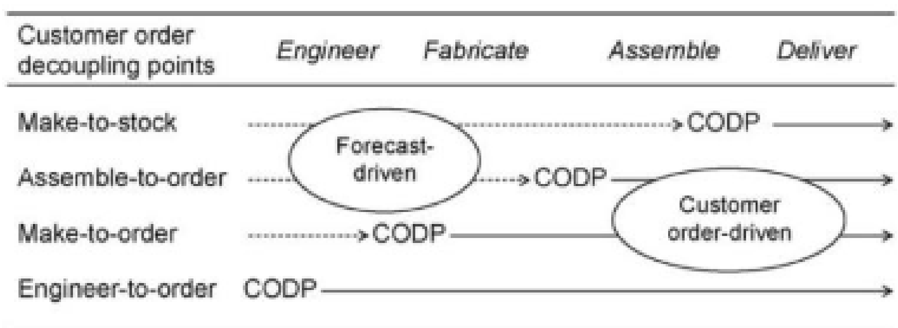

Figure 2.1 The Differences Position of CODP
Source: Sharman (1984) in Olhager (2010)

The differences on the manufacture will relate to the product customization. One of CODP concepts is to combine the production system of MTO and MTS or called as hybrid production to minimize lead time of production. In the CODP concept, it were divided between the material flow based on forecasting (upstream CODP) and process after CODP based on customer order (downstream CODP) (Olhager, 2010), as shown in Figure 2.2.

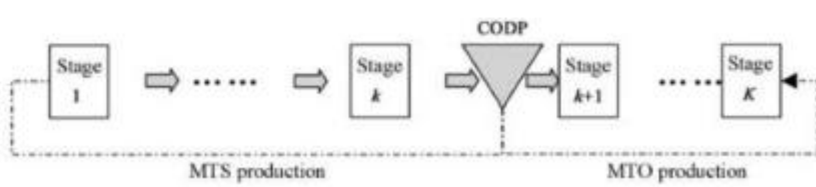

Figure 2.2 Customer Order Decoupling Point
Source: Jian-hua et al (2007)

2.2.6 Lead Time

Lead time defines as the release time of an order to the production system until the order leaves the system. It can be an interoperation time which consists of waiting time, transport time, set up time also the operation time (Higgins et al., 1996; Nyhuis and Wiendahl, 2009). For instance, the production systems which has due dates from the customer can be classified as backward planning approaches. It means that there should be a due date increasing on reliability which can extend the planned lead times in the MRP master data. Therefore, by implementing this production system, it could lead to earlier order releases, increased WIP levels, lengthened lead times and increased the workloads process then all of the ways tend to make the lead times more uncertainty (Windt and Knollmann, 2014).

Nordas et al. (2006) indicated that Lead time is the amount of time between the placement of an order and the receipts of the goods ordered. It depends on the nature of the product e.g. whether it is made to order or if it is a from the shelf product. Lead time also depends on planning and supply chain management, logistics services and of course distance to customers and suppliers. Long lead time does not need to be a problem if delivery is predictable and demand is stable. However, if there is uncertainty about future demand, long lead time is costly even when the customer knows exactly when the merchandise will arrive. If future demand has been underestimated, running out of stock has costs in terms of foregone sales and the possibility of losing customers. If future demand has been overestimated, excess supply must be sold at a discount. Furthermore, the longer the lead time and the more varieties of the product in question are on the market, the larger stocks are needed. It is also important to notice that competitiveness on lead time is not a static concept. When some firms are able to shorten lead time, others must follow in order to avoid punishment in terms of discounted prices or at worst exclusion from the bidding process. The latter can happen when a critical mass of suppliers is able to deliver just-in-time and the customer finds it safe to reduce inbound inventories to a couple of days or in some cases even a couple of hours.

2.2.7 Supply Chain Management

Supply chain as a sequence of (decision making and execution) processes and (material, information, and money) flows that aim to meet final customer requirements and take place within and between different supply chain stages. The supply chain not only includes the manufacturer and its suppliers, but also (depending on the logistics flows) transporters, warehouses, retailers, and consumers themselves. It includes, but is not limited to, new product development, marketing, operations, distribution, finance, and customer service (Chopra and Meindl, 2001).

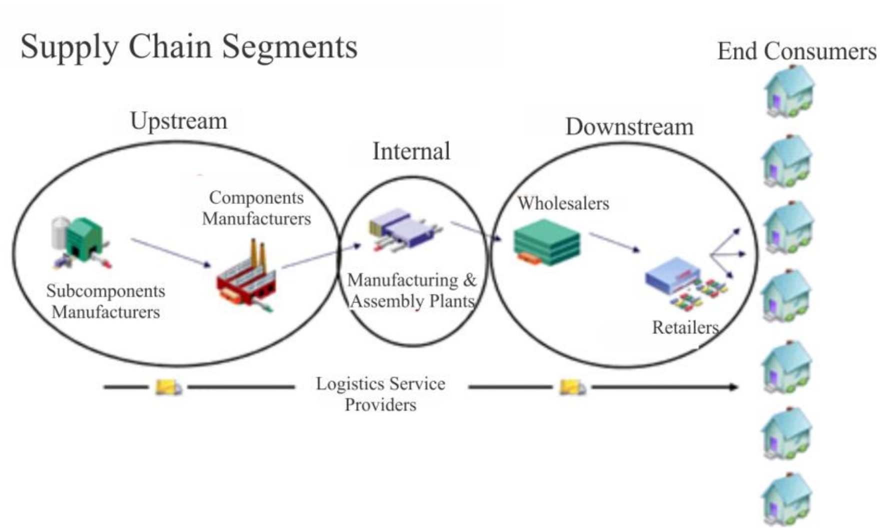

Figure 2.3 Supply Chain Segments

Source: Rajgopal, Jayant (2016)

According to Figure 2.3 Rajgopal (2016) showed the supply chain that has three integrated segments which have to determine a forecasting for whole segments consist of:

1. Upstream, where sourcing or procurement from external suppliers occurred
2. Midstream or internal, where manufacturing or assembling taken place for conducting production planning and execution

3. Downstream, where distribution (often by external distributors) and sales to the customer taken place. In downstream usually, there were warehousing and logistics, distribution and transportation, marketing and sales

Supply Chain Management is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements. In the supply chain management there consist of three conceptual components which are Supply Chain Configuration, Supply Chain Relationship, and Supply Chain Coordination (Lu, 2011) shown in Figure 2.4.

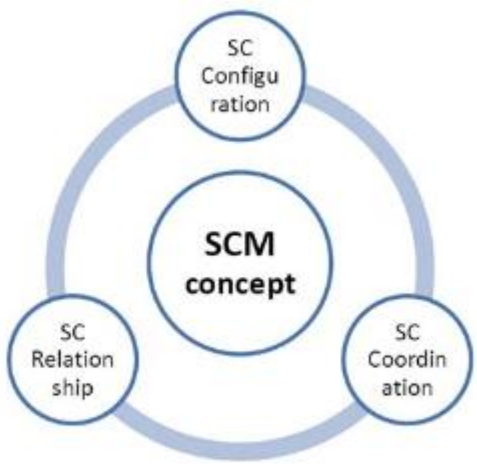

Figure 2.4 Supply Chain Management Conceptual Model

Source: Lu, Dawel (2011)

2.2.8 FlexSim 6 Simulation

Simulation is a set of techniques, methods, and tools for developing a simulation model of a system and using the simulation model to study the system. The purpose of the simulation is developing a simulation model, run experiments with the simulation model, and to gain better and understanding about the behavior of the real system that the model represents which is shown in Figure 2.5.

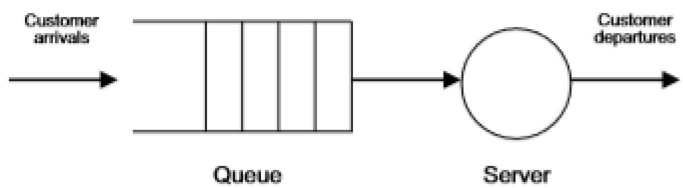

Figure 2.5 A simple model of a single-server system
Source: Garrido (2009)

In the practice, the simulation usually performed using a computer program or simulation software which has to model in the behavior of real systems. Simulation can be classified into three categories:

1. Static or dynamic
2. Deterministic or stochastic models
3. Continuous or discrete-event models

Flexsim is a powerful and easy-to-use modeling and simulation software tool that allows the user to construct a three-dimensional computer simulation model of a real-life system and run experiments on the model. Flexsim is classified as discrete-event simulation software tool that provides realistic graphical animation and extensive performance reports that enables the user to identify problems and evaluate alternative solutions in a short amount of time.

In discrete-event simulation, model will normally have dynamic objects known as flow items that move or flow through the model. A process flow is a series of processing, queuing and transportation stages in the model. Each stage of the process flow represents a task and may require one or more resources. A model is constructed in the Model View window, which is the workspace of the model. From the Object Library panel, the user drags the Flexsim objects needed into the model view window and connects the objects. In discrete-event simulation model there are consist of four the most common Flexsim objects which consist of (Garrido, n.d.):

1. The Source

   It has a function to create the items that flow through the model. These items are known as flow items.
2. The Queue

   It is a temporary storage for items waiting for the availability of resources.
3. The Processor

   It is a resource that simulates a processing stage in the model's process flow.
4. The Sink

   It is a terminating object for the flow items in the model.

To build a simulation model and carry out simulation runs with Flexsim, there are several stages that can be followed:

1. Create the Flexsim objects of the model
2. Connect the ports for routing of flow items and define process flow
3. Add data to the model parameters
4. Reset the model
5. Perform a simulation run of the model
6. Analyze the simulation results
7. Modify and enhance the model according to the user needs

CHAPTER III

RESEARCH METHODOLOGY

In this research, there are several stages that will be done that consist of identification and problem formulation, data collection, data processing, analysis and discussion and conclusion. The research methodology can be explained in the below.

3. 1 Research Object

This research was conducted in PT Mega Andalan Kalasan (PT MAK), a company located in Tanjung Tirto street 20, Tirtomartani, Kalasan Km 13, Yogyakarta. PT Mega Andalan Kalasan is one of big manufacturing company in Indonesia which concerns in hospital equipment production. This company was established in 1997 that have been grown and developed until now. PT Mega Andalan Kalasan produces the hospital equipment based on the customer order and desire. Therefore, the company opens for product custom to fulfill the customer demand. Therefore, this company can be categorized in the manufacturing scope as make to order (MTO).

In this hospital equipment company, there are several variations of the product such as infuse pole, wheelchair, bed and others product. The purpose of this research is to optimize the decoupling point of order and stock which the research object are product type of 73006 Economic Supramak Bed, the gap of lead time, and the improvement percentage by implementing CODP. This product type has been considered based on the highest demand and as the basic components which used by the third others product type. The data which related to the production activities are three types of products from quantitative data will be used to solve the mass customization problem also.

3. 2 Research Flow

In this research, there are several stages on the first step, which performed by the researcher to identify the problems in the research object. Then, there will be a problem formulation to determine the research focus. The literature review consists of inductive and deductive study to arrange the state of the art and basic theory which can support the research focus. The next stage is data collection based on the research focus. The data will be basic for data processing. The problem which has been identified and formulated then can be processed using Flexsim6 simulation. The researcher will simulate the initial manufacturing process which adjusted by the real case study in object research at manufacturing system. Then, the researcher will gain the calculation result such as the optimal product, the amount of lead time, and cost. Thus, there will proposed manufacturing design system for PT Mega Andalan Kalasan. The result of this calculation will be analyzed and compared with the condition at the object research. Thus, in the last process, there will answer the problem formulation.

3. 3 Conceptual Model

The research framework is constructed as the flowchart which shown in Figure 3.1 below:

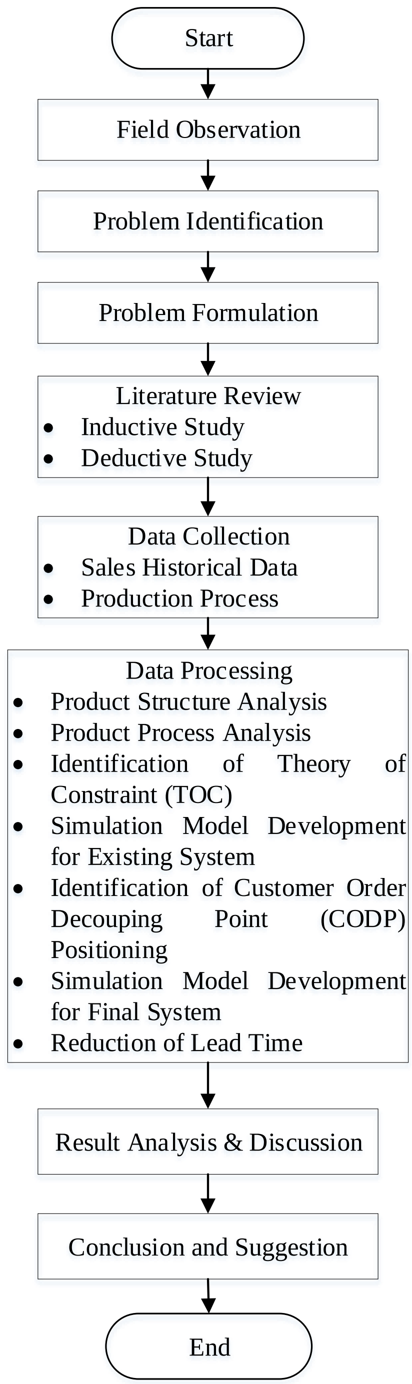

Figure 3.1 Flow Chart of Research

3. 4 Types of Data

In this research, two kinds of data will be employed, which consist of:

3.4.1 Primary Data

The primary data are data that have a direct correlation with data processing in this research about the production activities. This data will be the input for the calculation to support the simulation. The primary data which will be used in the production consist of:

a. The number of basic components
b. The number of customized components
c. Machine processing sequenced
d. Machine processing time
e. Amount of machine
f. Amount of labor time
g. Lead time of the arrival of raw materials
h. Type of raw materials
i. Production process layout

3.4.2 Secondary Data

The secondary data are data derived from some literatures such as journal and textbook. Besides, it using historical data also to compile the information that relevant to the topic discussed. In this study the real production process in the component's warehouse that can help in completing the research by compare three of products.

3. 5 Data Collection Method

In this research, there is data collection method which consists of:

1. Observation
   Direct observation will be performed by the researcher in the production activities to identify the production flow process on the production floor and the secondary data collection in this research will be used as quantitative data.

2. Interview
   Interview with the production manager and PPIC operator will be performed to obtain the data which cannot be collected from direct observation.

3. Literature Review
   Literature review had been employed by the researcher to collect the data through the track record of historical data from the company and another reference sources such as book and journal.

3. 6 Data Processing

This research uses Simulation of FlexSim6 software as the research instrument. Therefore, there will be the simulation to identify the optimum components quantity, the gap of lead time from the beginning and the new system, and the improvement percentage after simulation model while implementing CODP in the production process of product type 73006 Economic Supramak Bed. The research involves data processing stages which are:

1. Product Structure Analysis

   This study was conducted in a hospital equipment production company in Yogyakarta, Indonesia. The main product of this company when the research conducted was hospital bed. There are 4 types of bed in high demand last year. The first step in this study is to analyze the products' design in detail. It means that the researcher has to identify all four items to identify the common components.

2. Product Process Analysis

   According to the components production flow and Rich Picture Diagram (RPD), there are identified machines and the processing time to create every component. Besides, there is production layout identification to determine the available machines in the production shop floor.

3. Identification Theory of Constraint (TOC)

   Theory of Constraint is an important tool for solving the root problem. In this research, TOC can be classified as the constraint that raises in the production flow. The function of TOC itself used to identify the existence of block or bottleneck which can cause the longest processing time during components production in PT MAK.

4. Simulation Model Development for Existing System

   Based on the production layout and operation process chart (OPC), the researcher can make a simulation model to determine the initial components production quantity and the initial lead time. However, in the simulation model development for the existing system, first it needs a validation. Validation has a purpose to make sure that the simulation model can represent the real manufacturing system in PT MAK.

5. Identification of Customer Order Decoupling Point (CODP)

   In this stage, there is production process identification to adjust the product components in order to adjust the requirement and the customers' preferences, thus mass customization analysis is required. The implementation of mass customization has a role in determining the uniformity level of components which offered to the customers. The uniformity level of components has high influence during the determination of the CODP position. In this research, CODP identification can be carried out based on the production process on each component by considering TOC firstly in the overall components production process for product type 73006 Economic Supramak Bed.

In Make to Order (MTO) manufacturing company, CODP position was located in the middle of the production process which CODP used to split the production process into two sections. According to the specified CODP position, the production process initiated from starting point till the specified CODP position which implements Make to Stock (MTS) system to fulfill the components stocks. In the production process, there is a need to produce the common components. Besides, the production process after CODP position used to adjust the common component with the customer desire. This stage can be implemented only after the demands are identified, then the production could be processed based on the orders.

6. Simulation Model Development for Final System

   In this stage, after knowing the block from the processing time then this research conducts customer order decoupling point to determine the position of stock and order. After implementing CODP, the differences among the existing system simulation models should be located in accordance with the final system simulation model. If there is a small gap, it can be concluded that wrong processing is occurred. Later, recalculating and re-simulating final system simulation model should be performed to overcome the issue.

7. Lead Time Reduction

   To determine the lead time reduction which occurs based on the CODP implementation, this research applies a simulation approach. Simulation model development is carried out by using software FlexSim6. Simulation model is developed based on the production process and production layout from the manufacturing system on the company that applies MTO. This simulation model is used as the basis to determine the entire lead time before the existence of CODP and reduction of lead time which existed after the implementation of CODP. Through this simulation model development, it can be notified the CODP performance that implemented in the manufacturing system.

3. 7 Result Analysis

The result analysis in this research is to determine the amount of optimum components quantity in product type of 73006 Economic Supramak Bed by implementing mass customization, identifying the gap among lead time from the beginning and the new system, as well as identifying the improvement of percentage after simulation model while implementing CODP in the production process.

3. 8 Conclusion and Suggestion

The last stage is the conclusion to answer the question about the problem formulation of the research. Furthermore, there is also a suggestion as the recommendation in developing this research and further suggestion for manufacturing industry that can be carried out in the future research.

CHAPTER IV

DATA COLLECTION AND DATA PROCESSING

4.1 Data Collection

In this stage, there was data collection based on the research focus. Data collection was taken from PT Mega Andalan Kalasan (MAK) Kalasan regency. In this company, the researcher concerned on the typical product of bed which consists of:

1. 73004 Supramak Bed-Manual
2. 73005 Central Lock System Supramak Bed
3. 73006 Economic Supramak Bed
4. 73010 Supramak Fowler-Sg Stainless Steel

Table 4.1 shows about product specification which followed by data about a standard component or *"setara bed (STB)"* and product demand in a year.

Table 4.1 Types of Product

No	**Typical Product Code**	**Products**	**STB**	**Demand/years (Units)**
1	73006	Economic Supramak Bed	1	1600
2	73004	Supramak Bed-Manual	1.31	1180
3	73010	Supramak Fowler-Sg Stainless Steel	1.14	800
4	73005	Central Lock System Supramak Bed	1.56	740

From all four types of bed in PT MAK, there was one of products that determined as the standard components that are also used by the other products, which is product with type of 73006 Economic Supramak Bed. It can be classified as a standard component because based on Table 4.1 product type 73006 Economic Supramak Bed has STB equal as 1. For instance, product 73004 which is Supramak Bed-Manual has STB equal 1.31. It means that the components of product type 73004 Supramak Bed-Manual has 1.31 times more complex than product type of 73006 Economic Supramak Bed. Therefore, it needed to be traced for each component which used by the other three types of product bed or called as common components. After that, the researcher needs to identify the longest processing time from each components production in product type of 73006 Economic Supramak Bed. Besides, the data requirement covers a correlation on production activities of hospital equipment such as bed hospital production which are machine processing sequence, machine processing time, common components, customized components, and historical data about demand.

Below is shown the sales data of product 73006 Economic Supramak Bed in 2017 for each month:

Table 4.2 Sales Data of Product 73006 Economic Supramak Bed in 2017

No	Period	Amount of Production (Units)
1	January	120
2	February	120
3	March	160
4	April	240
5	May	-
6	June	80
7	July	120
8	August	280
9	September	160
10	October	140
11	November	180
12	December	-

According to Table 4.2, it can be explained about the sales data of product 73006 annually which can be the parameter for conducting a components production to fulfill the orders. Based on Table 4.2, it can be identified that on August, there was the highest production for product 73006 that reached up to 280 units. Since there was the historical data about sales product, then the researcher can forecast how many components that should be produced to build a complete product. Based on Table 4.2, it can be also be identified that on May and December, there were no product sales. Then, in this thesis, the researcher can fulfill and complete the components production to supply the components which have to be assembled for product 73006. Therefore, it can reduce lead time automatically.

4.1.1 Production Process

In the production process, there is business process in PT Mega Andalan Kalasan (MAK) that produces product type 73006 Economic Supramak Bed and shown by using Rich Picture Diagram (RPD) in Figure 4.1. This figure is one of the examples on components production process among 62 components.

Figure 4.1 Production Process of Components 2 Infuse Hanger

According to Figure 4.1, it is described that one of the samples on the components production process out of 62 components started from Raw Material 2 is As St. St. 304 Ø ¼" x 6000 mm. From the above sample, after the preparation of raw material, then the next step is performing KL11 Pipe Punch, designated to make a hole in a few sections based on the type of product and the customer requirement. Then, it needs KL15 Metal Finish which has a function to make a softer component before being continued to KL12 Pipe Press. It has a function to make a pipe more delicate. After all of the processing sequences are accomplished, last components production process can be stored in Queue_KL11. Later, those components can be directly distributed into Queue for component 2 infuse hanger. To assure the quality and the accuracy of the components, quality control should be applied for further inspection before being stored in warehouse or sending to the other plan for an assembling process. Based on the above Figure, it was one of examples of the production process which can be identified as that most of the components production process that has a different machine processing sequence. Therefore, there will have different processing time to produce a component.

4.2 Data Processing

This research employs simulation method and FlexSim6 model simulation software as the research instrument. In Table 4.3, there are some types of components in product 73006 Economic Supramak Bed and in Table 4.4, it is described the detail information about processing sequence, processing time, and the number of quantity components which can be constructed as a unit product. There is also an explanation about the result of simulation from the existing simulation and based on two scenarios of CODP simulation usage.

4.2.1 Input Data

Hereby is an input data as the requirement to fulfill the object while running FlexSim6 model simulation. Below are a few samples from types of components in product 73006 Economic Supramak Bed which consist of material code, type of raw material or material content, components code, the name of components and components sequence.

Table 4.3 Types of Components in Product 73006

Material Code	Material Content	Components Code	Components	Components Sequence
RawMat1	As MS Ø ¾" (19mm) x 6000 mm	B0057CA02B	The Backrest Screw	1
RawMat2	As St. St. 304 Ø ¼" x 6000 mm	H0010B002C	Infuse Hangers	2
RawMat 3	As St. St. 304 Ø 3/8" x 6000 mm	B0034C008B	Head and Foot End 2	3
RawMat4	Ass MS St 37 Ø 5 mm x 6000 mm	B0016CB02B	Infuse Pole Stopper	4
RawMat5	Ass MS St 37 Ø 5/16"(8mm) x 6000 mm	B0057E005B B0057E006B	Bottom Mattress Holder Side Mattress Holder	5 6
RawMat6	Bahan Mur pendorong Bronze	B0001GA02A	Hi-Lo Booster Nut	7
RawMat7	Pipa St. St. 201 1 ¼" x 1.5 x 6000 mm	B0064CA01C	Frame Head & Foot End	8
RawMat8	Pipa St.st 202 Ø ¾" x 1 x 6000 mm	B0034KA01C	Bottom Infuse Pole	9
RawMat9	Pipa St.st 202 Ø 5/8" x 1 x 6000 mm	B0034KC01C	Above Pipe Infuse Pole	10
RawMat10	Pipa STKM 11AC/A 30x30x2.0x6000 mm	B0073B004B B0069EA01B	Rear Spaner Bottom Pipe Sideguard (right)	11 12

According to Table 4.3 which explains about types of components in product 73006 Economic Supramak Bed that consists of 62 components, which have different production process respectively. Despite, there was 22 different raw material but there can produce up to 62 different components among each other.

Table 4.4 Detail Information of Production Process in Product 73006

No Com pone nts	WS	Process	Quantity	Labor Time (Minutes)	Total Labor Time/1 PCS (Minutes)	Total Labor Time*Quanti ty
1	KL08 KL18	Circlesaw Cutting CNC Bubut	1	1.266 13.5	16.466	16.466

No Components	WS	Process	Quantity	Labor Time (Minutes)	Total Labor Time/1 PCS (Minutes)	Total Labor Time*Quantity
	KL13	Pipe Drilling		1.7		
2	KL11 KL15 KL12 KL11	Pipe Punch Metal finish Pipe Press Pipe Punch	4	0.33 1.6 0.167 0.33	2.427	9.708
3	KL01 KL04 KL05	Cutting Punch plat manual 2 Press plat	8	0.667 0.167 4.5	5.334	42.672
4	KL08 KL15	Circlesaw Cutting Metal Finish	2	0.5 0.67	1.17	2.34
5	KL11 KL11	Pipe Punch Pipe Punch	2	0.333 1	1.333	2.666
6	KL11 KL11	Pipe Punch Pipe Punch	4	0.333 1	1.333	5.332
7	KL18	CNC Bubut	1	2.5	2.5	2.5
8	KL08 KL15 KL09 KL09	Circlesaw Cutting Metal finish Roll Bending Manual Roll Bending Manual	2	0.5 0.667 4 4	9.167	18.334
9	KL16	Pipe Laser	1	0.500	0.500	0.5
10	KL08 KL15	Circlesaw Cutting Metal Finish	1	0.5 2.167	2.667	2.667
11	KL16	Pipe Laser	1	0.500	0.500	0.5

No Components	WS	Process	Quantity	Labor Time (Minutes)	Total Labor Time/1 PCS (Minutes)	Total Labor Time*Quantity
12	KL16	Pipe Laser	2	0.5	0.5	1

Based on Table 4.4, it is shown the detail information about the production process for each component. There is calculation for the time processing for each component and calculation is based on the quantity also. Therefore, the researcher can identify how many components should be produced to build a product based on the quantity of the components needed. The researcher identifies that there are several longer processing times that depend on the quantity. While determining the longest processing time, it needs to consider the common components which owned by the other three products which consist of:

Table 4.5 The Longest Processing Time

Raw Material	**Components**	**No Components**	**WS**	**Process**	**Quantity**	**Labor Time (Minutes)**	**Total Labor Time/1 PCS (Minutes)**	**Total Labor Time*Quantity**
RawMat3	*Dudukan Head & Foot End 2*	3	KL01	Cutting	8	0.667	5.334	42.672
			KL04	Punch plat manual 2		0.167		
			KL05	Press plat		4.5		
RawMat7	*Frame Head & Foot End*	8	KL08	Circlesaw Cutting	2	0.5	9.167	18.334
			KL15	Metal finish		0.667		
			KL09	Roll Bending Manual		4		
			KL09	Roll Bending Manual		4		
RawMat1	*Ulir pendorong backrest*	1	KL08	Circlesaw Cutting	1	1.266	16.466	16.466
			KL18	CNC Bubut		13.5		

Raw Material	Components	No Components	WS	Process	Quantity	Labor Time (Minutes)	Total Labor Time/1 PCS (Minutes)	Total Labor Time*Quantity
			KL13	Pipe Drilling		1.7		
RawMat16	*Pegas engkol*	20	KL01	Cutting	2	0.333	4.834	9.668
			KL03	Punch Plat Manual		0.167		
			KL03	Punch Plat Manual		0.167		
			KL03	Punch Plat Manual		0.167		
			KL15	Metal finish		4		
RawMat17	*FrameHead & Foot End 2*	21	KL01	Cutting	4	0.25	2.25	9
			KL01	Cutting		0.667		
			KL03	Punch Plat Manual 1		0.833		
			KL06	Bending		0.5		

According to Table 4.5, there are 5 long processing time that can be considered while determining CODP point. However, it needs to consider the existence of block for each variable that can be sourced, processor, separator or quality control in model simulation. In this research, it is conducted a simulation to recognize the optimal components quantity for a production and to know how many components that can be produced and can be sent to assembly plan.

The researcher did several simulations to gain the optimal production quantity and minimize lead time by implementing CODP system in the simulation by cutting the highest block in the production process based on a theory of constraint. This stage can be repeated until the block can be reduced and has a high gap from the third simulation with another block. In this research, there are 4 simulations which have been performed by the researcher. It consists of:

1. Simulation Model Development for Existing System
2. Simulation Model Development for CODP 1 System
3. Simulation Model Development for CODP 2 System
4. Simulation Model Development for Final System

4.2.2 Simulation Model Development for Existing System

According to the production layout and Operation Process Chart (OPC), then the researcher can develop a simulation of an existing system. This company applies MTO system with a repetitive order for every component then it called as MTO repetitive company. Before running a simulation model, it needs validation. Validation for simulation model had a purpose to state that the simulation model can represent from the real manufacturing system in the company then it can obtain a valid simulation result. Because of the company is ordered based, there need to consider lost sales quantity as the parameter for model validation (Purnomo & Sufa, 2015). Lost sales quantity will equal to zero if production quantity is greater than the total orders while lost sales quantity will equal total orders then the lost sales quantity will greater than zero. In this research, there needs a simulation model to do a validation, then it is used as a parameter of the number of deficiencies and overproduction of customer demand by 3%. Based on the validation result in this research shown as 2% then the simulation model can be categorized as valid and can be used to determine the lead time in the production. Hereby is an example of a simulation model of the company shown in Figure 4.2 and Figure 4.3.

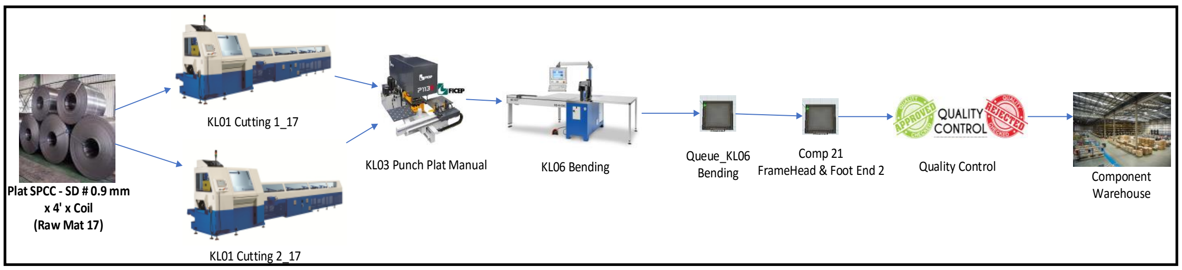

Figure 4.2 Simulation Model Development for Existing System in Component 21

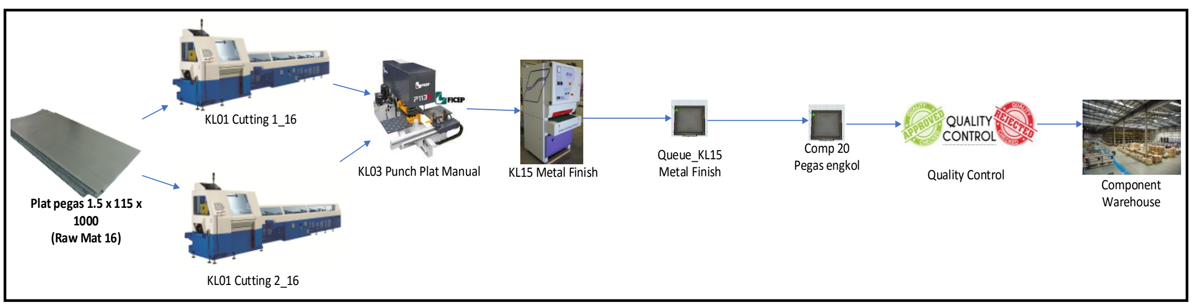

Figure 4.3 Simulation Model Development for Existing System in Component 20

According to Figure 4.2 and Figure 4.3, it is shown as an example of simulation model development for an existing system in the production process of component21 Frame Head & Foot End 2 and component20 Crank The Spring. It is started from raw material then can be processed in each processing machines until distributed in the quality control before being stored in the components warehouse as the final place before sending to the assembly plan. Based on the simulation above, the researcher identifies the components quantity in the simulation that closes to the reality of the company or yet. After that, it can be set for the runtime as the effective working time which influences the components production quantity and how the machines can manage for components production which is influenced by the probability of the components processing time.

Table 4.6 Block Data in Simulation Model Development for Existing System

No	Object	Class	Block
254	Queue_RawMat5_1	Queue	0.00%
255	QueueRawMat5_2	Queue	0.00%
256	RawMat8	Source	2.10%
257	RawMat9	Source	3.04%
258	RawMat10	Source	0.00%
259	RawMat11	Source	0.00%
260	RawMat15	Source	7.01%
261	RawMat16	Source	32.55%
262	**RawMat17**	**Source**	**37.98%**
263	RawMat19	Source	7.80%

After running the simulation model, it needs deep analysis on the state report of FlexSim6 which concerns in block data. Based on data in Table 4.6, it is needed to consider the bottleneck or block, which causes the components cannot be produced optimally and takes an adequate time for some components production among 288 data. Besides, it is needed to find out the correlation between the block and the longest processing time firstly. By recognizing the highest block in this simulation from RawMat17 with 37.98% then it can be matched that in Table 4.5 RawMat17 also includes as the longest processing time with 9 minutes starting from the raw material processed until KL06 Bending processed. RawMat17 will have an output for components21 that equal to 11 pieces. Therefore, it should be minimized for the block by implementing CODP. Hereby simulation model development for CODP 1 system.

4.2.3 Simulation Model Development for CODP 1 System

In the above discussion, there need to re-simulation to minimize block by implementing CODP 1 system in this model simulation. Usually, CODP was located in the middle of the whole manufacturing process. It used to separate the manufacturing process into 2 parts. The first part commonly called as manufacturing process before CODP. It means there can produce general components which can be continued to be customized components based on the coming orders. The second part also called as manufacturing process after CODP. It means in the components plan can modify the basic components which can be continued to the warehouse components. This CODP 1 system simulation model can be shown in Figure 4.4.

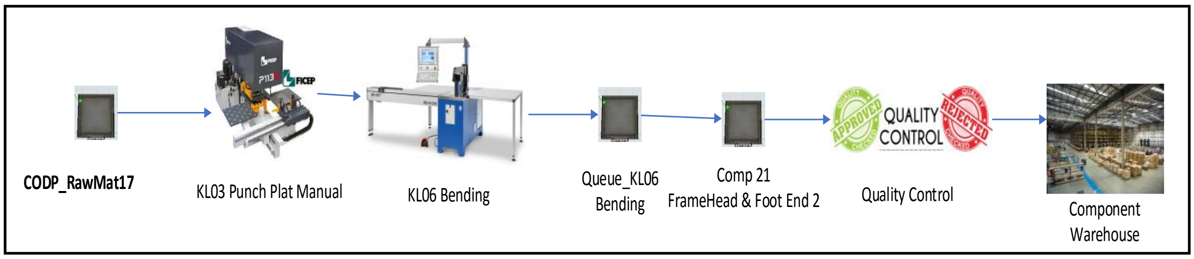

Figure 4.4 Simulation Model Development for CODP 1 System

According to Figure 4.3 it can be known the position of CODP which have been done based on the highest block in RawMat17 that should be cut until making a new source which assume should be produced firstly for 112 pieces. Thus, at the beginning of components production, there should do production until KL01 Cutting to minimized block and then can do a customization based on the ordered.

Table 4.7 Block Data in Simulation Model Development for CODP 1 System

No	Object	Class	Block
251	RawMat5	Source	0.00%
252	Queue_RawMat5_1	Queue	0.00%
253	QueueRawMat5_2	Queue	0.00%

No	Object	Class	Block
254	RawMat8	Source	2.10%
255	RawMat9	Source	3.04%
256	RawMat10	Source	0.00%
257	RawMat11	Source	0.00%
258	RawMat15	Source	7.01%
259	**RawMat16**	**Source**	**24.65%**
260	RawMat19	Source	6.21%

Based on the above simulation, there shows the increasing production of components21 from 11 pieces up to 112 pieces. Despite block in RawMat17 can be 0%, because of the new model simulation using CODP there caused another block which come from RawMat16 which produce component20 equal to 24.65%. Therefore, there should be minimized for block by implement another CODP. Hereby simulation model development for CODP 2 system.

4.2.4 Simulation Model Development for CODP 2 System

Because of in CODP 1 system there arise new block, there need to re-simulation again to minimize block by implementing CODP 2 system in this model simulation. This CODP 2 system simulation model can be shown in Figure 4.4.

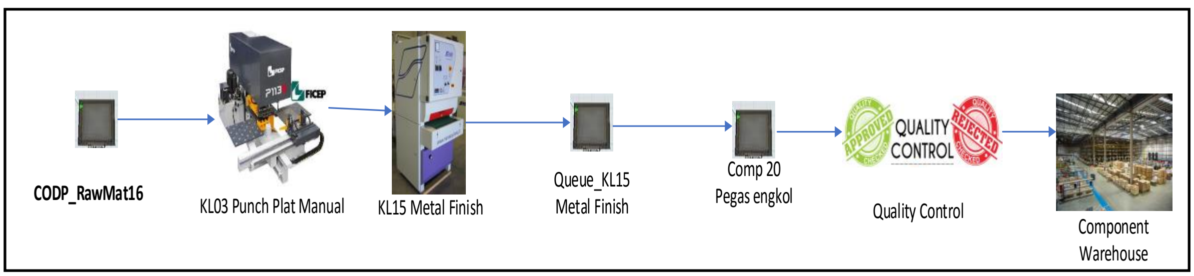

Figure 4.5 Simulation Model Development for CODP 2 System

According to Figure 4.4, it can be located the position of CODP which has been done based on the highest block in RawMat16 that should be cut until a new source is made, which assumed should be produced firstly for 152 pieces. Thus, at the beginning of components production, a production should be conducted up to KL01 Cutting to minimize block and then a customization based on the order can be performed. Based on the above simulation, it shows the stable production on components20 from 36 pieces to be remain 36 pieces. Despite of block in RawMat16 can be 0%, because of the new model simulation using CODP 2 system will cause another block in quality control. Therefore, the block should be minimized by implementing final system simulation. Hereby simulation model development for Final System.

4.2.5 Simulation Model Development for Final System

Quality Control (QC) have conducted an inspection for approximately a minute/component, thus it only covers 334 components from a whole ready component. However, there should be more components which can be produced without considering the quality control processing time which caused the block. This final system simulation model can be shown in Figure 4.6.

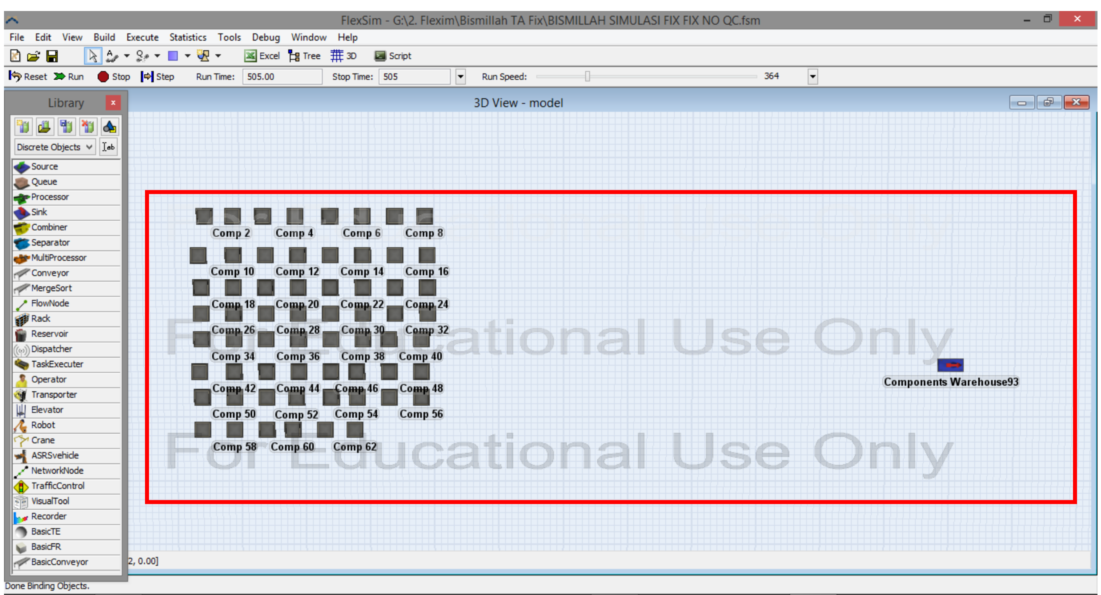

Figure 4.6 Simulation Model Development for Final System

According to Figure 4.6, it can be identified that the cutting position was located in Quality Control that caused by uninspected ready components due to limited processing time for conducting entire inspections on ready components. However, by implementing this simulation model, there is an optimal increasing in components' warehouse. Therefore, since the components' warehouse has been optimal employed, then the simulation model can be stopped at this stage.

CHAPTER V

DISCUSSION

5.1 Explanation of CODP Concept

In this research, a concept simulation model using the Theory of Constraint (TOC) and Customer Order Decoupling Point (CODP) in components production which concerns on the optimal components production quantity and minimizes lead time is applied. The simulation model used to solve the problem based on the production system in the research object. There are several limitations which is built to control the production flow in a simulation which consists of the biggest block and the longest production process. According to product structure analysis and product process analysis which used as the basic data to identify CODP position, there are 62 components that should be analyzed for each production process that should be considered from the longest production process and the existence of block. Below is the CODP position identification for RawMat17 which has the biggest block in simulation model as shown in Figure 5.1.

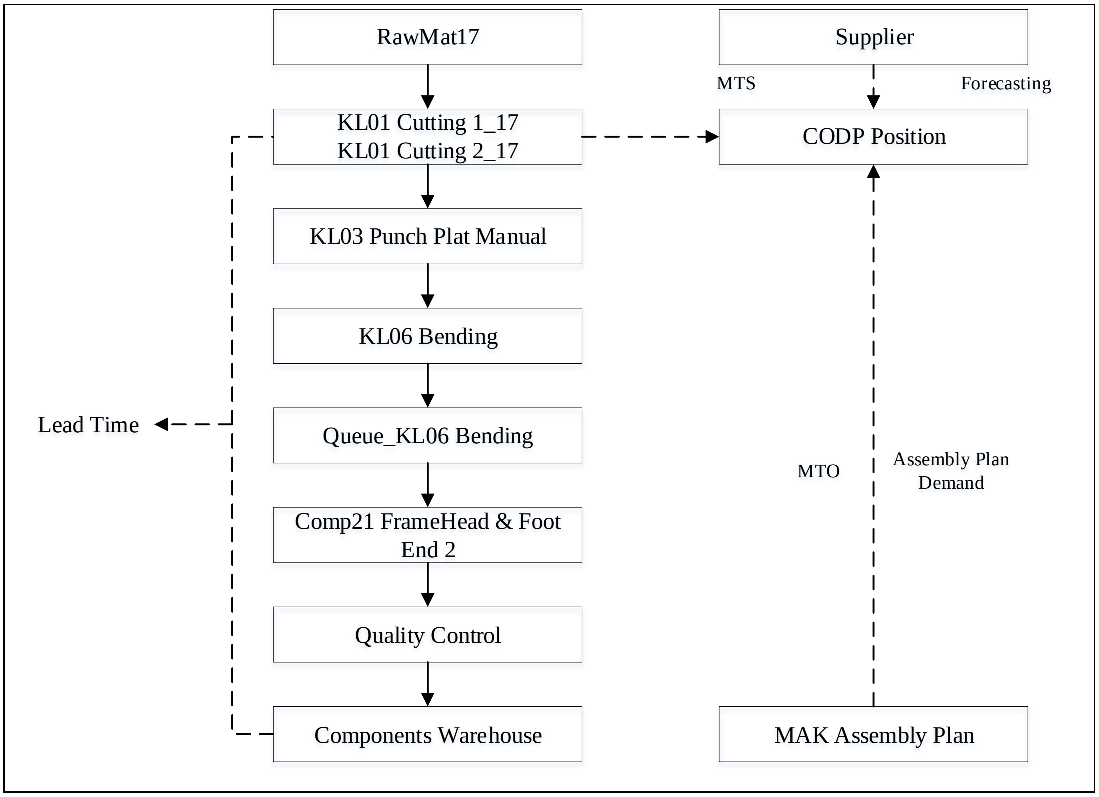

Figure 5.1 CODP Position in RawMat17

Besides, Table 5.1 shows the summary result of the calculation and simulation for the fourth simulation model to identify the optimal components production quantity. According to Table 5.1, the researcher should analyze the differences between both of simulations in the simulation model development for existing system and simulation model development for the final system. Based on Table 4.5 which considers the longest processing time, the researcher reveals the components that used by product 73006 Economic Supramak Bed and also exist in the third product, which are component20 and component21. Then, in the simulation model development for the existing system, the highest block is found in RawMat17 up to 37.98% which can produce comp20 equal to 43 pieces and comp21 equal to 11 pieces also the components warehouse equal to 336 pieces in 505 minutes production process time.

Later, since the RawMat17 and RawMat16 have the highest block for comp21 and comp20, it needs a repair for simulation model by implementing CODP to minimize lead time. Because of block exist in RawMat17 and RawMat16 then in KL01 Cutting, it needs a process cutting changing by using CODP system. It means that RawMat17 has been through KL01 Cutting process until it can be continued to the next step. Therefore, in the production process of RawMat17 until CODP position, MTS can be implemented to fulfill the inventory before the incoming order. However, the production process after CODP position, MTO system was implemented based on the order from assembly plan that performs a production by considering on the components' need and processing sequence. Then after implementing CODP 2 system, there are productions for comp20 equal to 36 pieces and comp21 equal to 112 pieces with followed by components' warehouse equal to 334 pieces. After a repair in simulation model development in CODP 2 System, the output for comp21 increases significantly up to 10 times from the number of existing systems. Therefore, it can be concluded that comp21 has optimal components production quantity. While, comp21 can increase the number of components quantity but the components' warehouse still decreases equal to 334.

Therefore, it is suspected that in simulation model development for CODP 2 System, block is moved to Quality Control. Then, the researcher made a simulation model development for the final system which is supposed to cut the Quality Control, then all of the components in the simulation model for the final system from comp1-comp62 directly stored in components' warehouse. Then, while running the simulation the whole components that can be stored in components warehouse are up to 1732 pieces. According to the differences among simulation model development for an existing system and simulation model development for the final system, they have a significant gap in the components' warehouse by cutting the process of quality control. It is supposed to be cut because while in the existing system, quality control takes approximately a minute for each component's inspection. It leads to the effective working time that accomplished only in 505 minutes but all of the components which queue in comp1-62 will not inspected in quality control.

However, by implementing CODP concept in hospital manufacturing system, it is notified that the manufacturing process before CODP is based on demand forecasting that can reduce manufacturing lead time but there was a consequence on inventory that leads to high inventory cost. Then to overcome this problem, it is required a production based on batch size which can reduce the inventory mount yet can increase set up time.

Table 5.1 Summary Simulation Report

No	Simulation Model Development for	CODP Position (Cutting Section)	Improvement (Pieces)		Components Warehouse (Pieces)
			Comp20	Comp21	
1	Existing System	-	43	11	336
2	CODP 2 System	KL01 Cutting	36	112	334
3	Final System	Quality Control	36	112	1732

5.2 Lead Time Measurement before CODP implementation and after CODP implementation

In this research, the simulation model has been validated using statistical test by chi-square and verification also lost sales quantity. The result shows that the simulation model is valid because the result of the simulation data < the real system data which are 0.26 < 42.55 means Ho accepted. Besides, it is also lost sales quantity as a parameter for model validation by calculating the number of deficiencies and overproduction of assembly plan demand equal to 3% which production quantity < total orders. According to the validation result in this research which shows the result up to 2%, then this simulation model can be categorized valid and can be used to determine the lead time in production.

The next stage is after simulation model validation, the simulation system is run to determine the lead time in the production process. Based on the simulation result, it can be identified by calculating the effective working time with the total output from components warehouse. For the whole lead time before CODP implementation or simulation model development for existing system equal to 505 minutes or 150.29% and lead time after CODP implementation or simulation model development for final system equal to 127.26 minutes or 29.15%. Therefore, the simulation result shows that manufacturing system which implements CODP can reduce manufacturing lead time for 121.14%. Based on the above calculation and analysis, it can be concluded that the researcher’s proposed manufacturing system could reduce manufacturing lead time from 505 minutes to 127.26 minutes or about 121.14% when producing components for building component 73006.

MTO manufacturing company which implements CODP concept in their production system can obtain a competitive advantage by reducing lead time significantly. This can encourage the company to fulfill delivery time because the components production can be produced quickly. Therefore, the company can increase the customer satisfaction and customer confidence which can influence in the inclining profit of the company.

CHAPTER VI

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Based on the calculation above, a conclusion can be drawn to answer the problem identification. It is stated in the following statements:

1. In the concept of the proposed model, the company can produce optimal components quantity up to 1732 pieces. However, for components20, it can only be produced for 36 pieces, while components21 can be produced for 112 pieces. Therefore, by implementing CODP system, it can be identified the common components that have same specifications, which are product 73004, 73005, 73010, especially for components product 73006 Economic Supramak Bed, it can be produced firstly to fulfill the inventory.
2. Lead time in simulation model development for an existing system or before the CODP implementation is equal to 1.5 minutes/components, while lead time after the CODP implementation or simulation model development for final system is equal to 0.29 minutes/components. Therefore, based on the simulation model among the existing system and final system, the lead time can be reduced for 1.21 minutes to produce each component.
3. The lead time improvement after conducting CODP simulation is up to 5.15 times better compared to existing lead time.

6.2 Recommendation

Several recommendations are presented in this study as follows:

1. PT Mega Andalan Kalasan (MAK) should aware and pay more attention to the longest processing time of components production by doing several things, such as:
    a. Determine the components that should be stock firstly by considering the highest demand from the type of products.
    b. Identifying the existence of highest block in the components production.
2. The company should prioritize production of components20 and components21, which need longer production process and can be stock firstly, later can be used for building another product.
3. Since, there is only one quality control available, it needs an additional quality control to provide faster inspection, Hence, all components can directly be inspected by the quality control after components production. Furthermore, it can be stored to warehouse before sending to assembly plan.
4. For the future research, it can be developed cost analysis to determine the components which have the longest processing time, to decide whether they should be self-produced or ordered from other company. It addressed to the reduce the cost on manpower, machine maintenance, and overtime. Besides, by recognizing the components inventory, it can minimize the inventory amount and the setup time.

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APPENDDIXES

APPENDIX 1. Types of Components

Material Content	Material	Components Code	Components	No Components
RawMat11	Pipa STKM 11AC/AH 30x60x2.0x6000 mm	B0073B001B	Side Frame	13
		B0073B002B	Edge Frame	14
RawMat12	Pipa STKM 11AC/AH Ø 31.8x2.0x6000 mm	B0057CA01B	Backrest Push Pipe	15
		B0057DA01B	Kneerest Push Pipe	16
RawMat13	Pipa STKM 11AC/AH Ø 41.9 x 2A x 6000 mm	B0057AA01B	Foot Pipe	17
RawMat14	Pipa STKM 11AC/AH Ø42.4 x 2.9 x 6000 mm	B0034E005B	Mattress Lever Pipe	18
RawMat15	Pipa STKM 11AC/H 20x40x1.6x6000 mm	B0073A001B	Foot Spaner	19
RawMat16	Plat pegas 1.5 x 115 x 1000	B0041G008A	Crank The Spring	20
RawMat17	Plat SPCC - SD # 0.9 mm x 4' x Coil	B0034JA02B	FrameHead & Foot End 2	21
RawMat18	Plat SPCC - SD # 1.1 mm x 4' x Coil	B0034D001B	Detailed Base Matters	22
		B0034F001B	Middle Mattres Plate	23
		B0057E001B	Backrest Mattress Plate	24
		B0057F001B	Kneerest Plate	25
RawMat19	Plat SPCC - SD # 1.8 mm x 4' x Coil	B0001CA01B	Bottom Support Mattres	26
		B0001E007B	Bottom Kneerest Hinges	27
		B0001EA01B	Bottom Support Kneerest Mattres	28
		B0034F002B	Middle Strengthener Mattres 1	29

Material Content	Material	Components Code	Components	No Components
		B0034F003B	Middle Strengthener Mattres 2	30
		B0041AA02B	Thrust Holder Plate	31
		B0057E002B	Right Side Mattres Reinforcement	32
		B0057E003B	Left Side Mattress Strengthener	33
		B0057F002B	Kneerest Booster	34
		B0057F003B	Kneerest Ki Amplifier	35
		B0034D003B	Basic Mattres Booster	36
		B0034E008B	Mattres Pipe Spanner	37
		B0058DB01B	Plat Nut	38
RawMat20	Plat SPCC - SD # 2.8 mm x 4' x 8'	B0001E005B	3 Kneerest Support Hinges	39
		B0034G004B	Wheel holder	40
		B0057B006B	Kneerest Support	41
		B0064B006B	Bottom Kneerest Support	42
		E0025A002E	Roof nut	43
		B0057BB01A	Nylon plate as hexagon	44
		B0057CB01E	Plat U	45
		B0073AA01B	Foot plate	46
		B0073AA02B	Strengthening the foot plate	47
RawMat21	Plat SPHC - PO # 3.8 mm x 4' x 8'	B0001L001B	Bottom Base Mattres	48
		B0034E004B	Backrest Hinges	49
		B0034E006B	Mattres Lever Hinges	50
		B0034E007B	Mattres Lever	51
		B0034F004B	Middle Mattres Hinges 1	52
		B0034JA03B	Right Head & Foot End Holder	53

Material Content	Material	Components Code	Components	No Components
		B0034JA04B	Left Stand & Foot End	54
		B0057BC02B	Lager House Plate 1	55
		B0057BC03B	Lager House Plate 2	56
		B0057BC04B	Lager House Plate 3	57
		B0057B005B	Lager House Holder	58
		B0034F005B	Middle Mattres Hinges 2	59
		B0073B005B	Mount The Base Mat Bolt	60
		B0073B006B	Foot Holder Plate	61
RawMat22	STKM 11AC/AH 40x60x2.3x6000 mm	B0073B003B	Front Spanner	62

APPENDIXES 2. Detail Information of Production Process

No Components	WS	Process	Quantity	Labor Time (Minutes)	Total Labor Time/1 PCS (Minutes)	Total Labor Time*Quantity
13	KL16	Pipe Laser	2	0.5	0.5	1
14	KL16	Pipe Laser	2	0.5	0.5	1
15	KL16	Pipe Laser	1	2	2	2
16	KL16	Pipe Laser	1	2	2	2
17	KL16	Pipe Laser	4	0.580	0.58	2.32
18	KL16	Pipe Laser	2	0.580	0.58	1.16
19	KL16	Pipe Laser	2	0.790	0.790	1.58
20	KL01	Cutting	2	0.333	4.834	9.668
	KL03	Punch Plat Manual		0.167		
	KL03	Punch Plat Manual		0.167		
	KL03	Punch Plat Manual		0.167		
	KL15	Metal finish		4		
21	KL01	Cutting	4	0.25	2.25	9
	KL01	Cutting		0.667		
	KL03	Punch Plat Manual 1		0.833		
	KL06	Bending		0.5		
22	KL01	Cutting	1	0.25	2.583	2.583
	KL02	Punch CNC		0.833		
	KL06	Bending		1.5		
23	KL01	Cutting	1	0.25	3.233	3.233
	KL02	Punch CNC		1.483		

No Components	WS	Process	Quantity	Labor Time (Minutes)	Total Labor Time/1 PCS (Minutes)	Total Labor Time*Quantity
	KL06	Bending		1.5		
24	KL01	Cutting	1	0.333	4.266	4.266
	KL02	Punch CNC		2.433		
	KL06	Bending		1.5		
25	KL01	Cutting	1	0.25	3.85	3.85
	KL02	Punch CNC		2.1		
	KL06	Bending		1.5		
26	KL01	Cutting	1	0.25	1.833	1.833
	KL01	Cutting		0.667		
	KL03	Punch Plat Manual 1		0.333		
	KL06	Bending		0.583		
27	KL01	Cutting	1	0.25	1.5	1.5
	KL01	Cutting		0.667		
	KL06	Bending		0.583		
28	KL01	Cutting	1	0.25	3.85	3.85
	KL01	Cutting		2.1		
	KL06	Bending		1.5		
29	KL01	Cutting	1	0.25	2.083	2.083
	KL01	Cutting		0.667		
	KL03	Punch Plat Manual 1		0.167		
	KL03	Punch Plat Manual 1		0.333		
	KL06	Bending		0.333		
	KL06	Bending		0.333		
30	KL01	Cutting	1	0.25	2.083	2.083

No Components	WS	Process	Quantity	Labor Time (Minutes)	Total Labor Time/1 PCS (Minutes)	Total Labor Time*Quantity
	KL01	Cutting		0.667		
	KL03	Punch Plat Manual 1		0.167		
	KL03	Punch Plat Manual 1		0.333		
	KL06	Bending		0.333		
	KL06	Bending		0.333		
31	KL01	Cutting	1	0.333	3.334	3.334
	KL02	Punch CNC		0.5		
	KL03	Punch Plat Manual		0.5		
	KL03	Punch Plat Manual		0.167		
	KL06	Bending		0.417		
	KL06	Bending		0.417		
	KL06	Bending		0.583		
	KL06	Bending		0.417		
32	KL01	Cutting	1	0.25	2.333	2.333
	KL01	Cutting		0.667		
	KL03	Punch Plat Manual 1		0.167		
	KL03	Punch Plat Manual 1		0.333		
	KL03	Punch Plat Manual 1		0.333		
	KL06	Bending		0.583		
33	KL01	Cutting	1	0.25	2.333	2.333
	KL01	Cutting		0.667		
	KL03	Punch Plat Manual 1		0.167		
	KL03	Punch Plat Manual 1		0.333		
	KL03	Punch Plat Manual 1		0.333		

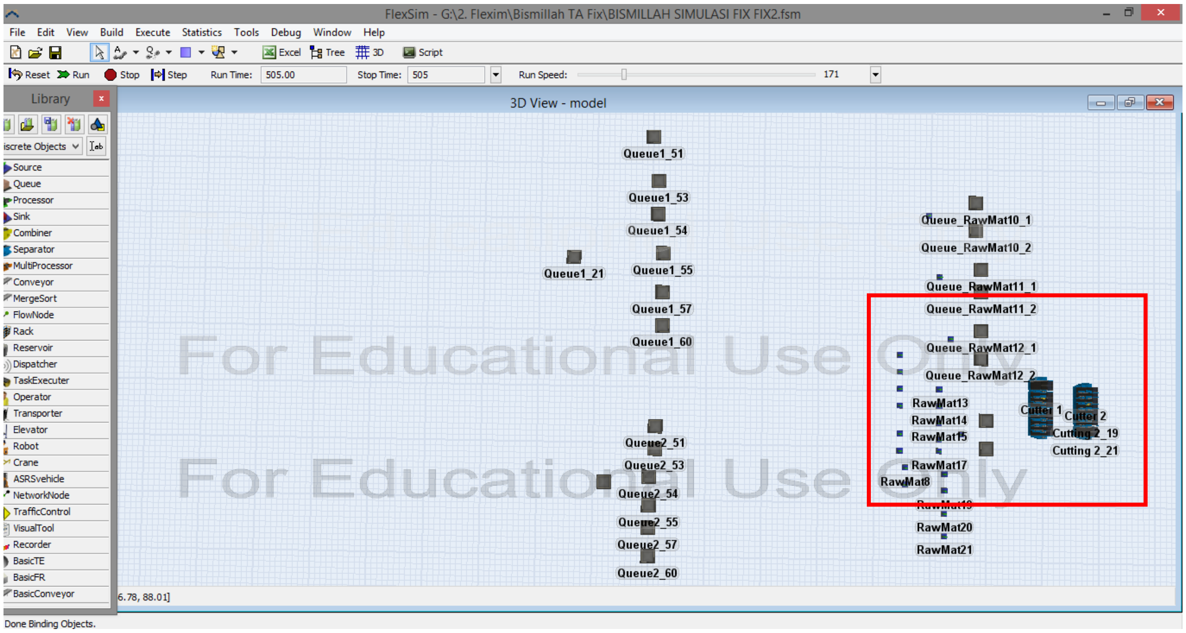
No Components	WS	Process	Quantity	Labor Time (Minutes)	Total Labor Time/1 PCS (Minutes)	Total Labor Time*Quantity
	KL06	Bending		0.583		
34	KL01	Cutting	1	0.25	2.583	2.583
	KL01	Cutting		0.667		
	KL03	Punch Plat Manual 1		0.333		
	KL03	Punch Plat Manual 1		0.417		
	KL03	Punch Plat Manual 1		0.333		
	KL06	Bending		0.583		
35	KL01	Cutting	1	0.25	2.583	2.583
	KL01	Cutting		0.667		
	KL03	Punch Plat Manual 1		0.333		
	KL03	Punch Plat Manual 1		0.417		
	KL03	Punch Plat Manual 1		0.333		
	KL06	Bending		0.583		
36	KL01	Cutting	2	0.75	1.75	3.5
	KL03	Punch Plat Manual 1		0.5		
	KL06	Bending		0.5		
37	KL01	Cutting	2	0.75	1.584	3.168
	KL04	Punch Plat Manual 2		0.167		
	KL03	Punch Plat Manual 1		0.167		
	KL06	Bending		0.5		
38	KL01	Cutting	4	0.5	0.667	2.668
	KL03	Punch Plat Manual 1		0.167		
39	KL01	Cutting	2	0.75	1.084	2.168
	KL03	Punch Plat Manual 1		0.167		

No Components	WS	Process	Quantity	Labor Time (Minutes)	Total Labor Time/1 PCS (Minutes)	Total Labor Time*Quantity
	KL03	Punch Plat Manual 1		0.167		
40	KL01	Cutting	2	0.75	1.416	2.832
	KL04	Punch Plat Manual 2		0.333		
	KL03	Punch Plat Manual 1		0.333		
41	KL01	Cutting	2	0.75	1.833	3.666
	KL03	Punch Plat Manual 1		0.333		
	KL03	Punch Plat Manual 1		0.25		
	KL03	Punch Plat Manual 1		0.25		
	KL06	Bending		0.25		
42	KL01	Cutting	2	0.5	0.834	1.668
	KL03	Punch Plat Manual 1		0.167		
	KL03	Punch Plat Manual 1		0.167		
43	KL15	Metal finish	2	1.08	1.08	2.16
44	KL01	Cutting	3	0.5	1	3
	KL03	Punch Plat Manual		0.167		
	KL06	Bending		0.333		
45	KL01	Cutting	4	0.333	0.999	3.996
	KL03	Punch Plat Manual		0.333		
	KL03	Punch Plat Manual		0.333		
46	KL01	Cutting	4	0.5	1.333	5.332
	KL04	Punch Plat Manual 2		0.167		
	KL03	Punch Plat Manual		0.333		
	KL06	Bending		0.333		
47	KL01	Cutting	4	0.5	1.334	5.336

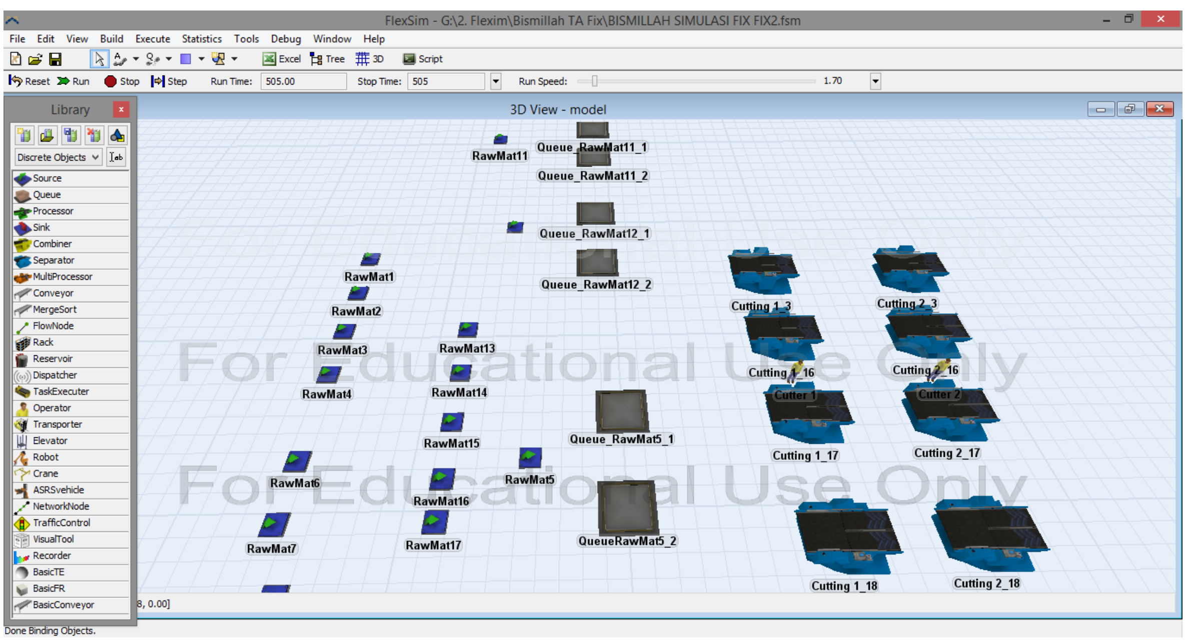
No Components	WS	Process	Quantity	Labor Time (Minutes)	Total Labor Time/1 PCS (Minutes)	Total Labor Time*Quantity
	KL04	Punch Plat Manual 2		0.167		
	KL03	Punch Plat Manual		0.167		
	KL06	Bending		0.5		
48	KL17	Plat Laser	2	0.75	0.75	1.5
49	KL17	Plat Laser	2	1.5	2	4
	KL06	Bending		0.5		
50	KL17	Plat Laser	2	0.967	1.800	3.599333333
	KL05	Press Plat		0.5		
	KL05	Press Plat		0.333		
51	KL01	Cutting	2	0.75	1.084	2.168
	KL04	Punch Plat Manual 2		0.167		
	KL05	Press Plat		0.167		
52	KL17	Plat Laser	2	0.75	0.75	1.5
53	KL01	Cutting	2	0.75	1.25	2.5
	KL04	Punch Plat Manual 2		0.167		
	KL06	Bending		0.333		
54	KL01	Cutting	2	0.75	1.25	2.5
	KL04	Punch Plat Manual 2		0.167		
	KL06	Bending		0.333		
55	KL01	Cutting	2	0.5	0.667	1.334
	KL03	Punch Plat Manual		0.167		
56	KL17	Plat Laser	2	0.5	1	2
	KL06	Bending		0.5		
57	KL01	Cutting	2	0.5	0.667	1.334

No Components	WS	Process	Quantity	Labor Time (Minutes)	Total Labor Time/1 PCS (Minutes)	Total Labor Time*Quantity
	KL03	Punch Plat Manual		0.167		
58	KL17	Plat Laser	3	0.5	1	3
	KL06	Bending		0.5		
59	KL17	Plat Laser	4	0.75	0.75	3
60	KL01	Cutting	4	0.75	0.75	3
61	KL17	Plat Laser	4	0.75	1.333	5.332
	KL06	Bending		0.583		
62	KL16	Pipe Laser	1	0.5	0.5	0.5

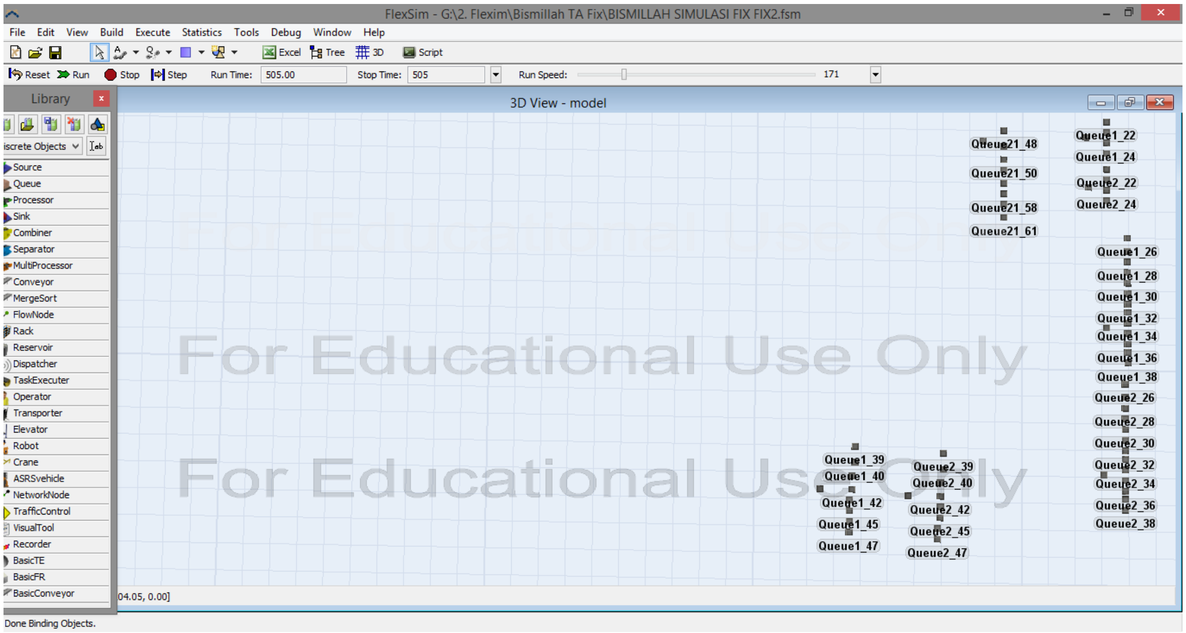
APPENDIXES 3. Simulation Model Development for Existing System



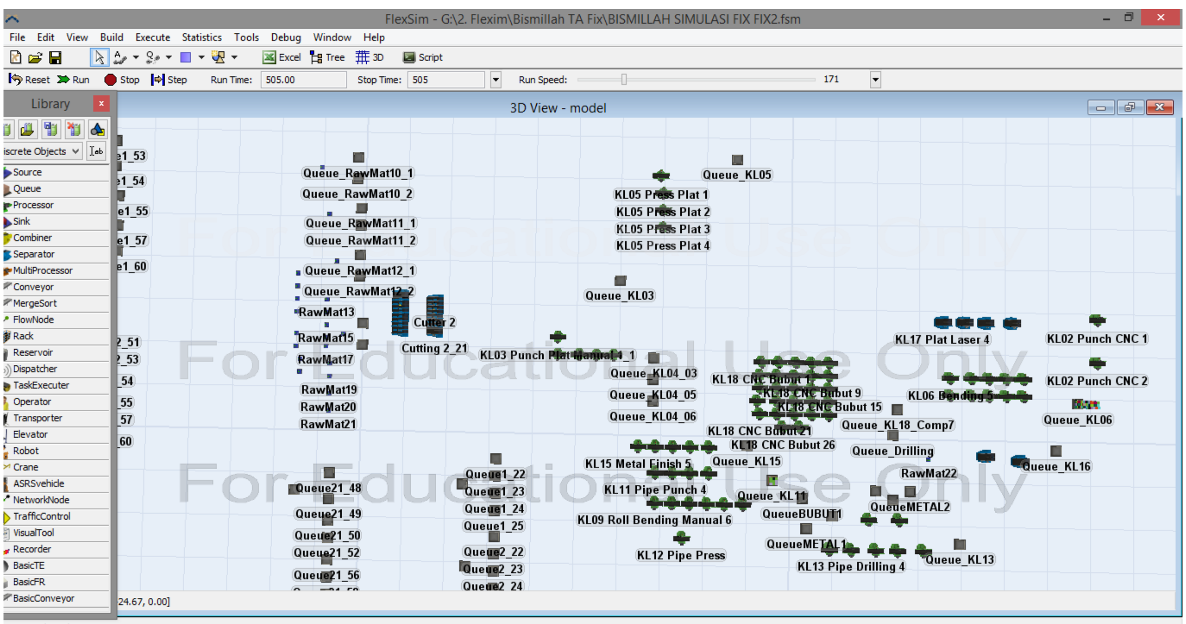
Simulation Model Development for Existing System for section (a1)



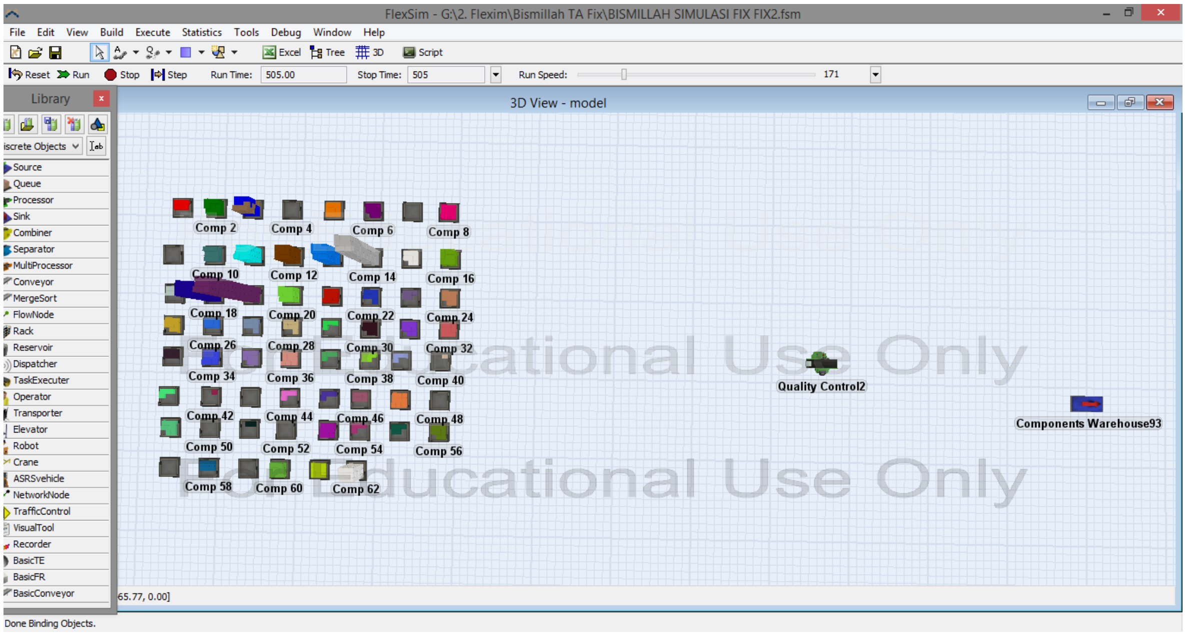
Simulation Model Development for Existing System for section (a1 detail)



Simulation Model Development for Existing System for section (a2)

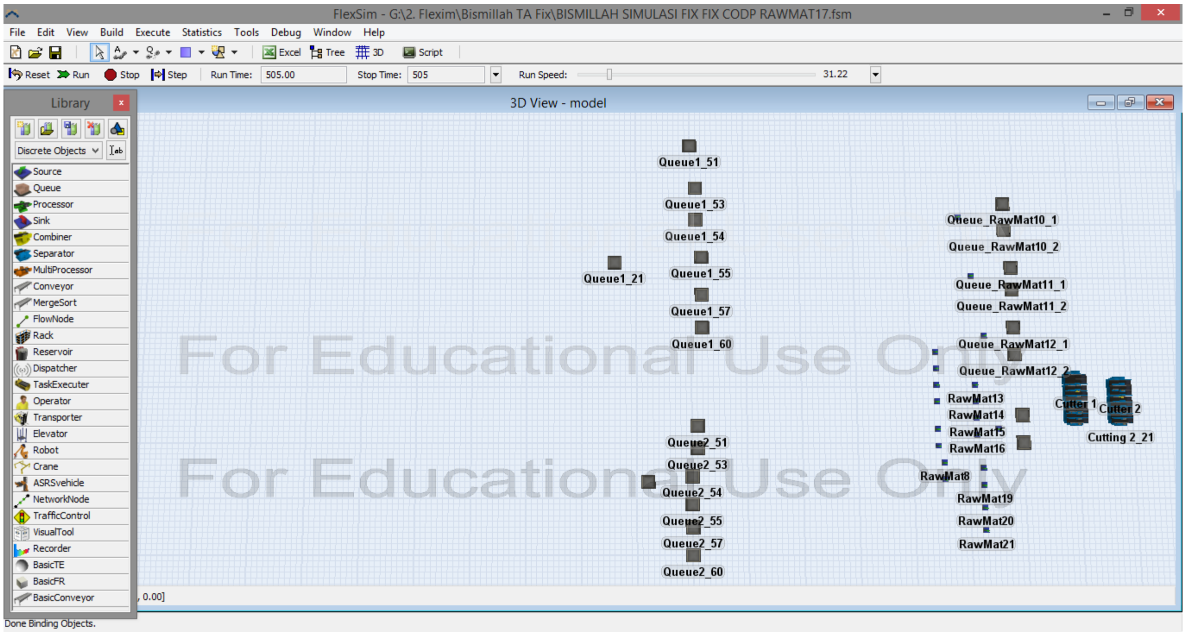


Simulation Model Development for Existing System for section (b)

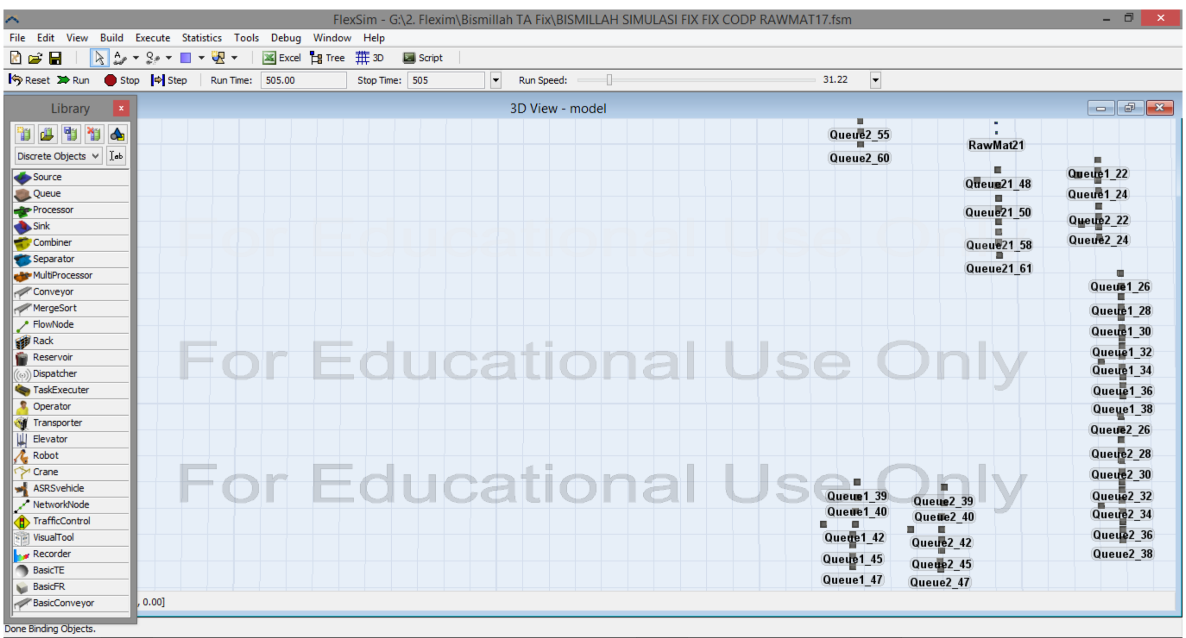


Simulation Model Development for Existing System for section (c)

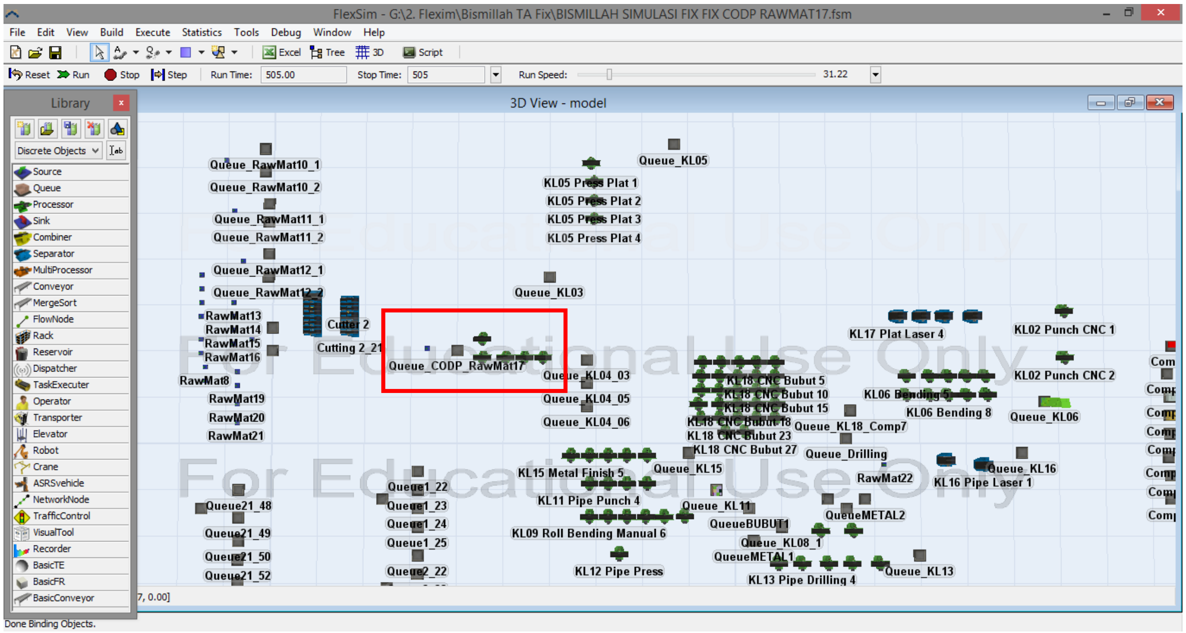
APPENDIXES 4. Simulation Model Development for CODP 1 System



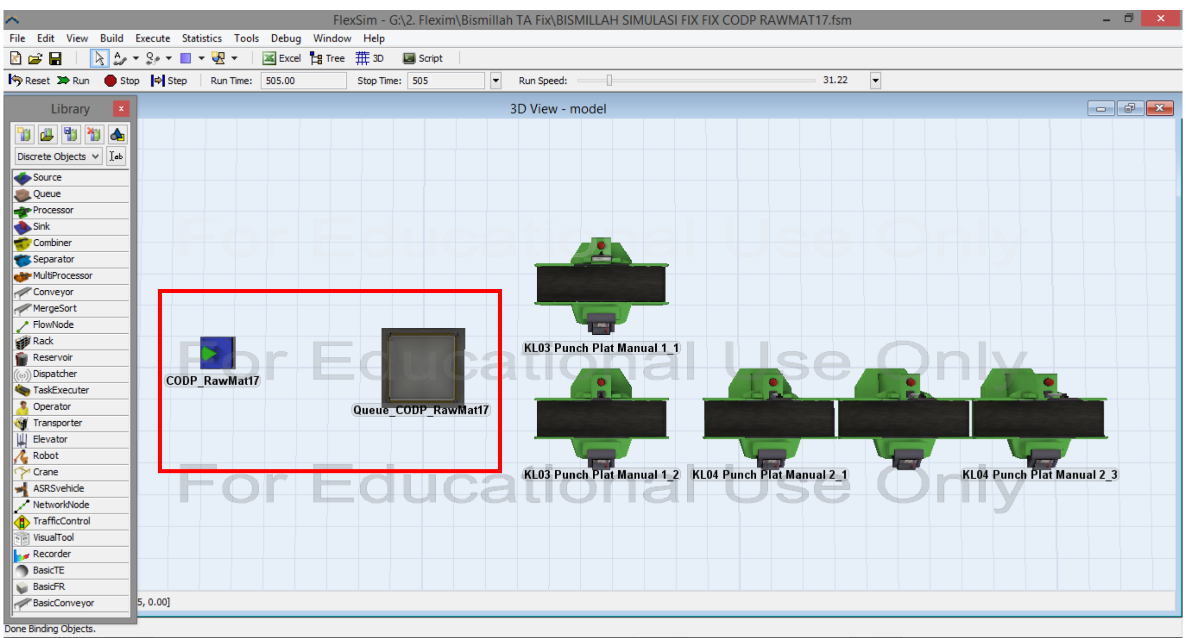
Simulation Model Development for CODP 1 System for section (a1)



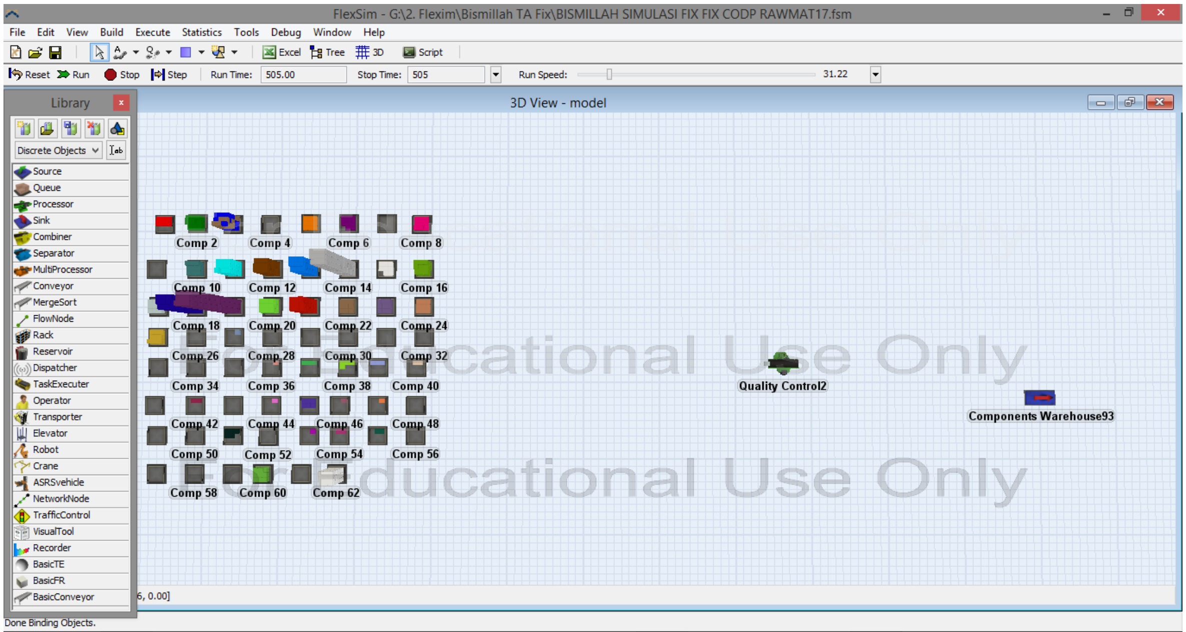
Simulation Model Development for CODP 1 System for section (a2)



Simulation Model Development for CODP 1 System for section (b)

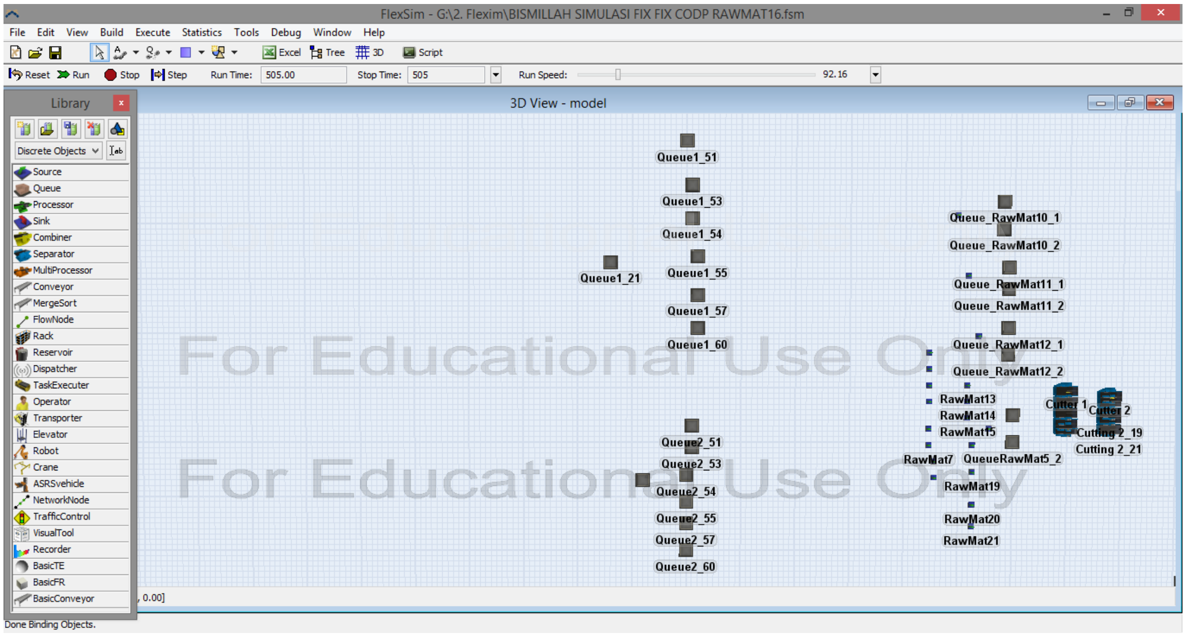


Simulation Model Development for CODP 1 System for section (b detail)

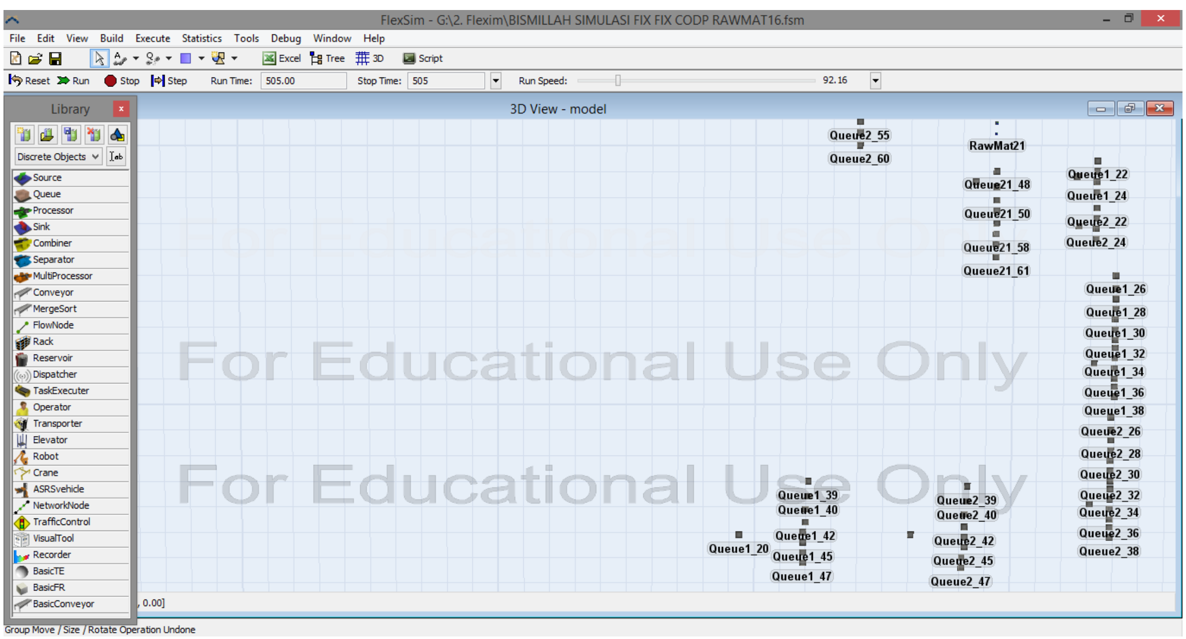


Simulation Model Development for CODP 1 System for section (c)

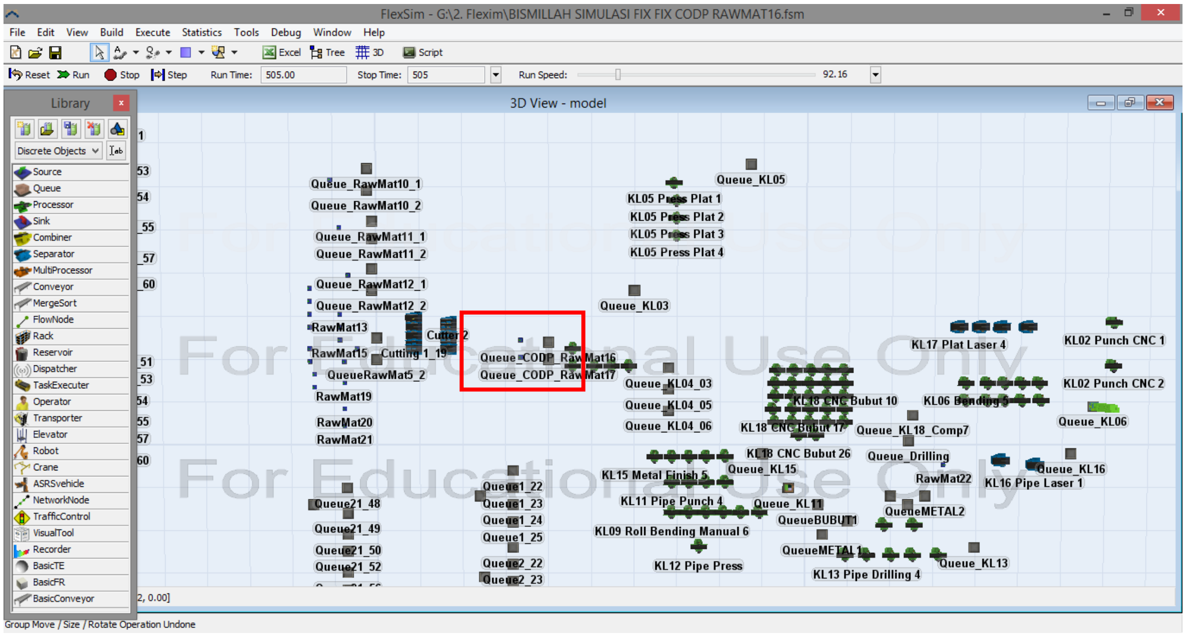
APPENDIXES 5. Simulation Model Development for CODP 2 System



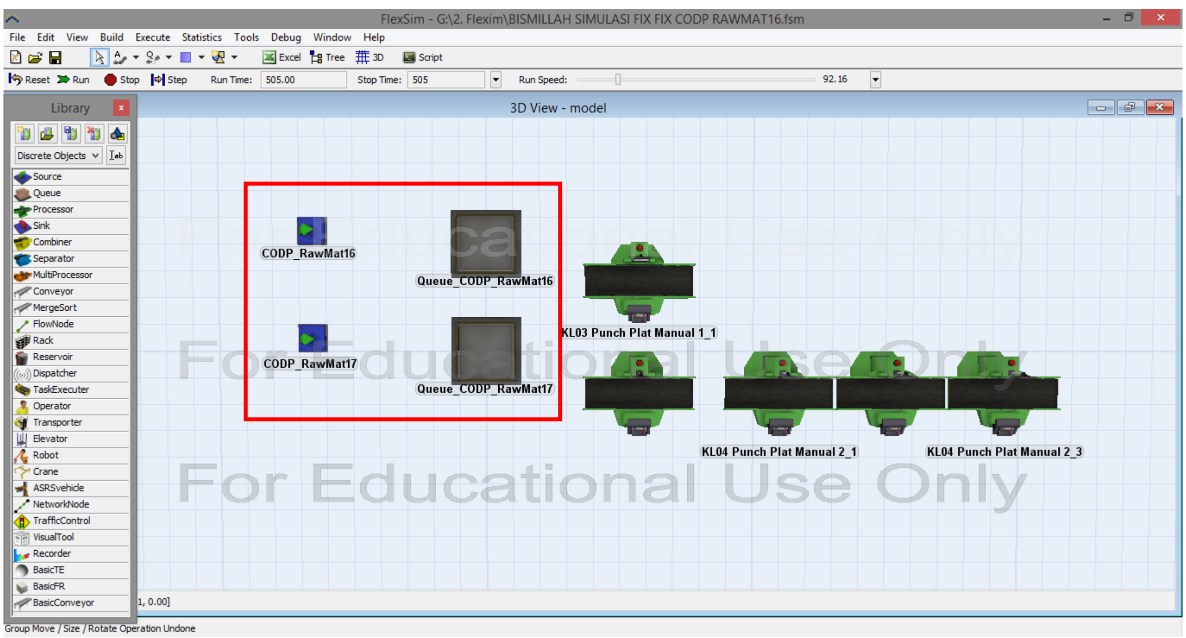
Simulation Model Development for CODP 2 System for section (a1)



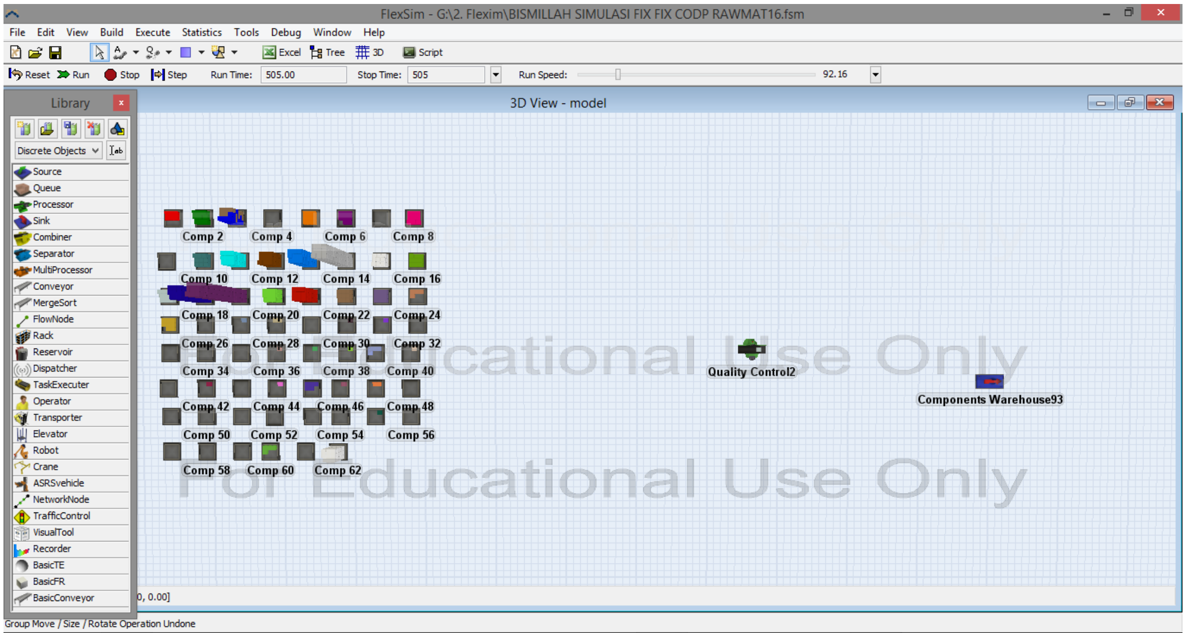
Simulation Model Development for CODP 2 System for section (a2)



Simulation Model Development for CODP 2 System for section (b)

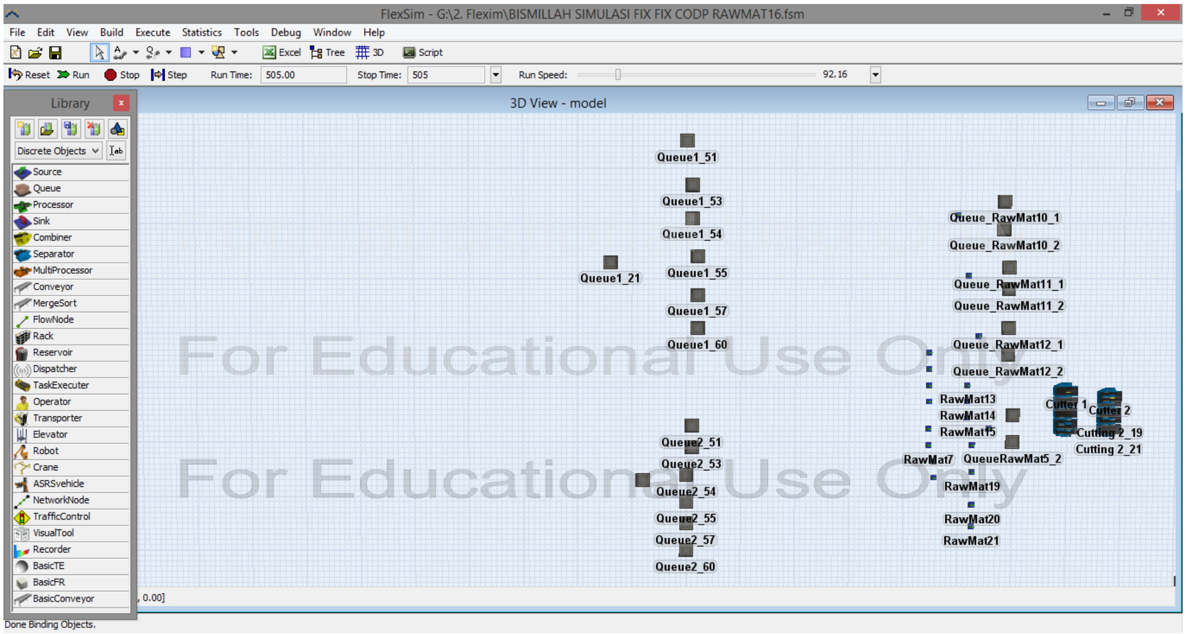


Simulation Model Development for CODP 2 System for section (b detail)

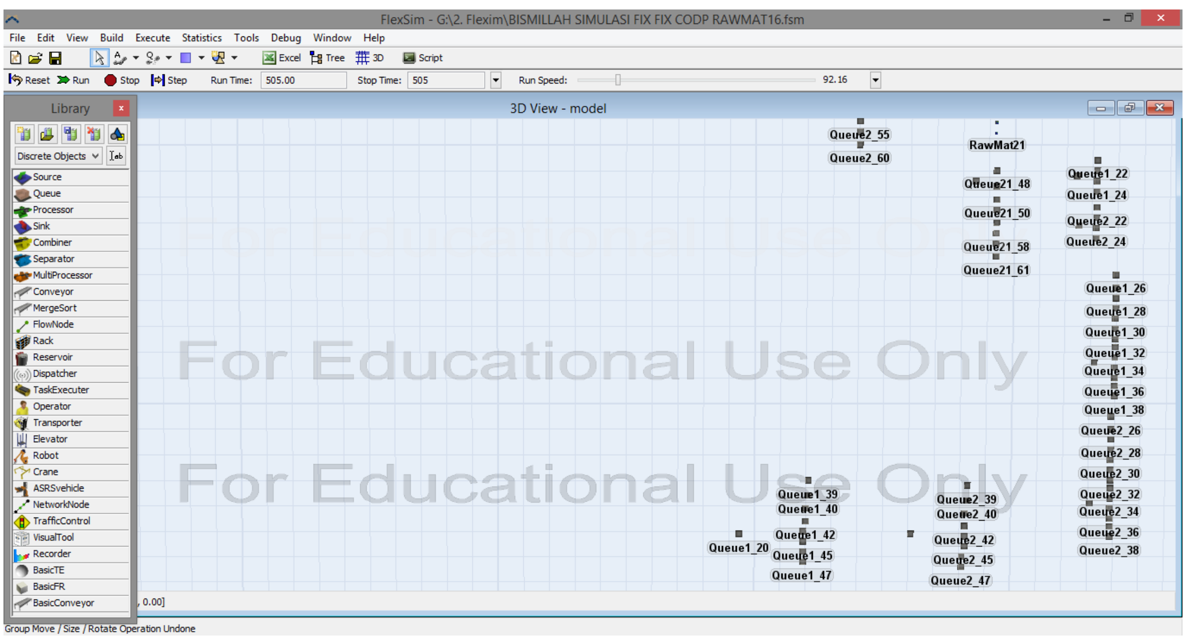


Simulation Model Development for CODP 2 System (c)

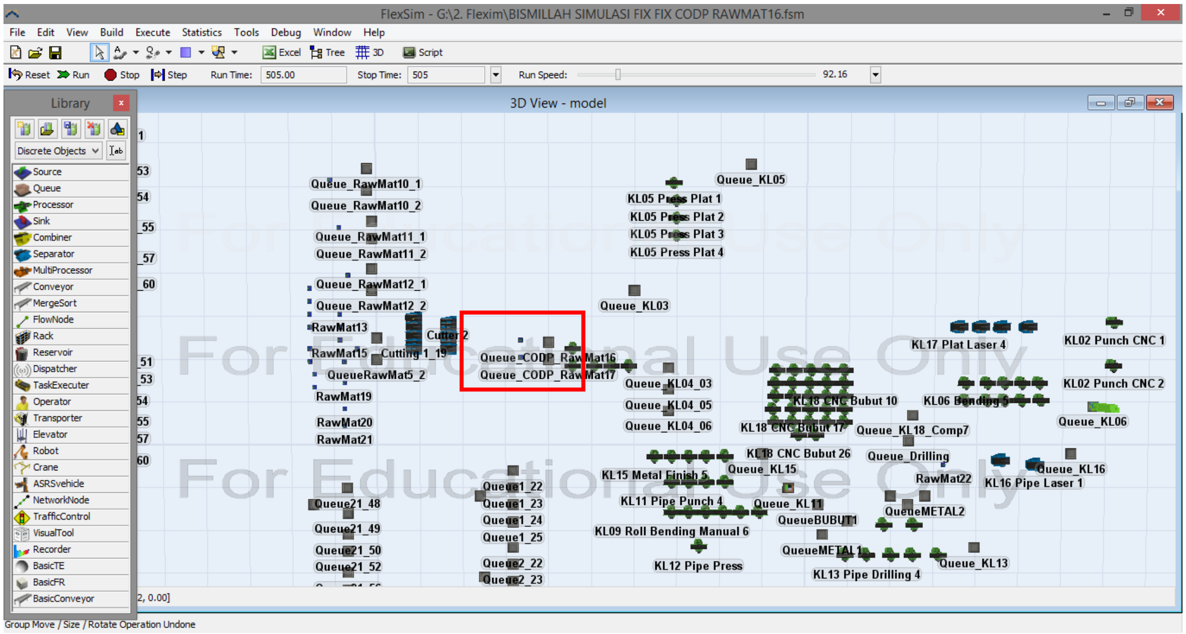
APPENDIXES 6. Simulation Model Development for Final System



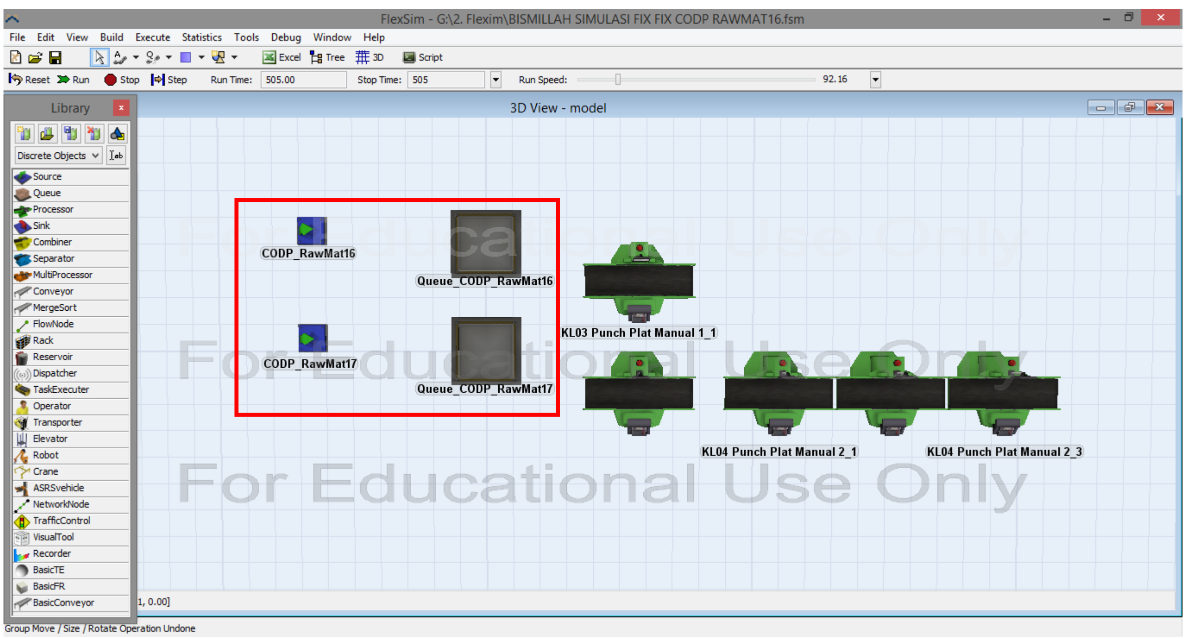
Simulation Model Development for Final System for section (a1)



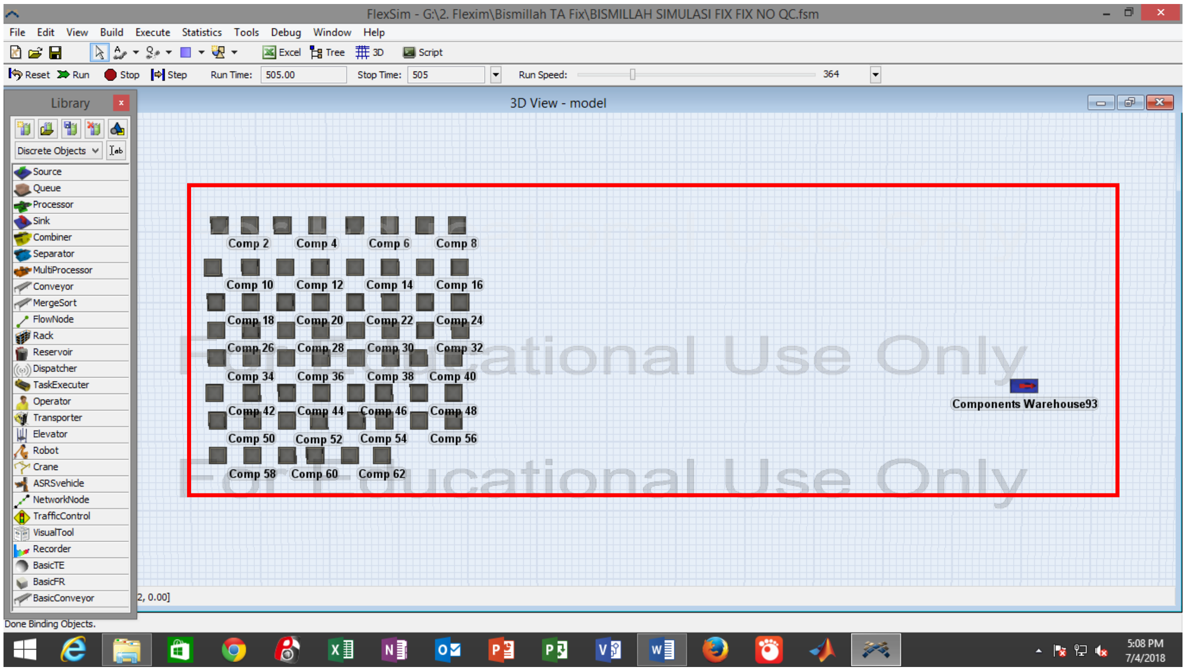
Simulation Model Development for Final System for section (a2)



Simulation Model Development for Final System for section (b)



Simulation Model Development for Final System for section (b detail)



Simulation Model Development for Final System for section (c)