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Investigation of Alternatives for Up-fitting Lead Time Reduction for Vehicle Assembly

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Investigation of Alternatives for Up-fitting Lead Time Reduction for Vehicle Assembly

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ABSTRACT

In this research, an investigation of the lead time reduction and cost control for vehicles with special parts ordered by the customers was performed. The production flow is not continuous for the installation of these parts. There is always time wasted waiting for the units. The aim of this research was to discover revised procedures to reduce lead time and costs. Value stream mapping was the tool to analyze the process. Flexsim^{TM} was the software used to simulate different production cases. The results from the simulations indicate that under the current production volume, moving the program back to the plant is the best option since it will reduce the waiting time between the plant and installation facility. Furthermore, it can reduce the overall manufacturing lead times and improve cost effectiveness. If the production volume increases, space, equipment and management limitations may require plants to use alternative production models and these limits should be studied in future research.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS/SYMBOLS

ABBREVIATION	FULL NAME
AP	Assembly Plant
VCC	Vehicle Completion Center
WC	Warehousing Canada
VSM	Value Stream Mapping
FIFO	First In and First Out
LEPT	Longest expected processing time
WIP	Work In Process
SDM	Shape Deposition Manufacturing

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

International competition is forcing companies to achieve World Class Manufacturing (a comprehensive production system) to compete in global markets. A short manufacturing lead time is considered one of the central factors for achieving World Class Manufacturing (WCM) expectations along with quality, flexibility and productivity [1]. The length of manufacturing lead time is a measure of the competitiveness of a company; therefore, to gain an advantage to survive and remain competitive, it is very important for the company to reduce their manufacturing lead time.

In the automotive industry, the manufacturing lead time is the amount of time between a customer placing an order and their receipt of the car. Once an order for a specific car has been received by the company, the next step is to manage the order in a process called order handling. In this part of the process, all relevant information is gathered (for example, the requests and production availability, quantities) to determine a production schedule. The order then moves to central scheduling, which will establish when the car will be built. This step usually takes several weeks before all the required parts are ready for production, since there is a wait for the delivery of the parts. In the assembly plant the production process starts in the body shop, where the vehicle body (body in white) is constructed. It will then come out from the body shop and will go through the paint shop and through the rest of the assembly process. At the end of assembly, the quality of the vehicle will be inspected and after successful completion the vehicles are ready for shipping.

Decades ago, after a vehicle order been placed, the customers had to wait for months, or even a year, before they could drive their car home since demand was much greater than supply. Now it is different since customers have more choices among different car brands and divisions. This highly intensive competition has encouraged manufacturers to understand the special needs of their customers and offer more options to the market. This thesis will study a Fortune 500 brand commercial vehicle production process and after-market assembly process for special options, as shown in Figure 1-1. Up-fitting, which is the specific term used to represent this after-market assembly, indicates the process of assembly for the customized option, which occurs offsite after the regular assembly process. There are several factors which effect the overall manufacturing lead time. Some of these related effects are reviewed in Chapter 2. To minimize the lead time, wasted time should be eliminated and a greater work load balance should be given to the workers. Three entities will be investigated in this research: the assembly plant, the third party transportation management, and the up-fitter workshop. According to the requirements of World Class Manufacturing, each entity has improvements that may be achieved: (1) The scheduling of plant can be optimized and synchronized with the working time of up-fitter workshop; (2) The transportation between the plant and up-fitter workshop can be dramatically reduced by rearranging routes; (3) The job sequencing and cycle time at up-fitter workshop needs to be optimized to reduce the stay time of the vehicle.

Assembly plant
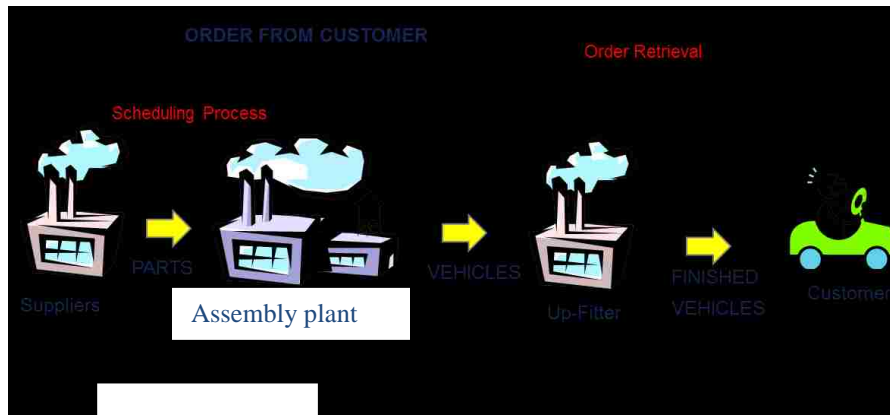
FIGURE 1-1 THE MANUFACTURING PROCESS FOR THE UP-FITTER VEHICLES [31]

1.2 TYPES OF UP-FITTERS, PRODUCTION VOLUME AND PRODUCTION SCHEDULING

There are different after-market parts installations which occur off the assembly line. All of these part installations can be done at the dealerships, in the plant, or in the partnership entities. The main reason to do the up-fitter option installations in the plant or at partner entities is mainly due to cost. Putting all the cars together and purchasing up-fitter parts in a higher volume can save costs compared to doing the task at the dealerships, where most of the time only one or two parts are purchased. The company can take advantage of having more pricing choices for these up-fitters by ordering a higher volume. Furthermore, the business of up-fitting can generate revenue for the company, option D below in the Table 1-1, demonstrates the profit margin for one of these up-fitters.

TABLE 1-1 PROFIT MARGIN FOR OPTION D (NORMALIZED DATA)

Item	Price & profit
Selling price per unit	$4.67
Parts purchasing per unit	$1.07
Manufacturing cost per unit	$0.87
Profit margin per unit	$2.73
Production volume per year	10000
Profit margin per year	$27,333.33

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From the table above, the selling price is marked up by about 2.5 times compared to the cost:

$$\text{Total cost} = \$1.06 + \$0.87 = \$1.93$$

The normalized profit margin for this single option is about $27,000, which indicates that is worth the effort to keep the up-fitting business within their own company. Therefore, investigating dealer related activities with respect to retrofitting is outside the scope of this research.

In this project, the up-fitting process for a vehicle assembly plant has been investigated and analyzed. Along with the four different simulation and production models examined, different assumptions have also been tested to reduce the process time for up-fitting. This research aims to discover the best production model.

In the project study, there are four different options involved in the up-fitting process. Each of these four options (A-D) has a unique process when coming off the assembly from plant, but the process will be completed at an extension of the plant (VCC is used as the name for up-fitter entity). The photos below demonstrate how the appearance of three up-fitter options in Figure 1-2). These options are too complex to be completed on the assembly line. Therefore, the installations are sent to off line stations to complete the work.

FIGURE 1-2 A) OPTION A

FIGURE 1-2 B) OPTION B CONNECTION DEVICE
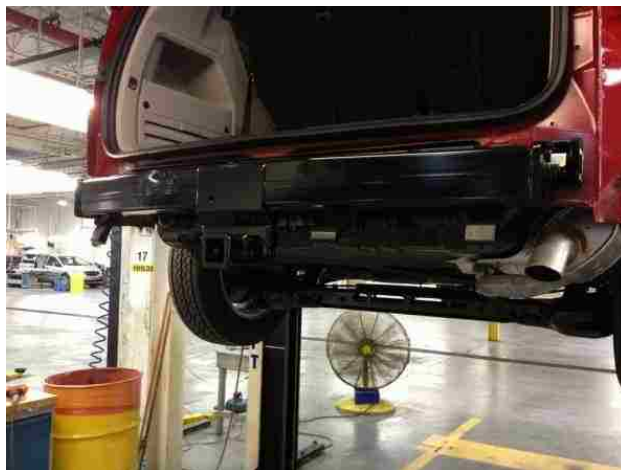
FIGURE 1-2 C) OPTION D

FIGURE 1-2 UP-FITTER PARTS

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These up-fitter options do not occupy a high percentage of the total production volume. The vehicles with up-fitter options consist of 5-6 percent of the regular production volume. With 1500 vehicles coming off the line daily, the number of vehicles which require special processing are 70-80 units per day or about 25 per shift. The following charts show the ordering patterns for these up-fitters in one recent production year, see Figure 1-3[32].
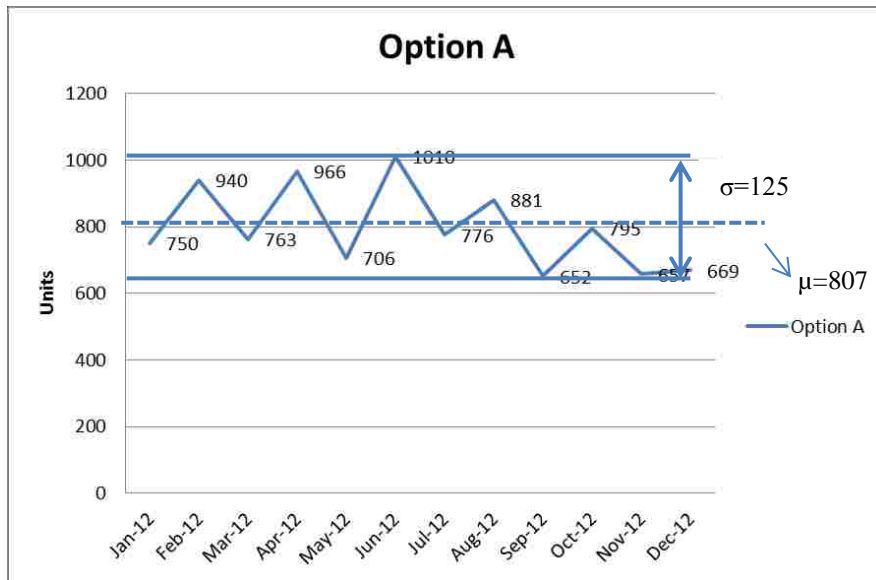
FIGURE 1-3 A) MONTHLY PRODUCTION VOLUME FOR OPTION A
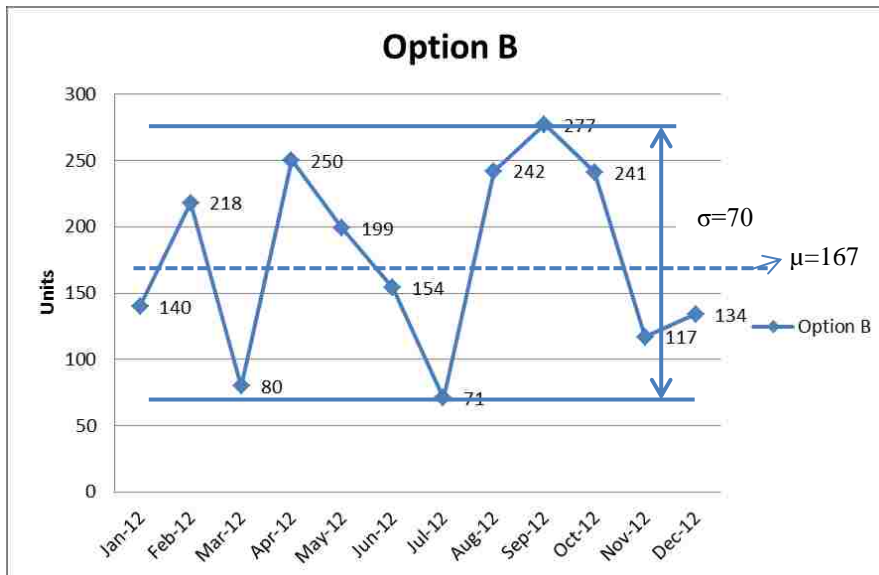
FIGURE 1-3 B) MONTHLY PRODUCTION VOLUME FOR OPTION B
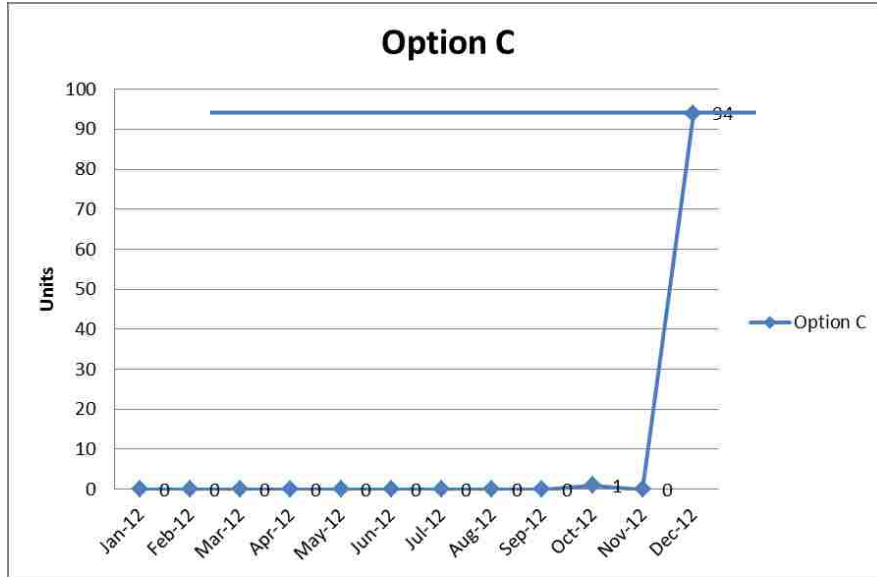
FIGURE 1-3 C) MONTHLY PRODUCTION VOLUME FOR OPTION C

Option C production volume is not a normal distribution. Since the order pattern for this option is unstable it will be treated as the noise.
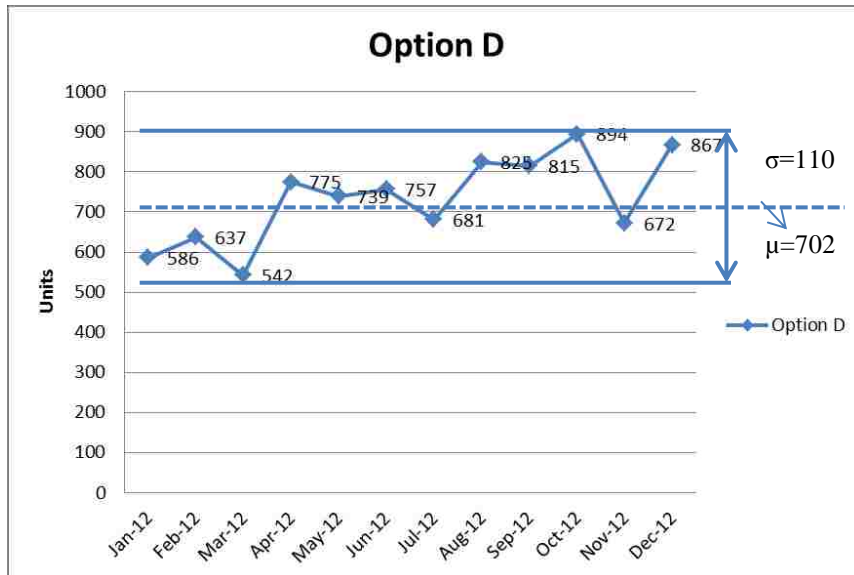
FIGURE 1-3 D) MONTHLY PRODUCTION VOLUME FOR OPTION D

FIGURE 1-3 MONTHLY PRODUCTION VOLUME FOR UP-FITTERS

From the volume charts, we can tell that the option A and option D have the highest production volumes and are relatively stable when compared to the other two options. The distributions for these two options are considered as the normal distribution. Option B's production is relatively random since the differences between months are high. Option C has very little demand over the year. Figure 1-4 summarized the production for all up-fitters.
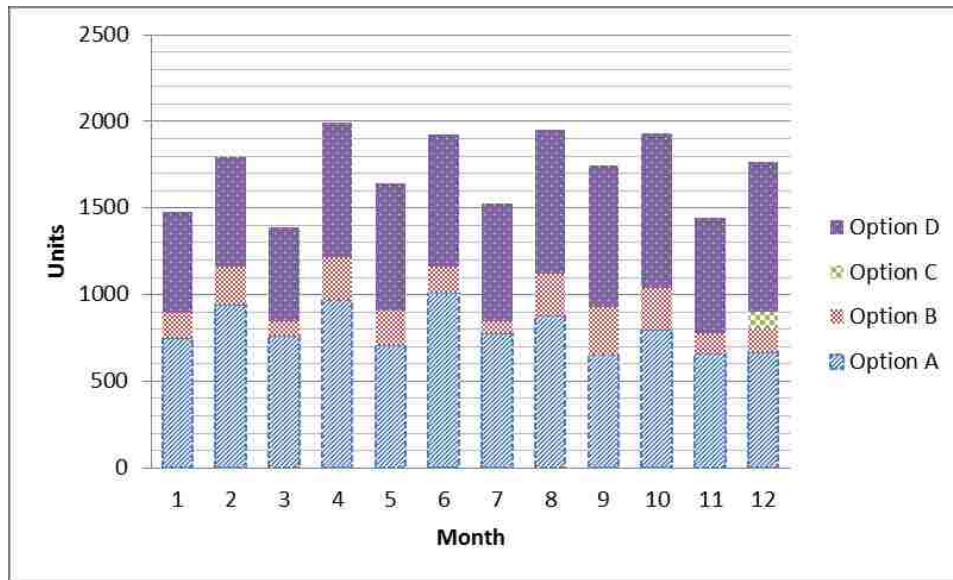
FIGURE 1-4 SUMMARY OF MONTHLY PRODUCTION FOR ALL THE UP-FITTERS

The average observed process time (± 1 min) for assembling each option, as determined by observing three operators for each option, is shown in the Figure 1-5. A formal time study should be conducted in future to improve the accuracy and efficiency of simulations. A major time reduction on Option D can be realized by vehicle transportation reroute and procedures optimization, it will be introduced in the value stream mapping process in chapter 3.
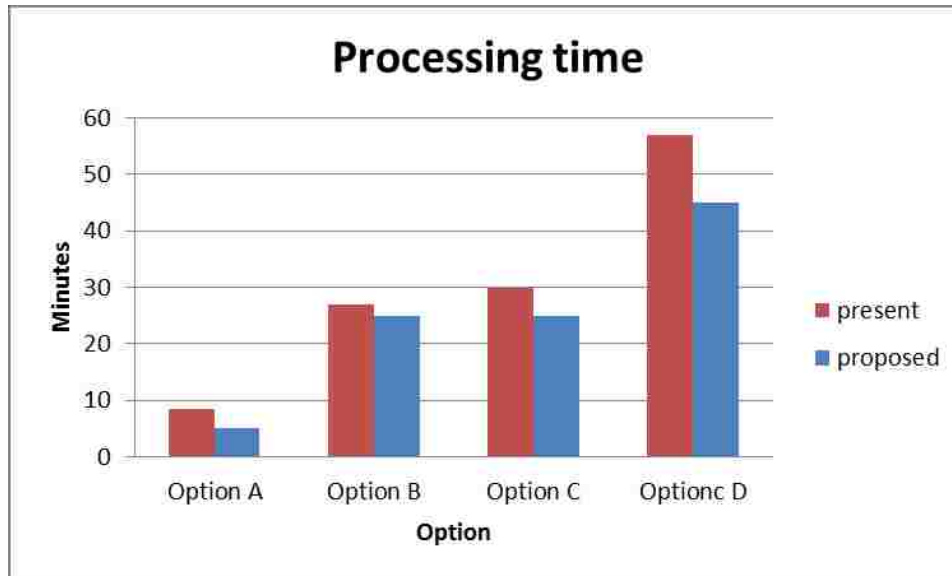
FIGURE 1-5 PROCESS TIME FOR EACH OPTION
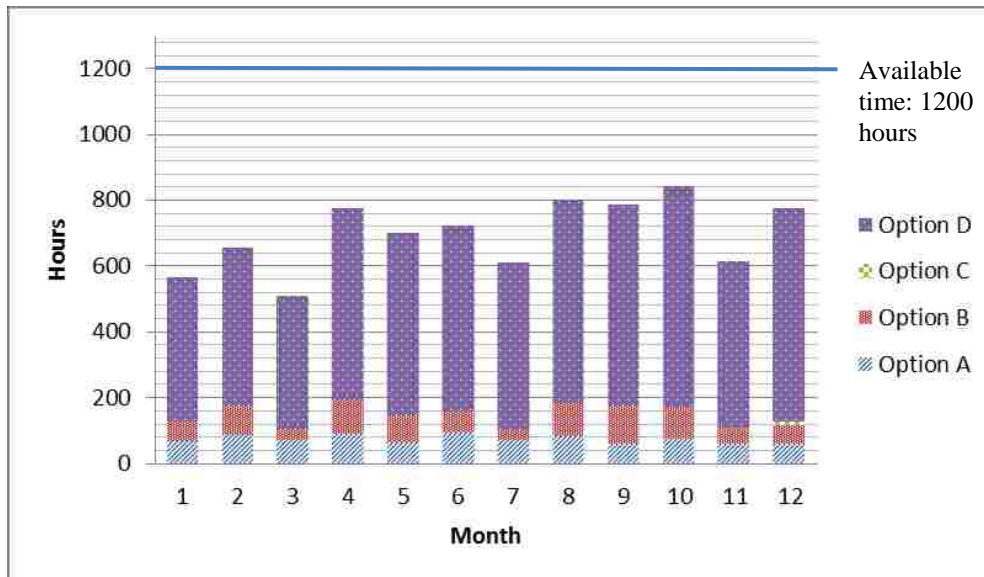
FIGURE 1-6 OVERALL TIME NEEDED FOR PRODUCTION EACH MONTH

Under the current working case, the available working time is about 1200 hours per month. That includes 22 work days/month and 8 hours/day with 70% up-fitting efficiency for 10 workers. Figure 1-6 shows that there is huge amount of time loss for the

production according to the work load calculation, there are about 400 hours' time waste

each month.

1.3 PROBLEM STATEMENT

The main purpose of the project is to reduce the lead time for the up-fitting process for

the vehicles with special requirements ordered by the customers. The manufacturing lead

time for up-fitter vehicles is almost twice the time for vehicles produced exclusively on

the assembly line. Since the production is not continuous between the plant and VCC,

this process flow has not been optimized. A methodology to synchronize the production

and improve up-fitting efficiency needs to be discovered. Cost control is another

important factor which has to be taken into consideration. Different solutions should be

studied and compared to find the best fit for current production.

Scheduling these vehicles for up-fitter options is one of the difficulties in the study. The

working time between the plant and VCC is not synchronized, as there are three shifts in

the plant while workers in the VCC only work for one shift per day. The best solution

would be to batch the production in the plant and synchronize the working time with

VCC. However, in reality this is not a feasible choice because of the complicated issue of

scheduling in the plants. In fact, all types of vehicles are mixed on the assembly line and

central scheduling should calculate and even out different options according to different

priorities standards to avoid overbuild or delivery delay. All the up-fitter vehicles should

be evenly spaced on the production line with respect to the others with a maximum

spacing ratio 1:20. If the daily volume is low, and the spacing ratio range can be 1:25 or

even spread out. There are up-fitter vehicles coming off the line during every shift from

the plant. During the time when the VCC is closed, these vehicles will be stored at the

parking lot at the third party transportation company (named WC in the this work). When

the VCC re-opens in the morning, drivers from the WC will bring the vehicles which

stayed overnight at the WC to the VCC, along with the new vehicles coming off the line

during the day shift. The VCC personnel will finish the work on all the vehicles which

arrive from the plant in one shift.

There are several reasons why the scheduling cannot be changed. A computer program

compiles the gateline (from where the vehicles are sent to assembly line) to the

acceptable mix/ ratio of about 1500 units per day. The units to the end of the gateline are

13 days' production volume. If there is a shift in the body shop, painting shop or

assembly shop where VCC units are batched in the gateline, the 14th day would correct

the issue with new days program compiler suggesting units to be scheduled accordingly.

The days prior to a scheduling change will be off schedule, which will lead to a loss of

information or breakdown. The company cannot bear this loss only to prioritize these low

production volume vehicles. The attempt to optimize the production from a central

scheduling point of view did not work at the beginning. This meant the downstream

entity, the VCC, has to compromise and work with the plant to improve the time

efficiency under the current situation.

To understand the whole problem, a literature review was first examined to investigate

several constraints which can significantly affect the lead time. This is presented in

chapter two. In chapter three, a local investigation will be performed to understand the

current production process. Value Stream Mapping (VSM) is used as the tool to analyze

the present situation and provide a basis for suggestions of improvement for this problem.

Many types of waste can be identified in the mapping process. The simulation software

Flexsim^{TM} simulation is utilized to show how much process time can be reduced in different production scenarios. In chapter four, the simulation results are analysed and cost analysis are performed for each production scenario to evaluate the feasibility of the solution. In the end, the trade-off solution is developed so that by reducing the lead time, the cost benefits will be improved or maintained at a certain level, chapter five will give the summaries and conclusions.

CHAPTER 2

LITERATURE REVIEW

2.1 MANUFACTURING LEAD TIME

Manufacturing lead time, by definition, is the total time required to manufacture an item, including order preparation time, queue time, setup time, run time, move time, inspection time, and put-away time. For make-to-order products, it is the time taken from release of an order to production and shipment [2]. Manufacturing lead time is sometimes compared with production lead time, which is also a measurement of production efficiency. Manufacturing lead time measures how fast an order is fulfilled, it starts from the moment that the order was input into the company, it is an external measurement. On the other hand, the production lead time starts only when the first piece of the product is on the production line. It measures how long the resources are tied up before they are of actual values to customer. It does not end when the product is finished and it ends when the delivery of the product, so it is an internal measurement, Figure 2-1 [3].

There have been many studies about the manufacturing lead time and the factors that can affect it. They can be Scheduling, Inventory, Flexibility, Value Stream Mapping (VSM) and so on. Take cooking as an example, scheduling is like the order lists from the customers at the restaurant, it shows how the chef wants to cook based on the ingredients, it does not exactly follow the customer's order sequences. Inventory is like the ingredients, purchasing the ingredients and make sure they get delivered on time is vital. Flexibility is how well they can handle if they were asked to cook different types of food using the same kitchenware. It can be seafood, meat or vegetables, or mixed and so on. NVA time is the time that customers don't want to pay for and it's not directly related to

the dish, for example, the time for purchasing ingredients. VSM tells us the detailed

procedures of how they work, by which we can learn if there is a potential to improve the

efficiency of the kitchen.
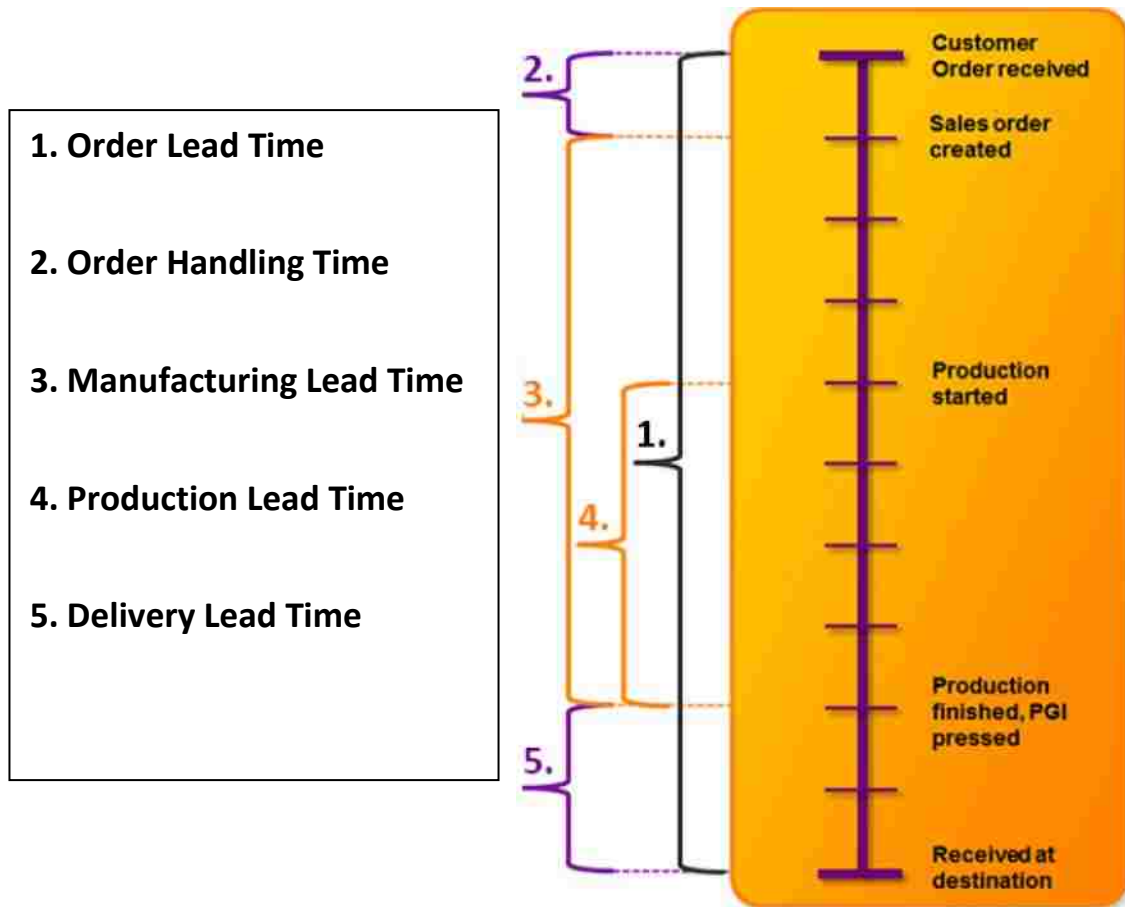
FIGURE 2- 1 MANUFACTURING STAGES AND LEAD TIME PROPORTIONS FOR EACH STAGE [3]

2.2 SCHEDULING

Scheduling is an important part for manufacturing process, it tells how and when to make

the product in an efficient way with minimum cost. There are different ways of

scheduling and among which the algorithms for production scheduling process are all

based on two categories: stochastic problems and deterministic problems. From practical

point of view, manufacturing scheduling models are more practical than theories, so we looked into some manufacturing models and their relationship with the lead times.

2.2.1   STOCHASTIC ALGORITHMS

Stochastic scheduling deals with problems in which the processing times of tasks are considered as random variables, so a job's process time can only be known after it is complete. A typical problem for stochastic algorithm is that the processing times of n jobs are exponentially distributed with different means. The jobs will be processed by m identical machines in parallel, production lead time will be minimized by longest expected processing time first (LEPT) [4]. The solutions for stochastic scheduling problems may include combinatorial optimization, stochastic dynamic programming and probability theory. The precedence constraints are considered for the stochastic machine scheduling problems, which means certain jobs can only be scheduled after others are finished. The objective is to find a scheduling policy for the jobs being processed on a set of identical, parallel machines to minimize the expected total weighted completion time [5].

The stochastic scheduling was used to solve the machine scheduling problem, which is described as the following: There are n jobs V = {1,2, . . . ,n}, each of the job has a processing time p_j ≥0. The jobs will be processed on m parallel machines, any machine can process only one job at a time and any job can be scheduled only on one machine each time. The jobs are required to be processed non-preemptively, which means once the job has been started, it has to carry on for p_j time units. The release date $r_j \geq 0$ is the earliest time for a job j ∈ V to start. And there might be precedence constraints between jobs, which means job j must not be started before job i has been finished [5].
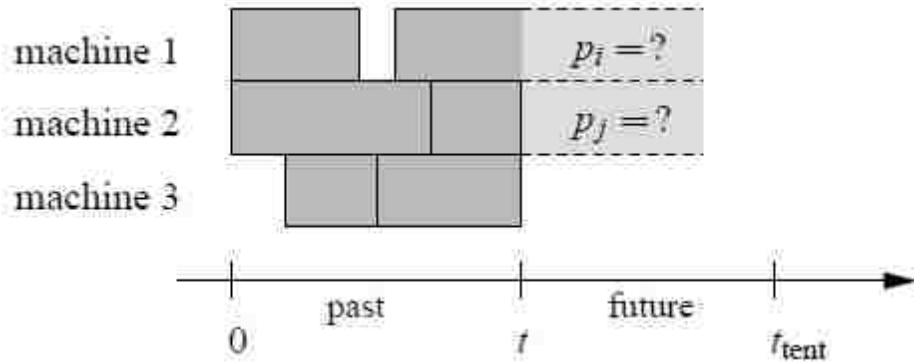
FIGURE 2- 2 THE ACTION OF SCHEDULING POLICY AT A DECISION TIME T [5]

The situation in Figure 2-2 was considered, both job i and j were not complete and the

assumption was that the scheduling policy starts a new job at tentative time t_{tent}. In other

words, the tentative decision time of any action of a policy was always chosen so that at

least one job will be scheduled at t_{tent} , and no other job was released before t_{tent}. Three

scheduling policies were discussed: list scheduling policies, earliest start policies and pre-

selective policies [5].

2.2.2   DETERMINISTIC SCHEDULING

In deterministic scheduling, the data is known with certainty in advance for all problems,

the solution is to schedule a set of start time for all the jobs [5].

Deterministic Scheduling is used to solve multi-tasking problems in which processing

times are known or known to be equal to models in which process time are known. The

bounds on completion times and applicability of optimal deterministic schedules to

probabilistic models were studied. Level algorithms are proved to be the optimal for

forest precedence graphs in which the process times are independent and identically

distributed exponential or erlang random variables [6].

The algorithms for single and multi-objective unrelated parallel-machine deterministic scheduling problems have been studied. The algorithms for the lead time, total weighted sum of completion times, maximum tardiness, total tardiness, total earliness and tardiness, and multiple criteria performance measures were researched. The review is limited to the deterministic problems without setups, pre-emptions, or side conditions on the problem. It showed that the lead time minimization has been widely studied and problems that include processing characteristic such as release times, sequence dependent setups and pre-emption's still need more study. And the studies on unrelated parallel-machine scheduling problems involving the minimization of the number of tardy jobs, weighted number of tardy jobs, total tardiness, and total weighted tardiness are very limited [7].

In the traditional parallel machine scheduling problems, offline or online (continuous flow line) condition was considered as an assumption. But in practice, the problems can be somehow in between, compared to the online problem, more information of the task is available, it is called semi-online problem. This shows the potential to improve the performance with the best possible algorithms. The semi-online problem P2 |decr|lp (p>1) was considered when the jobs' processing time are not in increasing order and the objective is to minimize the sum of the lp norm of every machine's load. The LS (least squares) algorithm is the optimal solution for any lp norm [8].

Deterministic scheduling problems with machine availability constraints have attracted a lot of researchers to work on them. From the survey about complexity results, exact algorithms and approximation algorithms in single machine, parallel machine, flow shop, job shop scheduling environment with different criteria, the major part of the studies were

focused on the offline version of problems and little is known about the online problems. However in real industry, online version happens a lot, it's worthwhile to develop more algorithms to solve the online problems in future. Because of the simplicity, single machine and parallel machine scheduling problems under different criteria have been widely studied and many of them can be optimized. But for flow shop problems, only the production time was extensively studied and they mainly deal with two machine problems. So in the future, studies might focus on some practical criteria such as the total flow time, the total lateness, the sum of the weighted completion times, the maximum lateness and the number of tardy jobs. And extending the two machine models to more machines and more complicated job shop and open shop problems will also be an interesting research direction [9].

2.2.3   SCHEDULING MODELS AND LEAD TIME

For scheduling, deterministic algorithms are particularly used for synchronization of material, energy and information flows. It means the methods used for modeling, optimization and functioning of systems are based on exact mathematical findings and rules of logic. But in the real production world, the process is very dynamic with many unpredictable events, new requirements keep emerging all the time. So the exact scheduling can't always satisfy all the requirements. In many different areas of science and technology it has been noticed that the shift towards the conceiving of integrated systems is capable of learning and efficiently responding to increasing complexity, unpredictability and changeability of the manufacturing environment [10]. Depending on the common sense ''from easy to difficult'' and '' from simple to complex'', a survey of scheduling models is shown as in Figure 2-3 [11] [12].

Job-shop scheduling models deal with determination of the operation sequences on the machines to minimize the lead time. This problem has already been confirmed as one of the NP-hard problems. Flexible job-shop scheduling model is the extension of Job-shop scheduling with the assumption that a machine may be capable of performing more than one type of operation. For any given operation, there must be at least one machine available of performing it. Integrated operation sequence and resource selection model was originally derived from the real production process in manufacturing systems and approximates to them. Integrated scheduling model with multi-plant is a scheduling system using integrated data structure and scheduling algorithms to combine both manufacturing and transportation scheduling. Manufacturing and logistics models with pickup and delivery extend integrated scheduling model with multi-plant, it provides schedules that satisfies customer demands for just-in-time delivery [10].
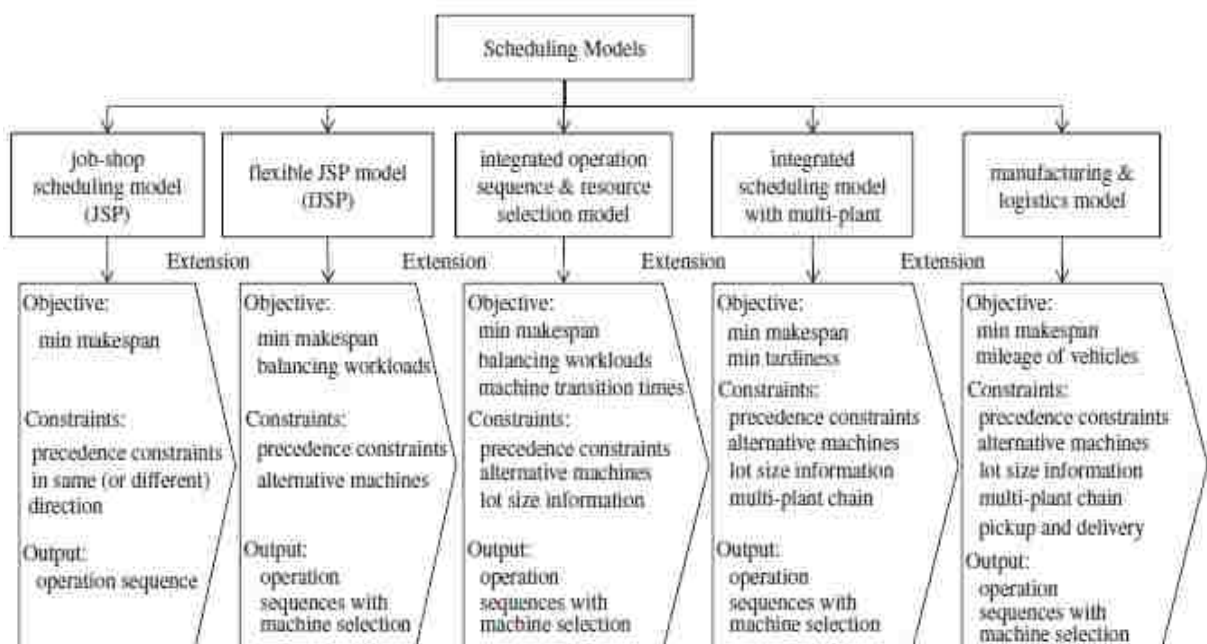
FIGURE 2- 3 SUMMARIES ON DIFFERENT SCHEDULING MODELS FOR PRODUCTION

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2.3 INVENTORY

In the manufacturing plant, inventory has three different levels of meanings depending on the stage of the production. Production inventory refers to the level of raw materials and supplies on hand for the product manufacturing. Work-in-process inventory is the semi-finished goods in the middle of the production process. Finished goods inventory is the value of the final products to customers.

The global relations between inventory and manufacturing lead time are studied, it showed that the lead time increases with the work-in-process inventory. The raw material inventory has very little effect on manufacturing lead time and finished goods inventory seems to have no effect at all, see Figure 2-4 [13].

a) lead time VS raw material inventory   b) lead time VS finished goods inventory
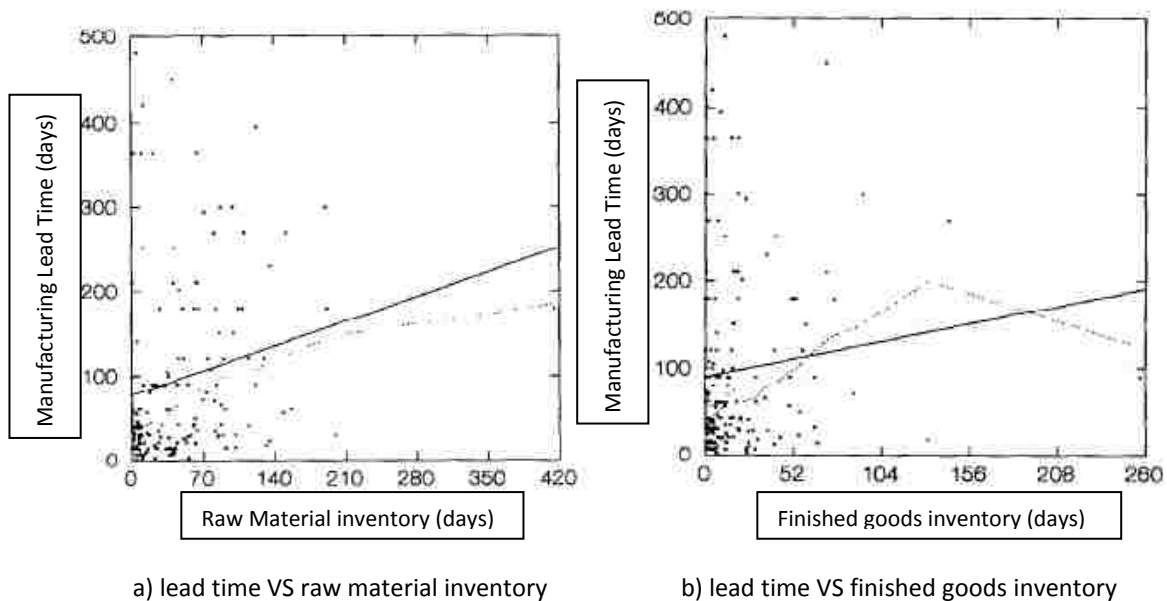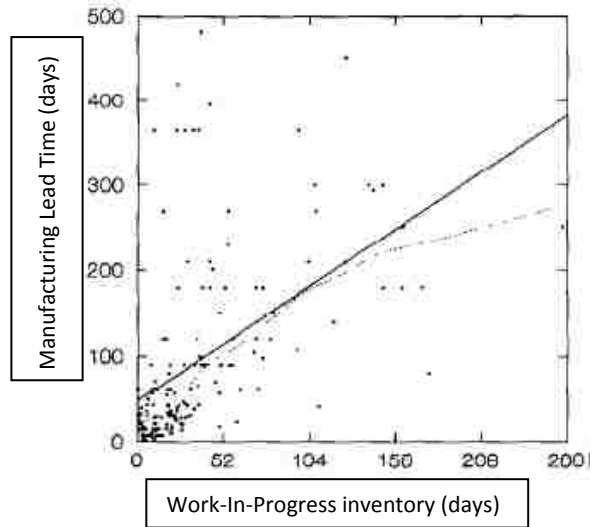
c) lead time VS work in progress inventory

FIGURE 2- 4 THE RELATIONS BETWEEN LEAD TIME AND INVENTORY [13]

2.3.1   PRODUCTION INVENTORY

The production inventory is related to supply chain management or purchasing

management. Just-in-time (JIT) plays an important role in supply chain management, it

helps the company to gain and maintain the competitive advantage. The characteristics of

JIT systems are consistent high quality, small lot size, frequent delivery, short lead time

and close supplier ties. Lead time reduction is one of the major tasks of maintaining the

competitive advantages of JIT production. In the dynamic, competitive environment, lots

of successful companies have considered inventory cost and lead time reduction

simultaneously as key factors for business. Many studies focus on the benefit from

quality improvement or lead time reduction in inventory models only from a single

party's point of view. A dyadic relationship between the vendor and purchaser is

important for just-in-time purchasing model. An integrated inventory model was built by

Jin-Shan Yang and Jason Chao-Hsien Pan to minimize the sum of ordering/setup cost,

holding cost, quality improvement investment and crashing cost by optimizing the order quality, lead time, process quality and number of deliveries [14].

Component part standardization is one of many factors that can reduce the manufacturing lead time. Maskell suggests that increasing commonality can improve material availability and reduces the system complexity. In addition, high commonality makes a larger part of the product structure suitable for repetitive manufacturing, which in turn simplifies the planning and scheduling procedures. The effect of commonality on manufacturing lead time has been tested by Chwen Sheu and John G. Wacker, it showed that the commonality affects both design and manufacturing lead time, see Figure 2-5. The reuse of common parts can reduce the design portion of the new product development cycle. The shortening of design time makes the manufacturing system more responsive to the markets [1].

Note: The top time line represents typical lead time for a new product development cycle; and the bottom time line indicates lead time with commonality.
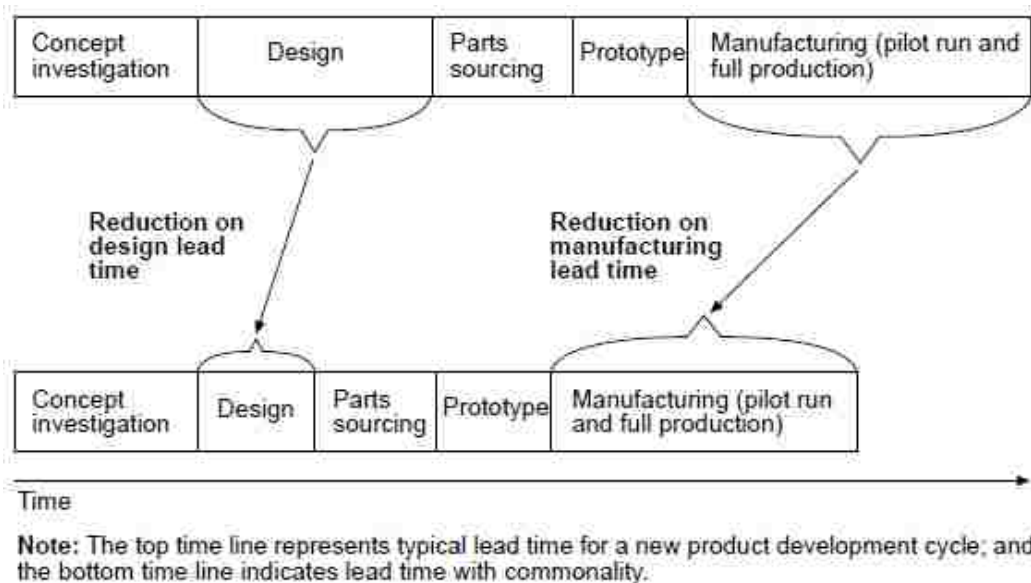
FIGURE 2- 5 THE EFFECTS OF COMMONALITY ON NEW PRODUCT DEVELOPMENT TIME [1]

The performance of a production/inventory system with periodic review and endogenous lead times has been evaluated. The system was single item production/inventory with random period demands. Inventory levels were reviewed periodically and the base-stock policy was used to manage it. Replenishment orders are placed based on the production system which processed the items one at a time, the demands determines the arrival pattern of production orders at the queue. The inventory behavior in influenced by the correlation between demand and lead times, which means a larger demand size leads to long lead time, it takes longer to deplete the inventory. A numerical procedure based on matrix analysis was built to analyze the system and several performances such as lead times, fill rates and safety stock levels were characterized [15].

2.3.2   WORK-IN-PROCESS (WIP) INVENTORY

Work-in-process inventory are the semi-finished goods waiting to be completed in the production process, from the lead time point of view, the less work in process inventory is, shorter the lead time will be. Most production lines would like to keep a minimal level of WIP inventory to save costs and space. However, the random nature of processing, breakdown and repair times can drag down the efficiency of a production line and increase the work-in-process inventory. An important characteristic that can affect the efficiency of a production like is the size of the buffer. A mathematical model for two-station production line has been developed under the assumption that processing time, time to breakdowns and repair time are random and the buffer has finite capacity. The mean and variance of inventory level in, relationship between the first stopping time and buffer size are resulted from the study, see Figure 2-6 [16].

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Time (hour)	$\hat{E}(X(t))$
10	24.8942
20	24.7577
30	25.0724
40	24.8848
50	24.9599
60	24.9682
70	24.9380
80	25.3025
90	25.1137
100	24.9891
110	25.1556
120	25.0780
130	25.1389
140	25.1212
150	24.8241
160	24.7281
170	25.0372
180	25.1649
190	24.9767
200	25.5173

a)   INVENTORY LEVEL OVER TIME [16]
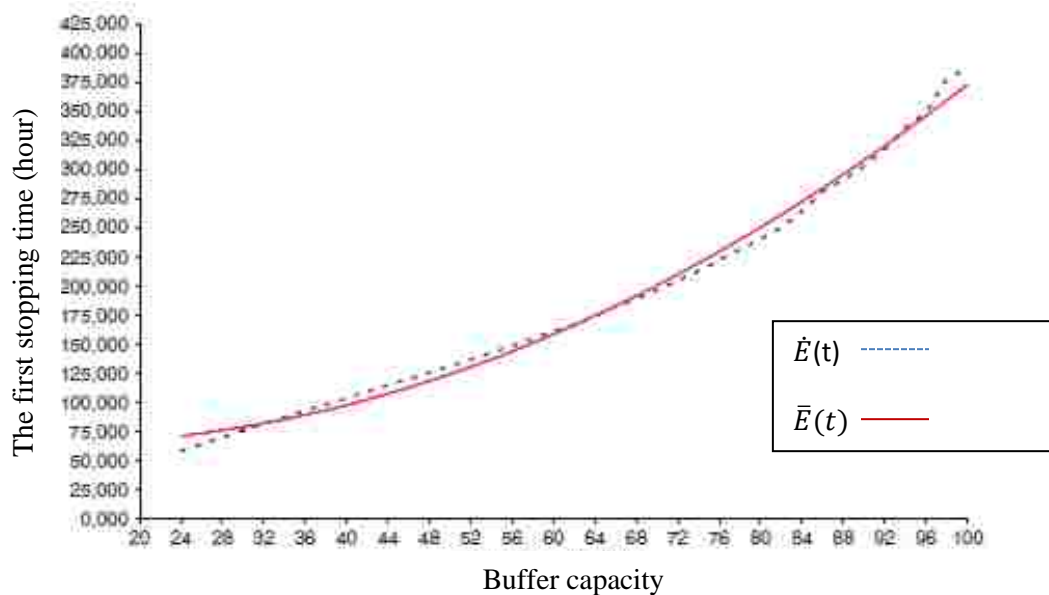
b)   FIRST STOPPING TIME VS BUFFER SIZE

FIGURE 2- 6 INVENTORY LEVEL AND RELATIONSHIP BETWEEN THE FIRST
STOPPING TIME AND BUFFER SIZE [16]

In the design of a production system, the relationship between utilization, range, lead

time and work in progress is very important. The utilization should be high due to the

cost of the available capacity, but it on the other hand gives a negative impact on the lead

time and work in progress. The some relationships for a continuous production system

24

are formulated and tested between average lead time, average range, average work in progress and average utilization for a multi-item system with a dynamic demand. The basic equation is developed from the little law theory. The results showed that the variability of the inventory or of the production load causes a waste of capacity and therefore a reduced utilization and increased lead time [17].

When break down happens for the production line, the WIP has effects on the lead time depending on the inventory. The existence of WIP can relax the repair time. If the capacity of WIP inventory is too more, it will take more storage room and delay the production cycle and brings loss for the company. If the capacity of WIP is too less, it cannot satisfy requirements for production capacity. Therefore there is need to control the WIP dynamically. An intelligent control on WIP inventory based on biological modulation mechanism has been developed, which includes a two-level controller with master controller and secondary controller. The master controller can adjust dynamically the input value of the secondary one according to the real time control error, so the control error can be eliminated quickly and stably. The results showed that the control performance and adaption of the two-level controller were better than that of the general PID controller [18].

2.3.3   FINISHED GOODS INVENTORY

In a complex supply chain system, the products inventory costs make up a significant proportion of total network costs. One way to manage the inventory is to wait for specific orders to arrive before starting to manufacture, which is called make to order (MTO). Alternatively, if the product can be manufactured ahead of time in anticipation of demand and held in inventory, is called make to stock (MTS). If manufacturing times for a

particular product are short and the production network is relatively uncongested, the firm can use a MTO to achieve the desired short lead time while minimizing inventory holding cost. But the manufacturing time is frequently greater than the acceptable delivery lead time for a product, so firms must start manufacturing in anticipation of time to meet customer demand in an acceptable amount of time. Study showed that combined MTO-MTS systems perform more than 50% better than pure MTO or MTS systems, and MTS system works better for more congested systems and MTO performs better as the congestion level in the supply chain decreases [19].

Delayed differentiation or postponement is often used to mitigate conflicts between product diversity and inventory cost savings. Constrained finishing capacities and noticeable finishing lead times affects the manufacturers practicing postponement. So inventories are still needed for finished products. Base-stock inventory models with or without demand forecasting had been studied and a computationally efficient method to set optimal inventory targets for finished products under capacitated postponement has been provided. It showed that inventory-saving benefit vanishes quickly after the capacity reaches a certain level. Finishing capacities usually urge manufacturers to build ahead according to demand forecast, when capacity limitation is severe, intuitions guide producers to build to forecast even more than finishing lead times ahead. Research indicated that these intuitions may be invalid and build to forecast more than finishing lead times head may not be a good practice [20].

The joint management of finished goods inventory and demand for a product in a make to stock production had been studied. The production process is random with controllable mean rate and the demand process is stochastic with changeable mean rate depending on

the sale price. The management issue is to dynamically adjust the production rate and the sale price to maximize the long run total discounted profit. The study showed two conclusions: 1) the optimal management of the finished goods inventory follows a base stock policy: when the inventory is above a certain level, the production will be stopped, otherwise the maximum production rate is used to raise the inventory to the base stock level; 2) the optimal management of the demand process follows a price switch threshold policy: when the inventory is above the threshold, the sale price will be lower to sell more product and below the threshold the high price will be chosen to reduce the demand. The algorithm of computing the base stock level and price switch threshold had been developed [21].

2.4 FLEXIBILITY

Flexibility is used as attribute of various types of systems. For engineering, it means the ability to respond to potential internal and external changes affecting its value delivery.

The literature on manufacturing flexibility discusses several types of flexibility. The terms and definition used by different researchers may not be consistent, the same terms often being used in different ways [22].

Although there is much literature related to flexible manufacturing, the exact mechanism that enables flexibility to reduce the lead time is not fully understood. The study is to know how flexibility can be employed in a proactive manner to reduce the manufacturing lead time and to understand the underlying mechanisms. The results indicated that the sequencing flexibility has a significant effect on the lead time performance of

manufacturing system and the effect of the flexibility varies under different conditions of load balancing [22].

There are three important flexibility types, transformation flexibility, sequencing flexibility and product flexibility. Their impact on the lead time had been studied through simulation models, and studies showed that among the three, product flexibility has the greatest influence on lead time, followed by transformation flexibility and sequencing flexibility. The reason for inferior performance of sequencing flexibility is the reduction of dynamic flexibility levels compared to its static flexibility level and for superior performance of product flexibility is found to be the lower movement of products within the manufacturing system, see Figure 2-7 [23].
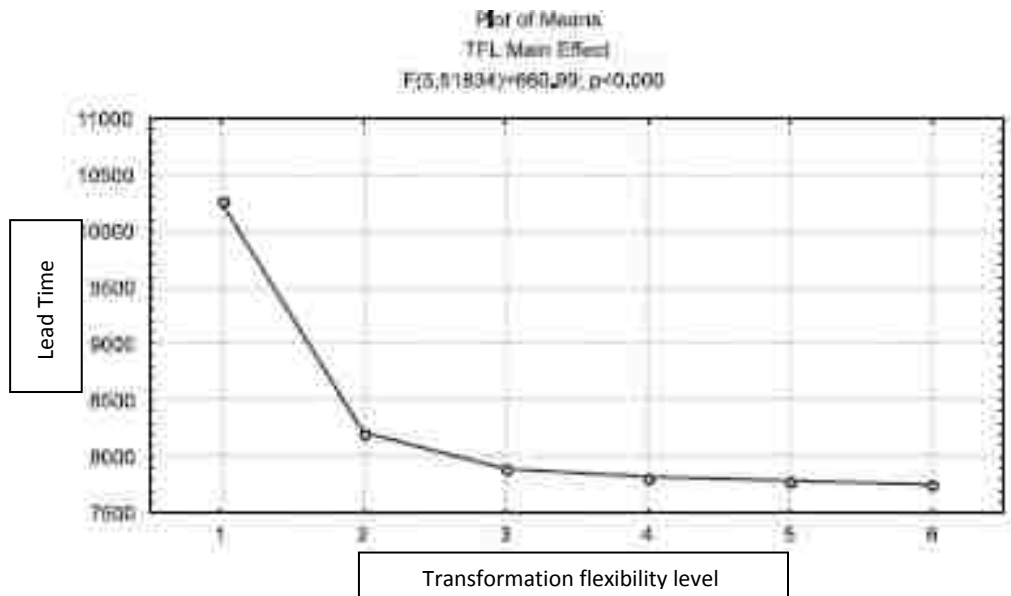
a)   LEAD TIME REDUCTION VS TRANSFORMATION FLEXIBILITY LEVEL [23]

Plot of Means:
SFL Main Effect
$F_{(5, 51634)} = 2.13, p < .0590$

Lead Time

Sequence flexibility level
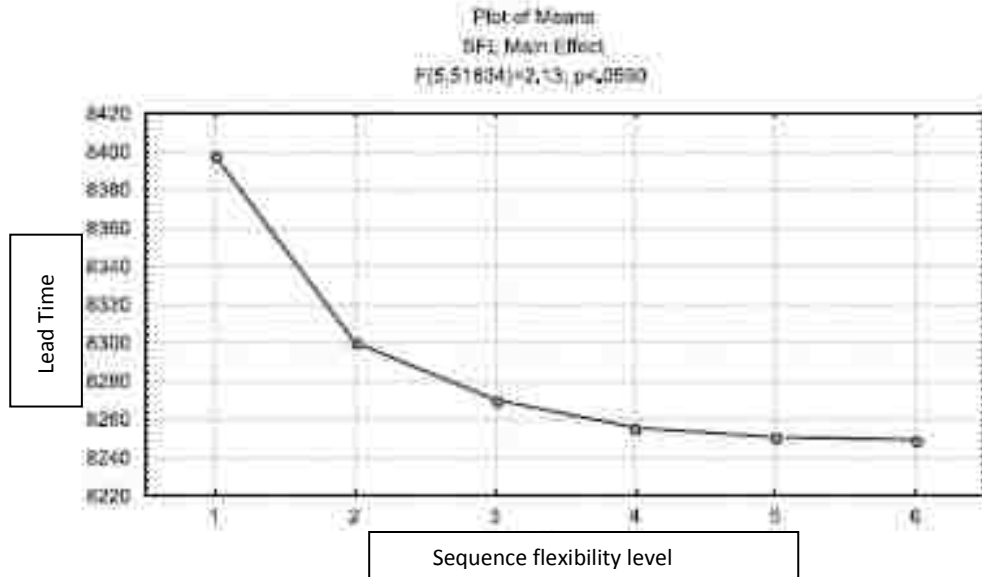
b) LEAD TIME REDUCTION VS SEQUENCE FLEXIBILITY LEVEL [23]

Plot of Means:
PFL Main Effect
$F_{(5, 12954)} = 770.40, p < 0.000$

Lead Time

Product flexibility level
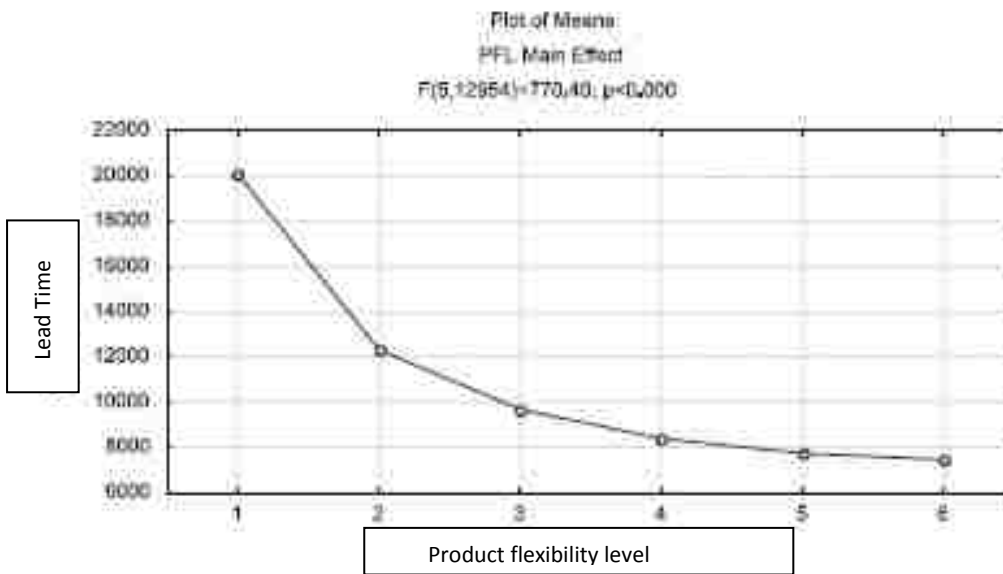
c) LEAD TIME REDUCTION VS PRODUCT FLEXIBILITY LEVEL [23]

FIGURE 2- 7 RELATIONS BETWEEN LEAD TIME AND DIFFERENT FLEXIBILITY LEVEL

Manufacturing process plans are usually defined by the sequence of operations a job has

to go through to transform raw materials to a finished product. Restricting process plans

to be a sequence of operation often over-constraints the process plan beyond what

processing technology would require. Reducing the strict ordering of operations in

conventional process plans can result in substantial reductions of lead time in manufacturing. Machine scheduling can optimize simultaneously the job schedule and order of operations in each job. However, static optimization has well-known problems dealing with process variability, schedule nervousness when the program conditions are disturbed by addition of a new job or machine downtime, etc. and the effect of a planning horizon. The new study showed that reductions of queuing time of up to 80% can be achieved by delaying ordering decisions until the job is already in the shop even in the absence of global optimization by shape deposition manufacturing (SDM) [24].

Most of the previous literature on production flexibility is centered on the flexibility of manufacturing system. However, the manufacturing system is just one of the several key components of a supply chain. A supply chain network involves lots of activities within individual facilities that link material suppliers, manufacturing factories, distributors, warehouses, retailers and customers. So the flexibility study extends from the intra-organisational flexibilities to the inter-organisational flexibilities. Order quantity flexibility and lead time flexibility had been clarified as the two most common changes within the supply chains. Order quantity flexibility refers to the ability to provide proper order quantity for customer needs. Lead time flexibility allows customers to set the order due date depending on their needs. A simulation model was built to evaluate the performance on different flexibility levels of a supply chain. The results showed that when unit holding cost dominates the total costs, flexibility of order quantity may provide significant cost savings. The service level mush be an important consideration and should be kept at least at a certain level to keep customers' loyalty [25].

2.5 VALUE STREAM MAPPING

Value stream mapping is a lean manufacturing technique used to analyze and design the

flow of materials and information required in the manufacturing process.   All value

produced by an organization is the end result of a complex process, a series of actions

that lean thinker call a value steam. And moreover, the customer, no matter internal or

external, is interested only in the value flowing to them, not in the weighted average of an

organization's effort for all products or in value flowing to other customers. So it is

surprising how hard it will be for managers to focus on the value stream for each product

for each customer to improve it for the benefit both of the customer and the company.

The first step of value stream mapping is to identify a product family. This is the group of

similar items that proceed through the same basic procedures and machines in the

organization. Mapping will be greatly simplified and the benefits will be maximized if

careful thought is given at the family identification stage. The second step is to determine

the current problem with the value steam for product from both the customer and

organization standpoint [26]. The current value stream will be mapped and potential

improvements will be analyzed, in the future state mapping, all the modifications to the

current map will show.

Lean concept has been applied across many companies which offer value and eliminate

wastes. Value stream mapping (VSM) is one of the fundamental tools in lean

manufacturing that records the material and information flow for a product family to

reduce waste at discrete event production process. A reduction of production lead time

when the Takt time is much higher than the highest station's cycle time was studied. The

evaluation of present routing event using current state map and future state was created

by answering eight standard questions. A simulation model was used to help verify the results from the future state map [27].

An methodical approach was introduced which connects value steam mapping and methods-time measurement and provide new advantages to reducing lead time and increasing productivity based on lead principles and standardised process. The mutually aligned design and improvement of assembly and logistic processed considered the workplace, their surroundings and the supply areas as well as the overall value stream chain. The principles, benefits and the procedure of application were described [28].

Lean manufacturing has been proved to be an effective management method for improving business in a competitive market by eliminating non-value added waste and improving in process operations. Value stream mapping is an important tool used to identify the opportunities for various lean techniques. Research was performed focusing on the description of a model that is developed to contrast the before and after scenarios to obtain the various benefits such as reduced production lead time, lower work in process inventory and different utilisation of the workforce. In a case study, the current manufacturing system had been compared with the pull system (Kanban), which showed a 50.5% reduction of lead time in the future state value mapping of the crank case and the number of operators involved in processing of crank case had also been reduced [29].

Value stream mapping is a lean manufacturing technique and it had been used to support and implement the lean approach. VSM is different than conventional recording techniques, it captures the information of individual stations about cycle time, up time or utilization of resources, set up time or change over time, work in process inventory, man

power requirement and the information flow from raw material to finish goods. All the value adding and non-value adding activities are covered by it. A review and classification of literature has been done and it showed the development of this technique. A very important part of the value stream mapping process is documenting the relationships between the manufacturing process and the controls used to manage these processes, such as production scheduling and production information. Unlike most process mapping recording only the basic product flow, the VSM also documents the flow of information within the system, where the materials are stored and what triggers the movement of material from one process to the next are key pieces of information. From the review, the literature has been classified into to four categories: conceptual work, empirical/modeling work, case studies, survey articles and then 23 attributes of value steam mapping were identified from the literature. Based on the review, the following areas need further study: 1) The cost- benefit analysis of proposed changes made in future state map; 2) More work needs to be done in the vendor management area; 3) Effect of changes done in current state during VSM has not been seen yet on human factor; 4) Comparison of this technique with other waste reduction techniques can also be done [30].

From the literature review, many scheduling and inventory models have been studied and the relationships between lead time and flexibility are relevant in different ways. However, none of them apply to the problem in the project since the production flow is not continuous. There are three shifts in the plant and there is only one shift at the VCC, and there is a third party entity (the WC) which also impacts the timing and distribution of the vehicle options. Studies that correlate to this type of production are not readily

available. The Value Stream Mapping is a useful tool to analyse the production process and it will be used in this project. The lead time reduction cost control plans will be based on the local investigation and simulations in the project. In the next chapter, the process details will be introduced and the simulation model will be established.

CHAPTER 3

METHODOLOGIES AND SIMULATION MODEL BUILD UP

3.1 PROCESS ANALYSIS AND VALUE STREAM MAPPING

In the automotive industry, there have been significant changes in the manufacturing

domain. Over the last century, craftsman based workshops have been replaced by highly

standardized volume production approaches. Many technologies (such as lean tools) have

been used to improve process efficiency and reduce the lead time. In regards to the global

competition in the automotive sector, technologies can be invented and shared by

manufacturers, so production management grows into a vital factor compared to past

century. For this project study, the up-fitting lead time reduction is an important part of

production management which is incorporated in two major aspects of manufacturing i.e.

production resource arrangement and cost control management. In accordance to the case

study, there are three entities involved in the up-fitting process: the assembly plant, the

third party transportation company, referred as WC, and the up-fitter entity, referred as

VCC.

3.1.1   JOB DESCRIPTION IN THE PLANT

The car assembly plant has a production capacity of about 1500 cars/day over three

regulated shifts. Each shift has a scheduled procedure in which cars go through a set of

operations for production purposes which are: body shop, painting and assembly. In each

of these stages, various sub-tasks/operations are performed on the car in a prescribed

sequence so as to complete the production process. Firstly, the body and frame of the car

is fabricated at the body shop, which is called the 'body in white', as this stage includes a

rust proofing process white coat. Once the frame parts are pieced together in the body

shop, the car body is sent to the painting shop by use of conveyors, where the interior and

exterior of the car is cleaned and painted. Finally, the car body is transported to the

assembly shop where various other parts such as chassis, engine, tires, doors, trimming

and other remaining painting-free parts are assembled. The above mentioned processes

are followed for each and every vehicle present on the production line. Once the cars

come off the assembly line, they are shipped to a third party transportation company and

distributed to different destinations from there. For the options studied in this case, the

vehicles will be sent to an up-fitter entity for further customization in accordance to

individual order via WC. Figure 3-1 illustrates an overview of the vehicle production

process in the plant [31]. Since all these vehicles which require up-fitter options are

evenly spread among regular vehicles in the production line, the production type is not

batch or continuous. The production scheduling is hard to change as explained in the

problem statement, which remains a big constraint to the project. Hence, the main focus

of this case study is to analyze and eliminate or reduce the time waste for the up-fitting

process and the transportation between plant and VCC, to identify the non-value-added

activities that increase costs and time.

FIGURE 3- 1 THE VEHICLE ASSEMBLY PROCESS AND LEAD TIME IN PLANT

3.1.2   JOB DESCRIPTION AT THE VCC

The process at the VCC is the main focus of the project study, here all up-fitting

processes are studied and analyzed, not only for the purpose of optimization under

current production situation but also for the cost/ benefit evaluation of the entire up-

fitting program . If the presented solution is worth considering, outsourcing should be

adopted by the VCC so that minimum lead time and cost solutions are applied; if the

presented solution is not worth considering, suggestions to bring the work back to plant

will be made to reduce the process lead time. As mentioned before, there are four

different up-fitters processes in this case study, each of the processes cars are pulled in

from the VCC parking yard and positioned at the stalls for the work to be completed, followed by final inspection. Job descriptions are explained in detail as follows:

For option A, the total time to perform operations is about 6 minutes. Firstly, the production code needs to be confirmed and the worker needs to make sure that the car is in a good condition to be worked on. In case of severe weather conditions such as snow or rain, some preparation work needs to be undertaken before performing further operations. The next step involves the car to be stationed on the installation station, where in it will follow the following procedures:

a) Move the driver and passenger seats fully forward and open sliding doors and hatch.

b) Remove the scuff plates on the floor, under the left and right sliding doors and set aside.

c) Remove the rear scuff plate as indicated in Figure 3-2 [32].

FIGURE 3- 2 REMOVE THE REAR SCUFF PLATE

d) Install two rivet-nuts as the base to fasten the option A, see Figure 3-3 [32].

FIGURE 3- 3 INSTALL TWO RIVET-NUTS

e) Place the foam covers over left and right tail lamp assemblies and lift-gate sill

to prevent scratches when insert the floor into the cabin, see Figure 3-4 [32].

FIGURE 3- 4 FOAM COVER

f) Get option A floor using ergonomic lift cart, locate three lift pins in center

fastening points of load floor and lock lift pins. Raise load floor about 10 cm to

clear lock points on rack and pull load floor out of rack. Push load floor to the

back of the van, lower the load floor until the boom strut unloads, and release

the strut clamp. Push the floor into the van so that the six fastening holes on the

front of the option A floor align with the carpet studs behind the front seats.

FIGURE 3- 5 LIFT CART AND FLOOR GRASPING

g) Lower the floor until the lift pin safety lock is disengaged. Adjust the floor until it is located to the six carpet studs, three second row seat bracket studs and the two rivet nuts on the lift gate sill. Release the lift pins, raise the boom, and withdraw the lift cart and boom from the van.

h) Use the impact guns to fasten the floor onto the frame. Run the nuts until the gun stops pulsing, which means the torque is achieved, see Figure 3-6.

FIGURE 3- 6 FASTEN THE NUTS IN

i) Get the left and right sliding door floor extension panel and locate to the fastening points on the load floor. Peel back the white protective film on the extension panels to allow the rivets to be set without capturing the film.

FIGURE 3- 7 INSTALL THE SIDE PANELS

j) Reinstall the left and right sliding door scuff plates, reinstall the lift gate sill scuff plate. Fill out the work summary tracking sheet and drive the van to inspection station.

For Option B, the total time needed to perform all operations is about 25 minutes. Here, the task is to install the device under the front passenger seat and connect it to the battery which involves various dissection and bending operations. The preparation work is similar to that of option A and the procedures are as follows:

a) Dissect the console from the car, find the power supply circuit to the car charger, and replace the two-end interface with a three-branch interface.

b) Connect the wiring to the branch and insert it through front cavity of the console, fish it through underneath of the carpet of the front passenger seat and make sure there is enough length for the Option B receiver to connect.

c) Remove the front door side panel, move the front passenger seat fully backward and drill four screw holes under the front seat for the base bracket. Fix the bracket on top of the holes with electrical screw driver.

d) Connect the Option B receive to the branch and get power, fasten the Option B receiver on the bracket.

e) Turn on the power of the car and check if the device works.

f) Reinstall the console back, put the front door side panel back in. put the sticker with Option B sign on the front windows. Fill out the form and drive the car to inspection station.

For Option C, the production volume is very low as compared to the other options. The total time needed to finish all operations for Option C is generally 25 minutes. The preparation work is similar to option A and Option B. Once the vehicle is driven on to assembly station, the following procedures are followed by the operator:

a) Open the front hood and unplug the battery, this is to avoid circuit shorting out during the operations.

b) Wrap the hoses to make more room for the protection cover to fit in.

c) Put the protection cover in and wrap it around the alarm, the shape is made similar to the alarm and it has steel cover to protect the alarm cable to be cut off.

d) Fasten the cover with screws.

e) Use a pop gun to insert the protector cover for the alarm needle.

f) Put the sticker with 'Alarm' sign on the front window, a template is used to make sure there are no bubbles.

For option D, which is the most time consuming option among all the four options, the rear beam has to be changed and the wiring hardness needs to be fixed underneath the car body. The whole process takes about 45 minutes to finish. A step by step orientation to the process is as follows:

a) Drive the vehicle to hoist station, pop hood and disconnect negative battery cable, set hoist arm and lift van to about 30 cm.

b) Use the cordless Makita net runner to remove the six 10 mm hex head screws that retain the tail lamps and rear facia. Set aside all 6 fasteners, to be reinstalled later. Set the facia and the two tail lamp assemblies aside.

c) Use the pry tool to remove the four push pins retaining the four lower facia hold downs to the facia hangers. Use the stubby screw driver and pry tool to remove the three fender anchor pins on both rear wheel wells.

d) Remove the three push pin securing the plastic facia support strip. Discard the three push pins and place the plastic facia support strip aside to be reinstalled later in the process. Raise the van to 1.8m and with the Cleco right angle nut runner, remove the bolt holding the rear muffler hanger. Use the Cleco impact gun to remove the two 15mm and four 18mm bolts attaching the metal bumper to the frame rails. Discard all six bolts and the metal bumper.

e) Slide the pre-assembled hitch receiver assembly into the frame rails. Insert the handle nuts into the rail extensions and align the holes in the rail extensions to those in the frame rails and handle nuts. Place the mounting plate over the two rear frame rail holes and hand start the bolts and washers supplied in the kit. Hand start the bolt and washer to the third frame rail hole. Complete on both

sides of the van. Use the Cleco impact gun, run all six 5/8''bots down until the

gun shuts off automatically. Run all four 19mm bolts down until the impact guns

shuts off automatically. Using the Cleco right angle nut runner, reinstall the

13mm bolt holding the rear muffler hanger, see Figure 3-8.

FIGURE 3- 8 SLIDE THE HITCH RECEIVER INTO THE FRAME RAILS

f) With a knife, carefully cut 17 cm off each end of the plastic facia support strip.

   Align the plastic facia support strip to the receiver hitch and secure with the two

   push pins supplied in the kit.

g) Lay out the 7-way wire harness on the floor and plug the connector labeled

   'right' into the right body connector. Plug the connector labeled 'left' into the

   left body connector. Use the supplied zip to tie fasten the tow harness onto the

   front side of the facia hangers. Trim excess off the zip ties using the side cutter.

   Use the provided screws, install the 7-way trailer tow outlet to the hitch. Connect

   the harness connector to the back of the 7-way trailer tow outlet, route the wiring

   harness along the parking brake cable towards the engine compartment and

fasten with zip ties. Route the harness on the outside of the front cradle mount and follow the brake lines up into the top of the engine compartment. Zip tie where necessary. Route the wire harness between the brake booster and shock tower. Zip tie where necessary. Connect the wiring with the battery in the engine compartment. See Figure 3-9.

FIGURE 3- 9 WIRING HARNESS FOR THE OPTION D

h) Take the rear facia to the cutting die and locate the two center lower facia hold downs to the dowels on the cutting die. Pull down sharply on the actuator handle until the cut in the facia is completed. Then take the trimmed facia back to the van and install the black rubber trim piece around the opening. Trim any excess so that the rubber trim piece aligns with the bottom of the facia cut out. See Figure 3-10.

FIGURE 3- 10 FASCIA CUTTING

    i)   Reinstall the facia to the van and place the receiver cover to the hitch tube. Fill out the form for work summary and drive to car to inspection station.

The operations for each option (A, B, C & D) for the up-fitters have been described in the above stated paragraphs, showing that the final stage (inspection stage) is common for all of the options. At the inspection stage, operators check if there is any damage to the car body or there is any kind presence of any malfunctions of major components due to the operations performed at the up-fitter stations. Next, the operator(s) confirm the VIN (Vehicle Identification Number) number and print out the stage form (from 'work in process' to 'ready for shipping') for the car. Once all the procedures are finished, the operator(s) will drive the vehicle to the parking yard and bring another vehicle in to follow similar operations. See Figure 3-11.

FIGURE 3- 11 INSPECTION STATION

3.1.3 JOB DESCRIPTION AT THE WC

WC is the transportation company that transports / ships car between the assembly plant and VCC. This facility is in charge of distribution of all the vehicles that come off the production line every day. A better understanding of WC functions can be illustrated by use of a map. The transportation company connects the exit of the assembly line to the up fitter facility. When there is a completed vehicle coming off the line, the driver hands over the vehicle to the inspection doom. Once the vehicle gets through the inspection, it is driven into the WC parking yard. At this stage, if a problem is detected, the vehicle is driven back to the assembly plant for further repair work before any further operations can be performed. The vehicles stay in the WC yard for half a day (average) and are then driven over to VCC for further up fitting operations. The driving distance between WC and VCC is only 100 meters, which is one of the flaws of the system pointed out through this case study. An alternative solution to deliver vehicles to VCC directly from plant will be suggested value stream mapping analysis. See Figure 3-12.
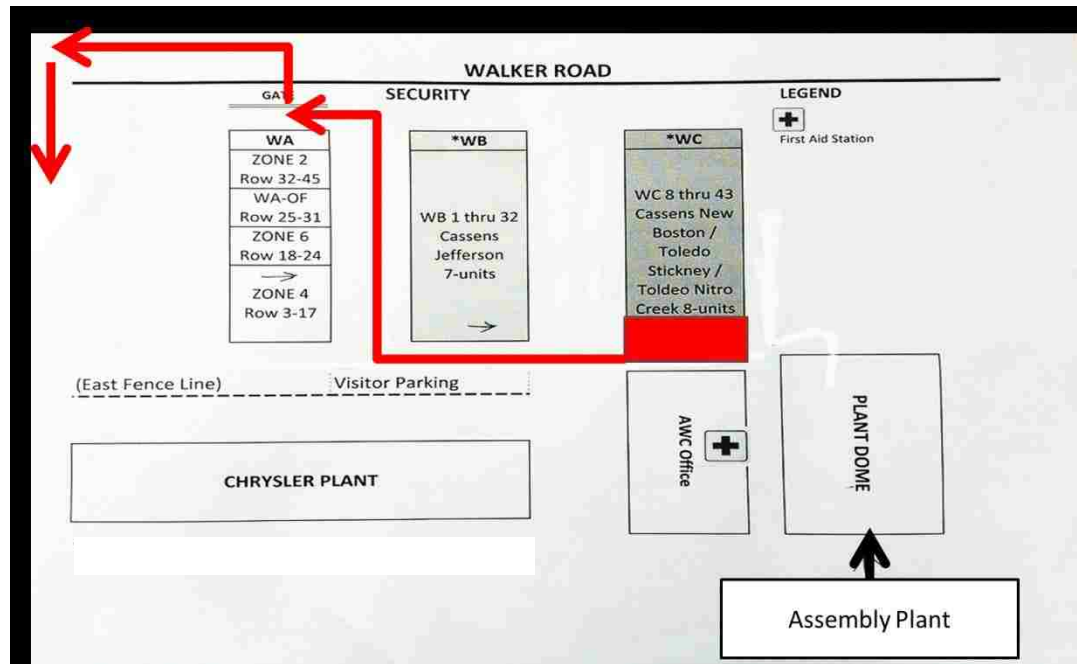
FIGURE 3- 12 LAYOUT OF WC AND CURRENT TRANSPORTATION ROUTE FROM PLANT TO VCC

3.1.4   VALUE STREAM MAPPINGS (VSM) FOR THE PROCESS

After all the processes have been recognized, a value stream mapping methodology can be applied to analyze potential problems / flaws in the system. Firstly, a value stream mapping of the complete process between plant and VCC (from high level) is drawn. See Figure 3-13 below.

From the VSM, a better understanding of the process time and inventory time for each stage is achieved. In the plant, each stage is standardized and the processing time presumed. There can be many issues during production that could lead to a breakdown, the major interest of this case study is in regards to the up-fitting process. We can see that inside the plant, it takes 26.1 hours to have a completed vehicle from gateline to final inspection. It takes another 12 hours in average for WC to bring the cars to VCC and 24 hours for the VCC to finish the works. The uptime at plant and WC is 24 hours and 5

days per week, which mean there are three shifts on each work day. The uptime at the VCC is only 33%, 5 days a week, which means there is only one shift at VCC. So there will be units stock at the WC buffer inventory, exhibiting lack of production synchronization. Hence, the main objective/ goal of this case study is to find solutions to synchronize the production process. There are several ways to do so, first, the VCC can add up more shifts, three shifts is the Scenario 3, but due to limited workloads, three shifts are not preferable. As, adding more shifts will cause other cost constraints, which is never the goal of successful business. So adding two shifts will be studied later in the simulation. The other way is to batch the production into one shift in the plant and ideally synchronize the production with VCC. But due to the scheduling difficulties, the eventual loss is unacceptable. Finally the idea to bring the work back to plant will be taken in consideration. Based on the above stated analysis, the future state map is also provided in Figure 3-14.
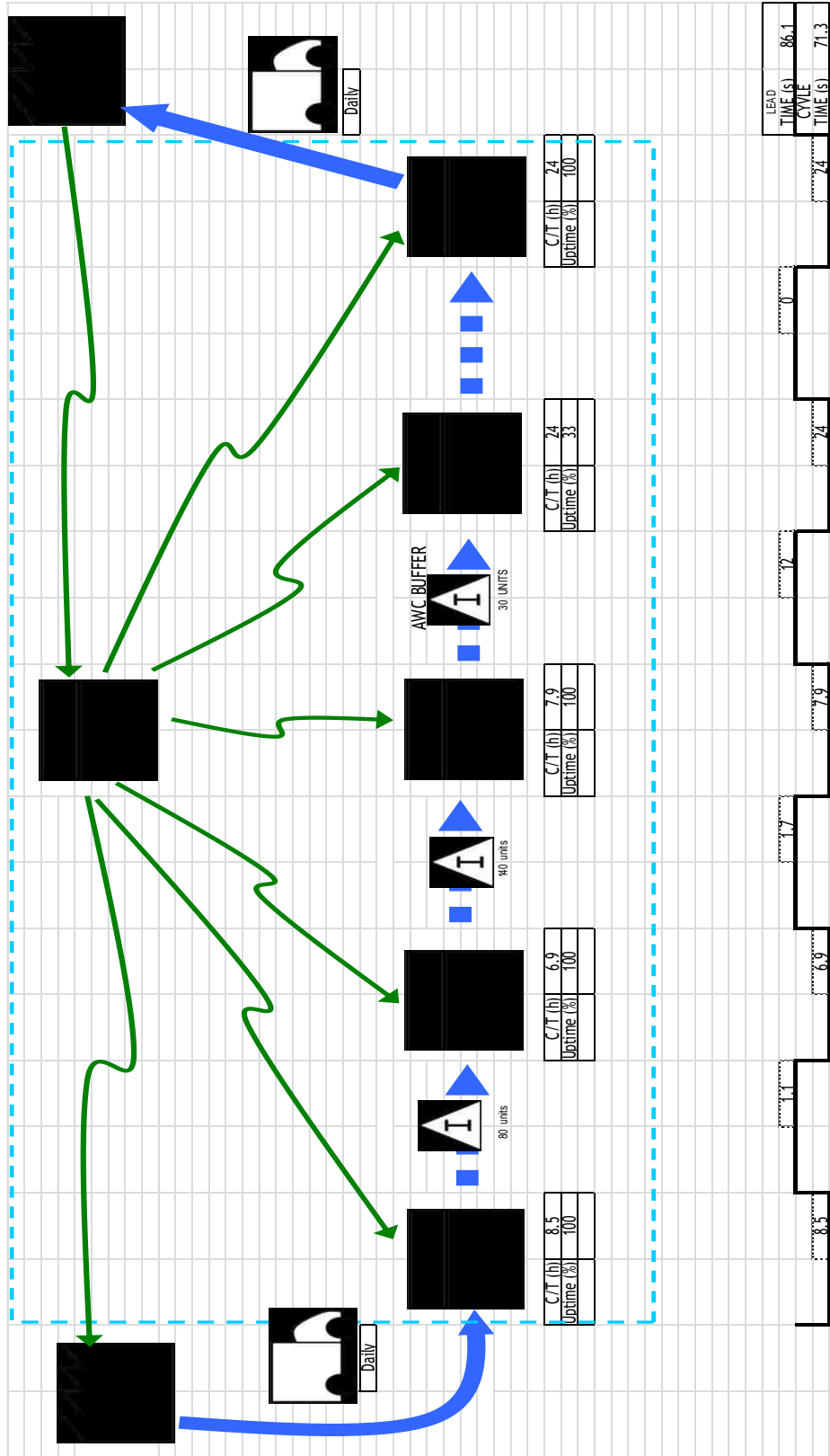
FIGURE 3- 13 CURRENT STATE VALUE STREAM MAPPING FOR THE PROCESS BETWEEN PLANT AND VCC

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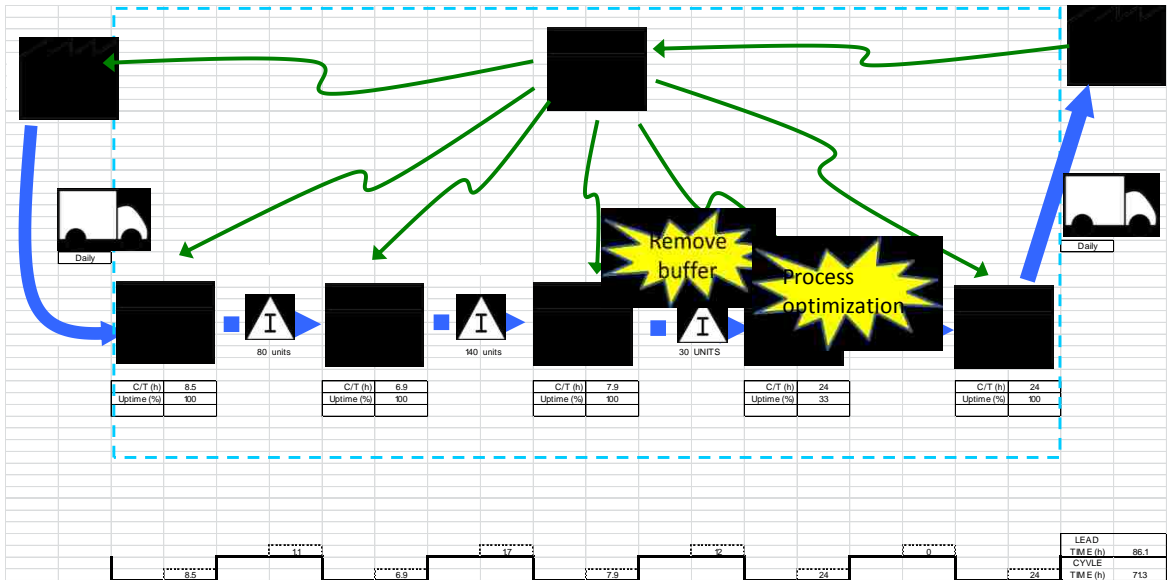
FIGURE 3- 14 FUTURE STATE VSM FROM PLANT TO VCC

In regards to the future state VSM (plant to VCC), it is recommended that the buffer at WC should be removed, as it will saves approximately 12 hours of waiting time for vehicles which takes about 20% of the overall process time for up-fitter vehicles. This way (by using shortcuts) helps to eliminate the time to drive the vehicles from plant to VCC, the layout of the route is shown below in Figure 3-15.
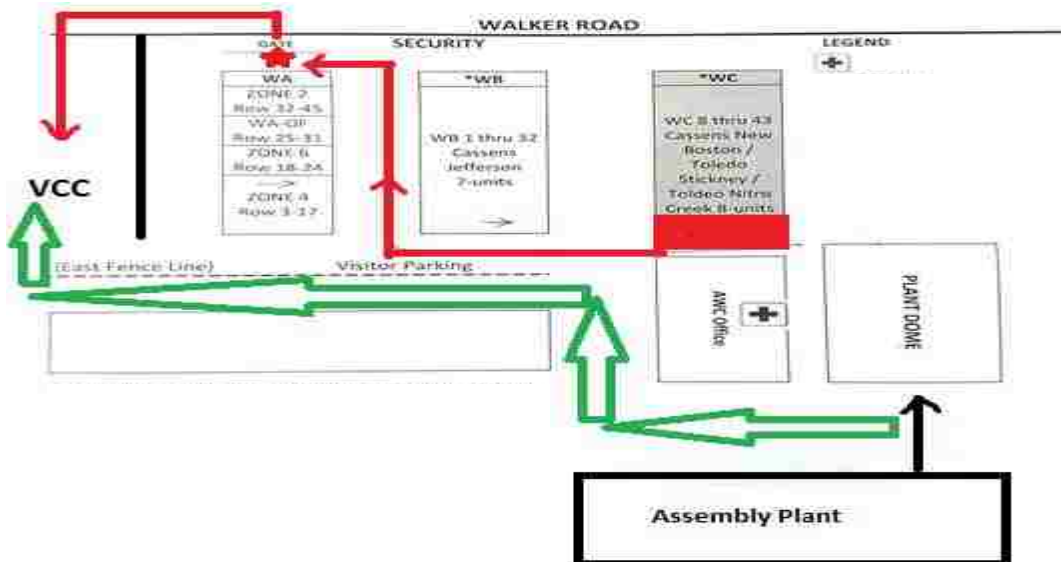
FIGURE 3- 15 SUGGESTED ROUTE FOR TRANSPORTATION BETWEEN PLANT AND VCC

From the Figure 3-15, it can be seen that instead of going through WC, the vehicles now follow the green arrows (new path) from plant to VCC directly. There are two issues that should be taken into consideration while choosing the path: the first one is the return cycle of the driver after delivering the vehicles to VCC. Since the drivers from plant will not take a completed vehicle from VCC and deliver it to next destination (WC's job), they have to return to the plant after delivery. The distance between VCC and plant assembly exit is about 150 m, which is a long walking distance and promotes the non-value-added movements for workers. The second issue is about the status change, during the building process, the vehicle will go through several different stages with a status tracking label, for example F status means in painting process and G means in assembly. For every change of location or building process, the build status will be checked and changed to track every single vehicle in process. If the vehicles are driven directly from plant to VCC, there will be a loss of status; on the other hand, if the vehicles go through WC, the inspection workers will scan, check and change the status of the vehicles. So considering the above mentioned constraints, the best option to eliminate the waiting loss at WC parking yard is to allow WC drivers to use the shortcut between plant and VCC. The building status will be updated in time and the return cycle of the worker (driver) would not be a big issue. The following Figure 3- 16 shows the proposed way of transportation in yellow arrows. Once the inspection and status change takes place in the dome and there are no build loss concerns. The drivers from WC can go to VCC and pick up a completed vehicle to go to another distribution destination, the working force will be fully utilized. Also, another advantage is that the proposed solution is better than the current bold solid line transportation and the dashed line route, during the time that VCC

is not working, the cars can still stay in the yard of WC and can be moved over to VCC the next day without hitting the road. The advantage of not going on the road will be shown in the process optimization at VCC.
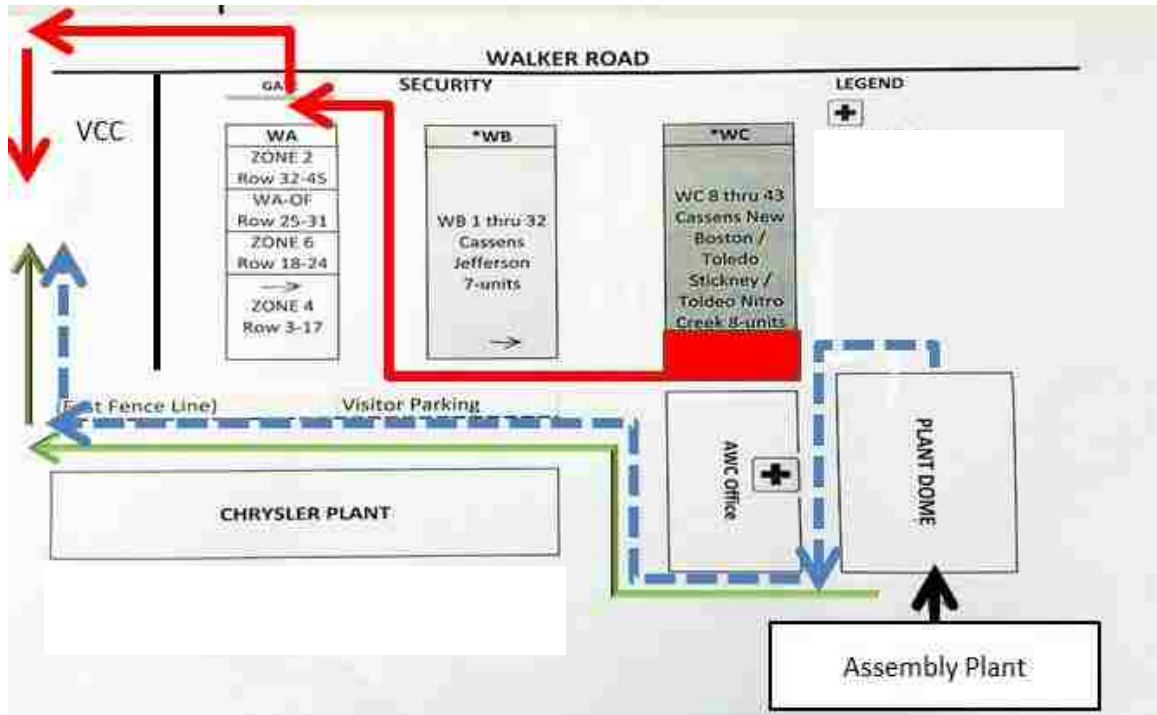
FIGURE 3- 16 PROPOSED TRANSPORTATION ROUTE FROM PLANT TO VCC WITH YELLOW ARROWS

Another problem detected from VSM in Figure 3-13 is the production at VCC, which needs to be optimised. In current situation, the facility works only for one shift per day compared to 24 hours 'back to back' production in plant and distribution work at WC. There are two shifts in which no vehicles are processed at VCC. The work load that comes from three shifts in the plant must be finished in one shift at VCC. In case of bad weather condition blocking the drive way between parking lots, or if there is part shortage at VCC, there will be no time to adjust to such conditions, it would have to wait until the problems get solved or just wait until next working day. Therefore, the system is

not flexible enough, so the up-fitting process must be investigated in details to find out

the optimized approach to tackle such a situation. The VSM of VCC is shown below in

Figure 3-9.

C/T (min) 0
Uptime (%) 100%
Shifts 0-24

C/T (min) 5
Uptime (%) 30%
Shifts 6:00-14:00

8 units

C/T (min) 5
Uptime (%) 30%
Shifts 6:00-14:00

C/T (min) 45
Uptime (%) 30%
Shifts 6:00-14:00

C/T (min) 20
Uptime (%) 30%
Shifts 6:00-14:00

C/T (min) 35
Uptime (%) 30%
Shifts 6:00-14:00

6 units

5 units

1 unit

50 units

put orde

| LEAD TIME (min) | 1096 |
| CYVLE TIME (min) | 51 |

0   5   40   45   45   1   960   0
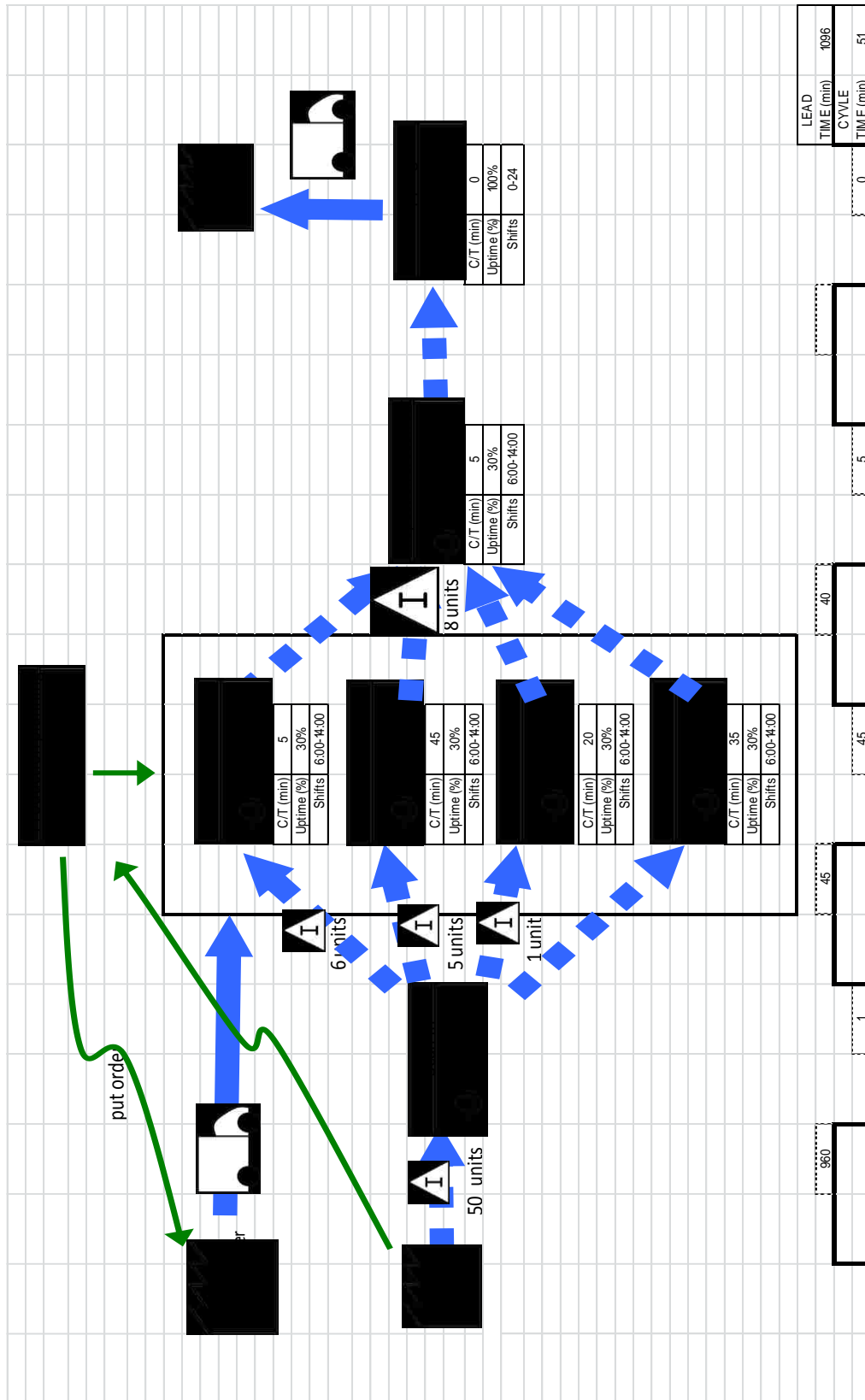
FIGURE 3- 17 CURRENT STATE VSM OF VCC

From the map, the process time for each step can be seen along with the equipment

numbers and worker numbers. Based on the observations, operation time for each stage

has the potentials to improve. Since the production process is not a continuous flow, the

time savings should be promoted in the workshop where the operators can control the

time by themselves. The workers get assigned a certain amount of workload every day,

whenever the number of jobs is reached, they stop working. Their actual working time

usually is less than required. The inventory is another problem. Since the VCC has no

control over the up-fitting volumes, the inventory has to be kept in a high level to avoid

part shortage when the production volume hits the peak. But according to World Class

Manufacturing requirements, the parts inventory has to be kept in a low level in order to

improve efficiency. As we can see from the current map, there is no communication

between the customer and VCC. The plant decides how many cars the VCC will process.

However, the forecasting number from the plant is not precise enough for the VCC to

place the right order amounts. This kind of unbalanced communication will cause an

unstable production at the VCC and it has to be improved. So the communication with

plant is quite important. Real time information can help VCC make the right ordering

decisions and make the just in time inventory delivery available. And about the up-fitting

process for each type, there is waste that can be saved on option D. Currently, as a

standard work procedure, the regular back steel beam is taken off before the strengthened

steel beam is slid into the frame rails. It is a waste in time and material since the regular

beam will be abandoned and it is duplication of works by installing the beam twice. The

only reason that the regular beam is installed in the plant is safety issues. WC drivers

have to drive on the road to bring the cars to VCC (Figure 3-12), according to the

Canadian law, a running car on the road must contain all the major parts for safety

concerns. In an event of an accident involving an incomplete vehicle, the company is held

responsible for that. By changing the transportation route, the vehicles do not have to go

on the road. This allows for the transportation processes to be considered as inbound

movement, which allows for the vehicles to be moved under an uncompleted condition.

Based on the time study conducted, this major change can save at least 15% of cycle time

for the option D process. After conducting all the relevant analysis, the major Kaizens for

VCC production process can be identified in the future state map, see Figure 3-18.
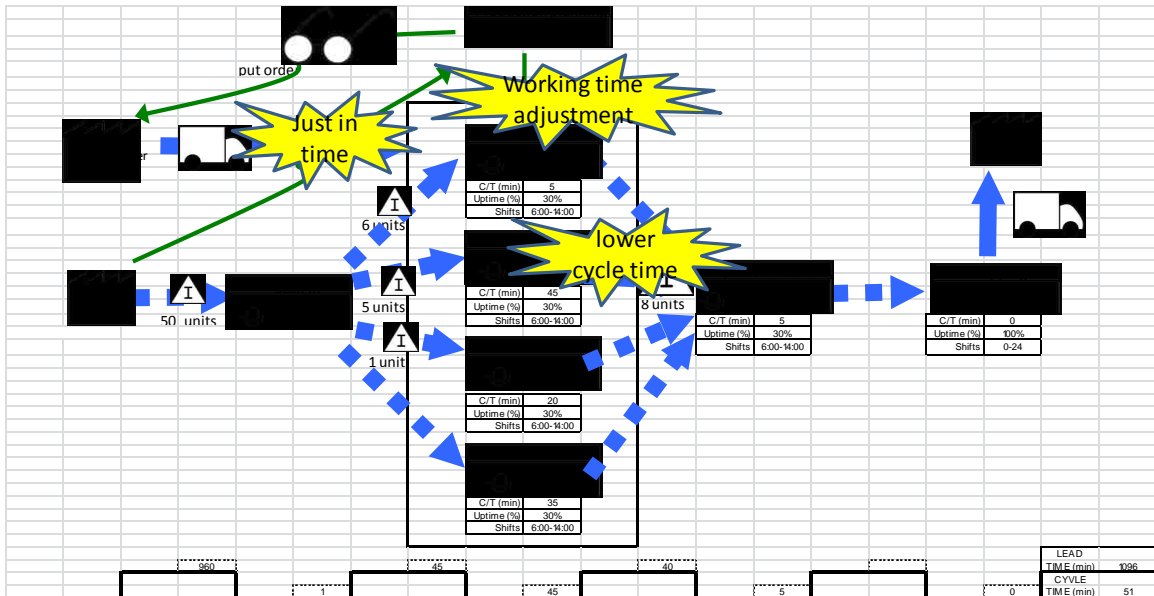
FIGURE 3- 18 THE FUTURE STATE VSM FOR VCC

The future state map of VCC, recommends major improvements about the available

operation time for workers, process optimization for option Ds and inventory

management. The time benefits will be shown with the aid of simulation later in the

following sections.

3.2 PRODUCTION ASSUMPTIONS AND CURRENT MODEL BUILD UP

The major problems are identified with the value stream maps and assumptions are given to improve the process efficiency and reduce waste. The advantages compared to current production model are obvious and simulations results in this section will provide numerical values to support these assumptions. The production simulation software Flexsim^{TM} is used as the tool for process lead time evaluation at the VCC. In the previous analysis, the time waste at WC was we eliminated by route changing. The overnight stay at WC is represented as the inventory queue in the simulation. There are four different production assumptions proposed including the current production model as shown in the Table 3-1. The first model is the 'present case model' which represents the current production model at the VCC, the second model is the VCC production model in its future state map (Scenario 1), the third model adds one more shift at the VCC to synchronize production with the plant and lastly, the fourth model represents an ideal situation with three work shifts to estimate the equipment needed to bring the work back to the plant. For each model, a cost analysis is provided to justify its feasibility. In this chapter, only the current model will be set up and tested. Other model assumptions will be built up based on the preliminary results analysis of the current model.

TABLE 3- 1 SIMULATION MODELS

Model	Details
Present case	Simulates the current production
Scenario 1	Improved efficiency after VSM
Scenario 2	Adds one more shift
Scenario 3	Moves the program back to the plant

3.2.1   PRESENT CASE MODEL BUILD UP

Under the current production model, there are 15 workers and one supervisor in the workshop. There are two stations for Option A, one station for Option B, one station for Option C, 6 stations for option D. 10 out of 15 workers are assigned to directly work on the stations while the other 5 are assigned for inspection and material handling. One union safety and health representative is also needed for production. The supervisor counts for one and a half times the labour cost. That makes the total labour force of 17.5 workers. The material handling part is ignored in the simulation because it does not affect the process lead time in this case. The model is composed of sources, which represents the incoming vehicles from plant; inventory queues, which represents the parking yard of WC/VCC and the waiting queue inside the VCC workshop; combiners, which represents the stations for each up-fitting process; processers , which represents the inspection stations. The dispatchers are in charge of coordinate workers among the stations. See the Figure 3-19 for the model layout.
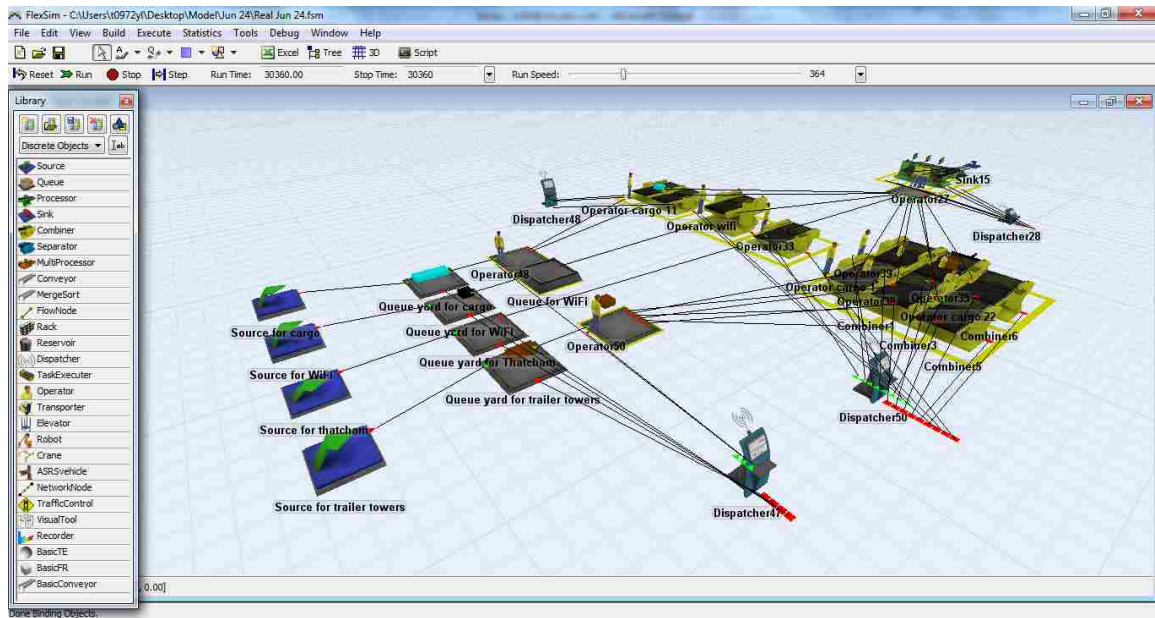
FIGURE 3- 19 MODEL LAYOUT FOR THE PRESENT CASE PRODUCTION

From the figure above we can tell that the up-fitting processes are parallel to each other

and finally go through the same inspection stage. From left to right, the sources are

related to the order patterns of each up-fitter. In section 3.2 the order patterns presented

are assumed as normal distributions. The patterns can also be assumed as other types of

distribution, but the levels of production volume will not change. The purpose of the

simulations is to find out what kind of decisions can be made under these levels of

production volume, other distribution types (such exponential) will lead to similar results

of decision making. In   Table 3-2 below shows the average and standard deviations for

each option.

TABLE 3- 2AVERAGE AND STANDARD DEVIATIONS FOR EACH OPTION ORDERING PATTERN

Option A	Monthly	Daily	Hourly	Inter arrival time mins/pcs	Option B	Monthly	Daily	Hourly	Inter arrival time mins/pcs
Jan-12	750	34.09	1.42	42.24	Jan-12	140	6.36	0.27	226.29
Feb-12	940	42.73	1.78	33.70	Feb-12	218	9.91	0.41	145.32
Mar-12	763	34.68	1.45	41.52	Mar-12	80	3.64	0.15	396.00
Apr-12	966	43.91	1.83	32.80	Apr-12	250	11.36	0.47	126.72
May-12	706	32.09	1.34	44.87	May-12	199	9.05	0.38	159.20
Jun-12	1010	45.91	1.91	31.37	Jun-12	154	7.00	0.29	205.71
Jul-12	776	35.27	1.47	40.82	Jul-12	71	3.23	0.13	446.20
Aug-12	881	40.05	1.67	35.96	Aug-12	242	11.00	0.46	130.91
Sep-12	652	29.64	1.23	48.59	Sep-12	277	12.59	0.52	114.37
Oct-12	795	36.14	1.51	39.85	Oct-12	241	10.95	0.46	131.45
Nov-12	657	29.86	1.24	48.22	Nov-12	117	5.32	0.22	270.77
Dec-12	669	30.41	1.27	47.35	Dec-12	134	6.09	0.25	236.42
AVE	797.08	36.23	1.51	40.61	ave	176.92	8.04	0.34	215.78
Standard	124.51	5.66	0.24	6.07	standard dev	69.94	3.18	0.13	108.68

A) VOLUME ANALYSIS FOR OPTION A   B) VOLUME ANALYSIS FOR OPTION B

Option C	Monthly	Daily	Hourly	Inter arrival time mins/pcs	Option D	Monthly	Daily	Hourly	Inter arrival time mins/pcs
Jan-12	0	0.00	0.00	0.00	Jan-12	586	26.64	1.11	54.06
Feb-12	0	0.00	0.00	0.00	Feb-12	637	28.95	1.21	49.73
Mar-12	0	0.00	0.00	0.00	Mar-12	542	24.64	1.03	58.45
Apr-12	0	0.00	0.00	0.00	Apr-12	775	35.23	1.47	40.88
May-12	0	0.00	0.00	0.00	May-12	739	33.59	1.40	42.87
Jun-12	0	0.00	0.00	0.00	Jun-12	757	34.41	1.43	41.85
Jul-12	0	0.00	0.00	0.00	Jul-12	681	30.95	1.29	46.52
Aug-12	0	0.00	0.00	0.00	Aug-12	825	37.50	1.56	38.40
Sep-12	0	0.00	0.00	0.00	Sep-12	815	37.05	1.54	38.87
Oct-12	1	0.05	0.00	31680.00	Oct-12	894	40.64	1.69	35.44
Nov-12	0	0.00	0.00	0.00	Nov-12	672	30.55	1.27	47.14
Dec-12	94	4.27	0.18	337.02	Dec-12	867	39.41	1.64	36.54
ave	7.92	0.36	0.01	2668.09	ave	732.50	33.30	1.39	44.23
stev	27.11	1.23	0.05	9136.90	stev	110.85	5.04	0.21	7.14

C) VOLUME ANALYSIS FOR OPTION C   D) VOLUME ANALYSIS FOR TRAILER

Table 3-2 (shadowed zone) shows the average and standard deviations for option A and option D as the most stable ordering patterns. Option B has a big deviation but the data can still be used. Since for Option C, the production is quite concentrated into a period of time, the trend is hard to predict. So the data in December is used as the input for simulation to provide capability for this kind of production. The numbers coloured in red are the production inter-arrival times for each option. So the parameters for sources in the

simulation model can be set as in Figure 3-20. Following the same procedure, the arrival time for other sources can be set as well. To distinguish between different options, Flexsim^{TM} allows to set different colour in the trigger label for each option. The queues in the second column represent the buffer inventory yard between the plant and VCC, where the maximum capacity is set to100. In reality the parking yard at VCC and WC can hold about 300 units in total, half of which are for completed vehicles. There are about 150 spots for the incoming vehicles from plant. The simulation model assumes a capacity of 100 for each option (400 in total) to allow for computation under extreme production volumes. There are operators in between the second column and the third column, which means the drivers bring the vehicles into the workshop and put in the assembly queue waiting to be processed. The dispatcher is used to assign drivers. See Figure 3-21.
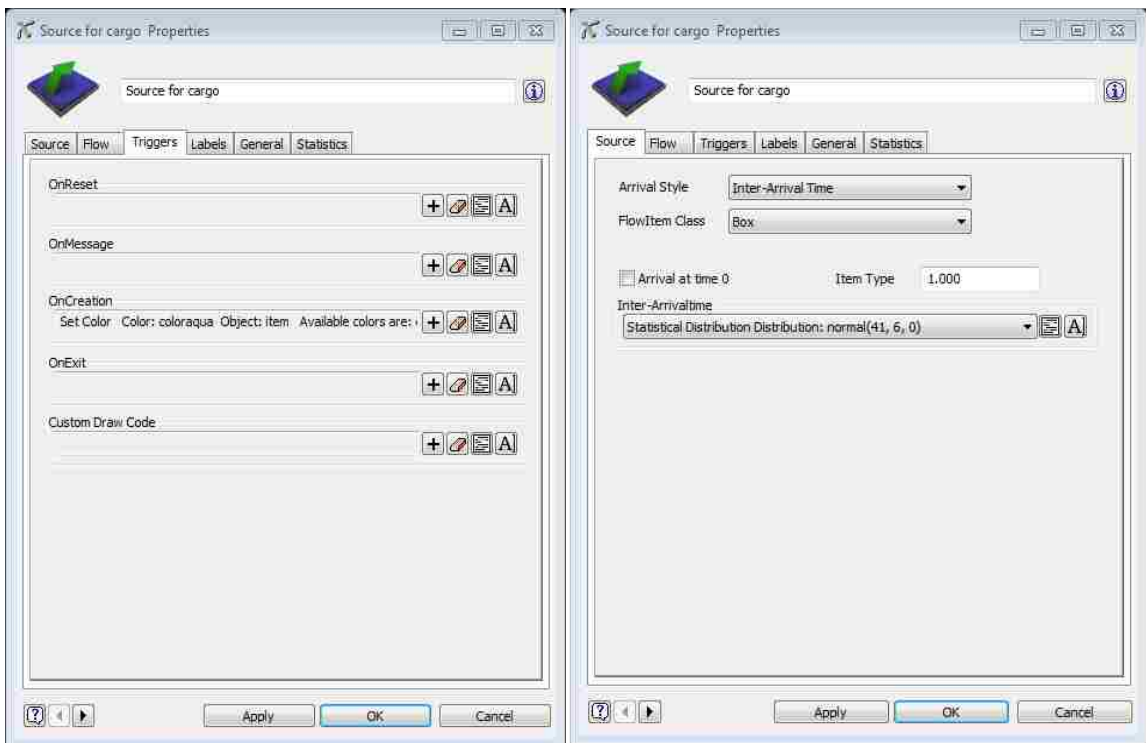
FIGURE 3- 20 INTER-ARRIVAL TIME FOR OPTION A IN MINUTES AND COLOR SETTING FOR EACH OPTION
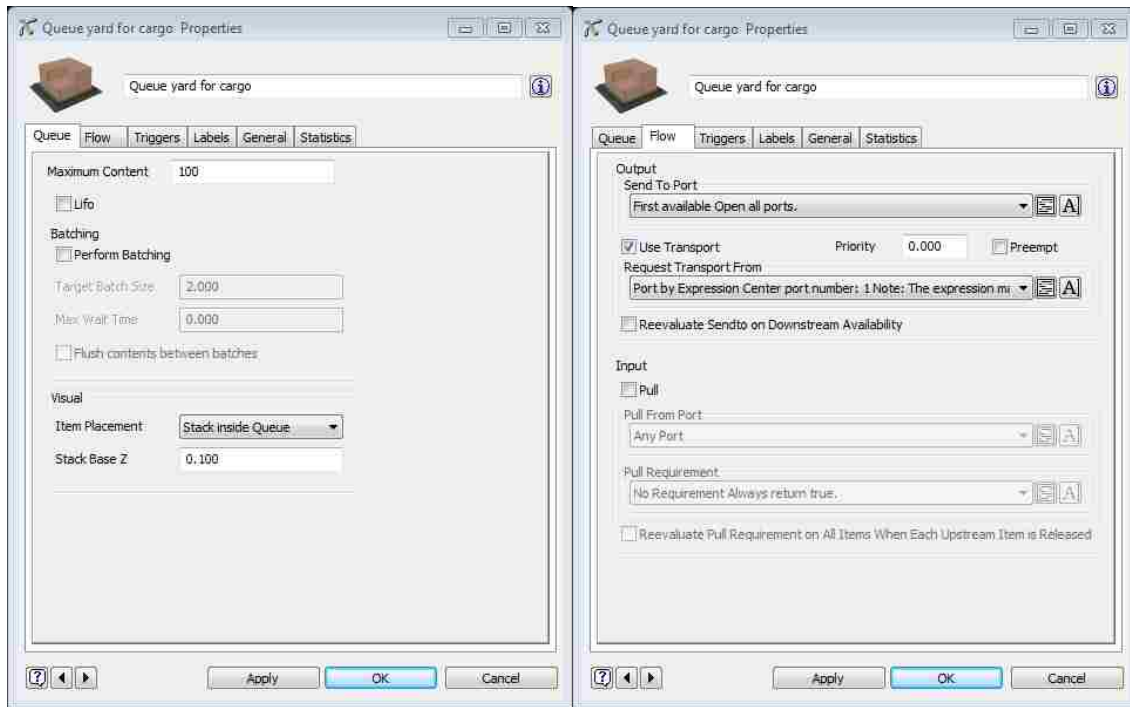
FIGURE 3- 21 CAPACITY AND TRANSPORT FORM SETTING FOR OPTION A

The drivers between queues that are presented in this model, are also used as operators on

the inspection stage. These workers bring new vehicles in, inspect them, and bring the

vehicles out. Settings for other options can follow the same procedures and guidelines as

presented in the first model. Based on observation, the capacity for option A queue inside

workshop is 8. The queue capacities for Option B and option D are 1 and 5 respectively.

Due to the layout limit, there is no queue for the Option C station, see Figure 3-22.
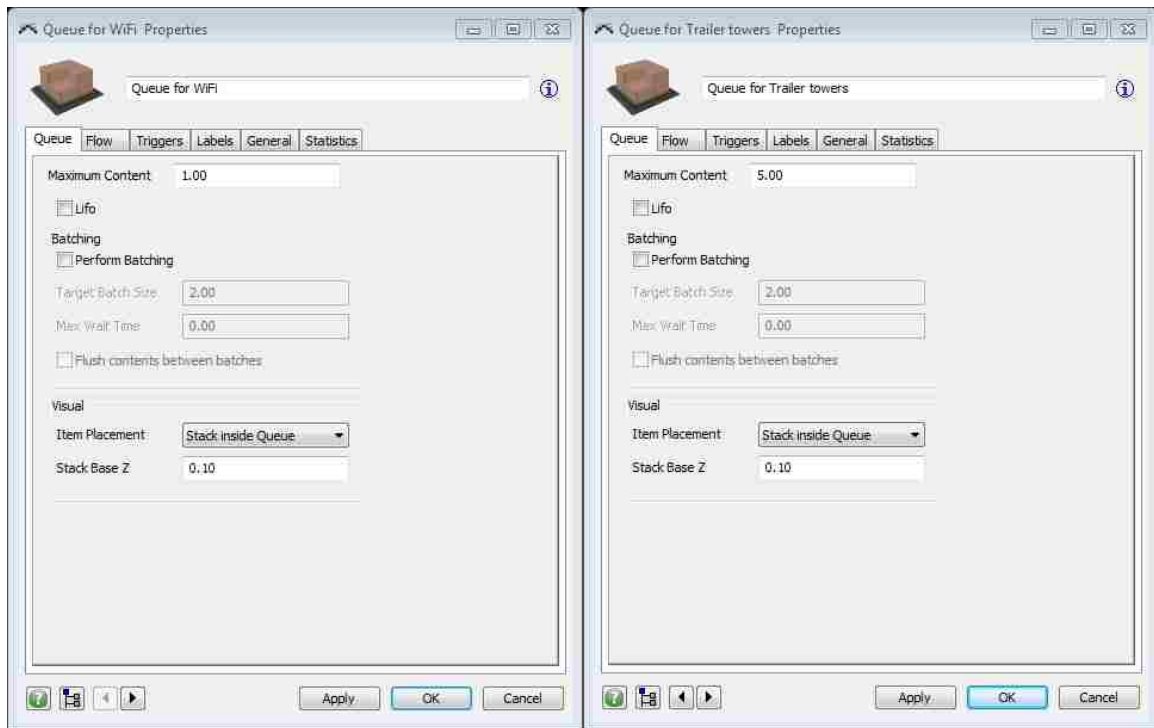
FIGURE 3- 22 QUEUE CAPACITY FOR OPTION B AND OPTION D UP-FITTING PROCESS

The process time and break downs are the most important parameters in the simulation for the combiner parameters setting. They represent the cycle time and working time for the workers. According to the company's tasks assignment, the cycle time for option A is 5.1 minutes, the cycle time Option B is 16.2 minutes, the cycle time for Option C is 18 minutes, and the cycle time for option D is 34.2 minutes. In real time scenario, the time allocated for each option can accommodate more work than assigned. The workers currently do not perform more work once their assigned work has been completed. In other simulation models, the new cycle times will be proposed. The scheduled breakdowns settings in Figure 3-23 represents that there are only 8 hours of working time for the day shift. By excluding the break time and lunch time, there is only 7 hours effective working time. The other 16 hours are scheduled breaking down time.
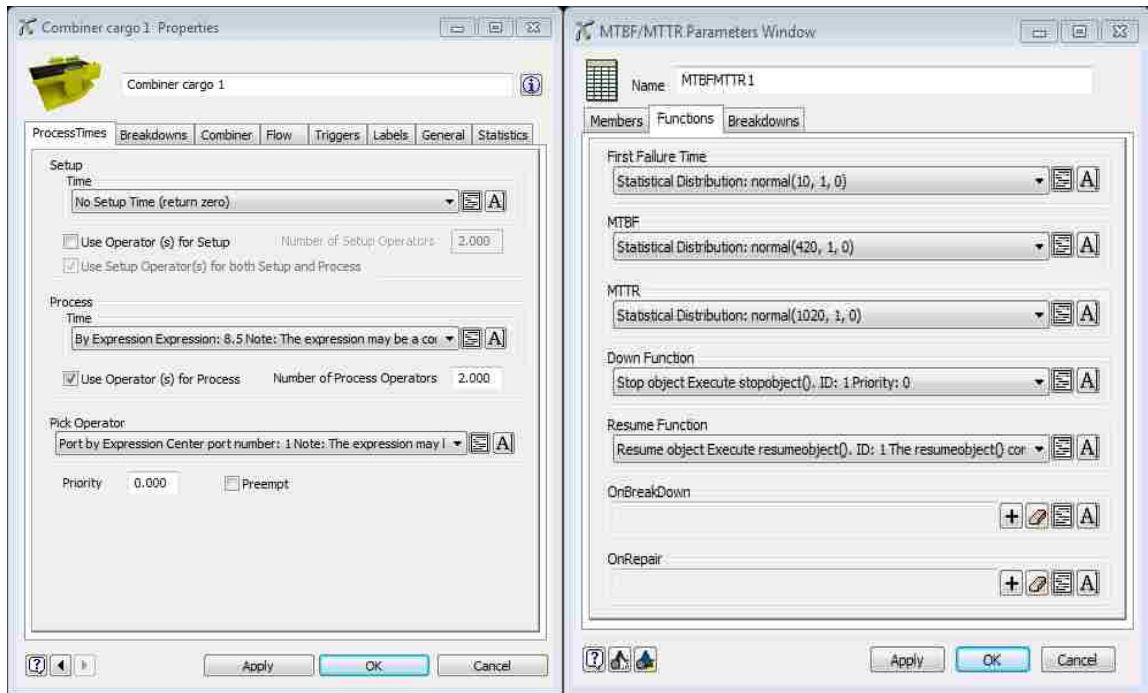
FIGURE 3- 23 PROCESS TIME AND BREAK DOWNS SETTING FOR OPTION A COMBINERS

When the up-fitting process is completed, the vehicles are driven to the inspection area

for quality check. The buffer area has a capacity of 8 units. There are three operators on

the inspection station. These operators are in charge of bringing the vehicles to work

stations from parking lot as mentioned before. The processor used in the simulation

process here indicates a working step. There are no physical machines for processing in

real time at this step. Work done at this stage includes checking the work done at the

station, marking any damaged area due to the up-fitting work or due to the overlook at

the inspection stage in the plant. It also includes checking the main electrical and

computer functions for power damage. If the vehicle is up-fitted well, identification paper

is taken from the car and the barcode is scanned to dispatch the vehicle to shipping.

Another vehicle is subsequently brought in to one of the queues which is then brought

back to the inspection station for next inspection work, see Figure 3-24 below.
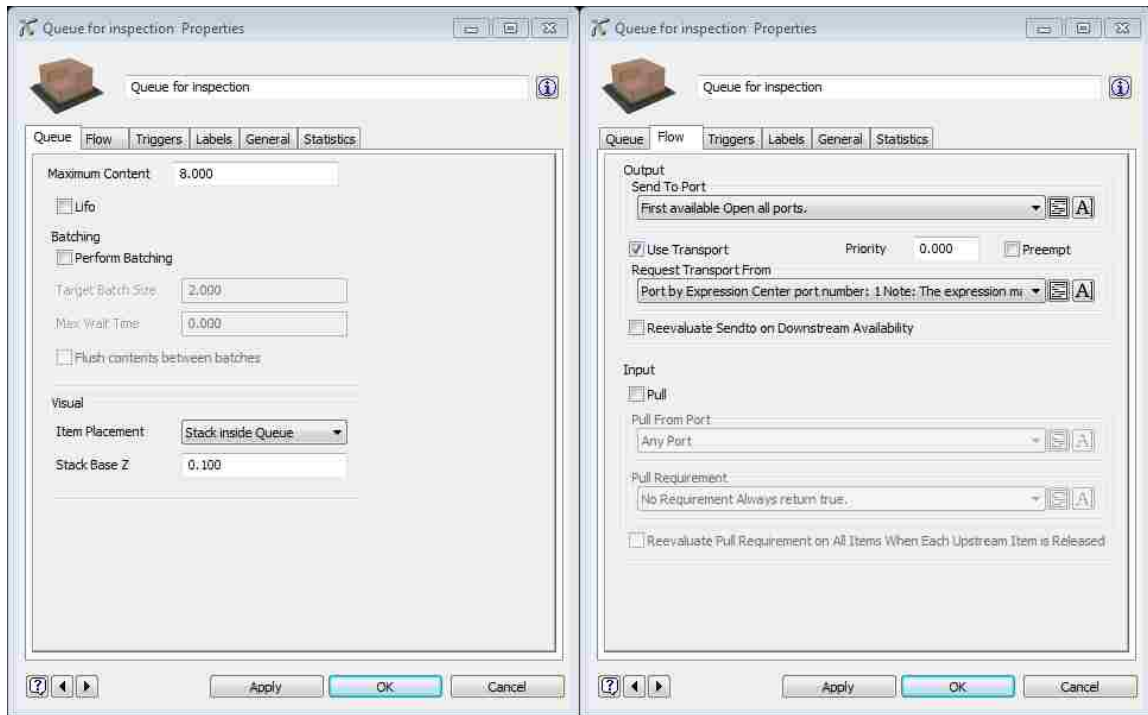
FIGURE 3- 24 CAPACITY AND TRANSPORT FORM SETTING FOR INSPECTION QUEUE

The operation time on the inspection stage is about 5 minutes. It is the time between two separate inspections, which is the time from the start of first inspection to the start for another inspection. The three inspection stations follow the same breakdown criteria as the combiners (up-fitting station). The dispatcher is used to assign the workers to the station by dispatching the worker to the first available station. After the final inspection, the vehicle is pulled back to the parking yard, waiting to be shipped. This waiting time is accounted for in the inspection time. This stage marks the completion of the up-fitting operation. A sink is used here to represent the end of operation. See Figure 3-25.
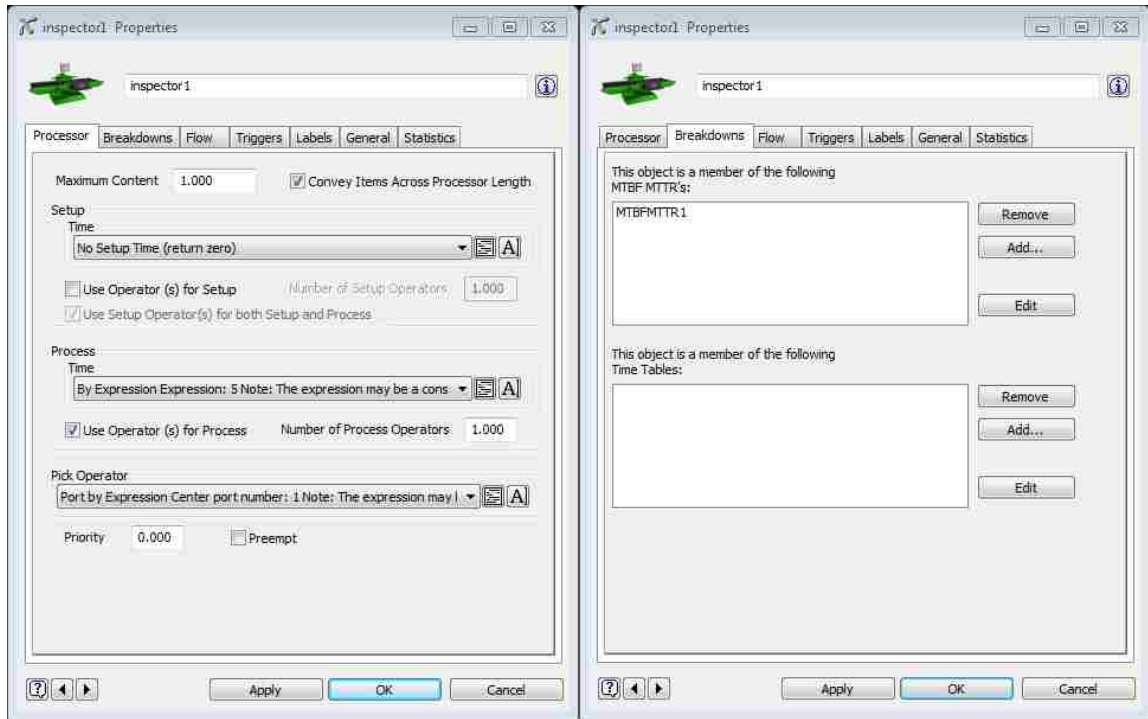
FIGURE 3- 25 INSPECTION STATION PROCESS TIME SETTING AND BREAK DOWN CRITERIA

The current model represents the 'present case' model setup where the simulation time is 22 working days in one month. The data for queues, combiner, inspection processing rate, and overall lead time is collected here. This model serves as a validation model to check if real production can be represented by the model. If the data fits the reality well, the model can be used as a base for other assumptions. The next chapter presents the simulation results for 'present case' after many times adjustment. Based on the 'present case' model, other production models will be built and analyzed. Cost analysis will be done after each production model analysis to compare advantages / disadvantages between different assumptions.

CHAPTER 4

RESULTS DISCUSSION, COST ANALYSIS AND FURTHER STEPS

4.1 PRESENT CASE RESULTS DISCUSSION

The simulation time has been set to the working time for one month (30600 minutes).

The monthly data was chosen since the plant takes orders a month in advance and the

production rate within one month can be considered stable. The summary report for the

queues and state report for the stations are recorded during simulation. See Figure 4-1

and 4-2.

TABLE 4- 1 SUMMARY REPORT FOR QUEUE MAXIMUM CONTENT IN PRESENT CASE

Flexsim Summary Report				
Time:	30360			
Object	Class	stats_content	stats_contentmin	stats_contentmax
Queue for Option A	Queue	0	0	8
Queue for inspection	Queue	0	0	4
Queue for Option D	Queue	0	0	5
Queue for Option B	Queue	0	0	1
Queue yard for Option A	Queue	3	0	26
Queue yard for Option C	Queue	1	0	3
Queue yard for Option D	Queue	2	0	25
Queue yard for Option B	Queue	1	0	7

From the summary report, the number of vehicles parked in the yard does not exceed the

parking capacity. According to the simulation results, there are maximum 61 vehicles in

the yard and the parking capacity is 150 units. So the model fits the reality from the

vehicle holding point of view. In the real production case, due to part shortage and

quality issues from the plant, sometime the yard holds about 70-80 units. In the project

study, the model considers mainly the normal production process, which means the

model fits the reality well enough.

TABLE 4- 2 STATE REPORT FOR COMBINERS AND INSPECTORS IN PRESENT CASE

Flexsim State Report				
Time:		30360		
Object	Class	idle	processing	breakdown
Combiner Option A 1	Combiner	12.90%	16.18%	70.92%
Combiner Option A 2	Combiner	15.69%	4.42%	70.92%
Combiner Option C	Combiner	17.44%	8.79%	70.92%
Combiner Option B	Combiner	12.60%	12.63%	70.92%
Combiner1	Combiner	2.28%	23.98%	70.92%
Combiner2	Combiner	2.84%	23.86%	70.92%
Combiner3	Combiner	4.44%	22.15%	70.92%
Combiner4	Combiner	6.42%	20.09%	70.92%
Combiner5	Combiner	5.56%	20.09%	70.92%
Combiner6	Combiner	5.87%	20.28%	70.92%
inspector 3	Processor	23.34%	5.47%	70.92%
inspector1	Processor	16.19%	12.84%	70.92%
inspector2	Processor	20.04%	9.04%	70.92%

The table above provides the processing rate for each station. The option A processing

rate is relatively low compared to others. This is because the production volume is

limited to 40-50 units per day and the production capacity is 50. The working load is

shared by two stations so the processing rate is low and there is a high rate of idling time.

This factor should thus be taken into consideration in the Scenario 1 simulation. The

Option C and Option B processing rates are very low mainly due to low production

volumes. The stations processing rates for Option D are higher than 20%, implying that

there is about 70% value added time during the 8 hours working shift. The high

processing rates at Option D stations can also be due to the long processing cycle time. If

the cycle time reduces, the processing rates may lower. Scenario 1 simulations can better

predict the results. Only one of the inspection stations has a processing rate higher than

10%. The idling times for these stations are extremely high. Thus in future, caution

should be laid in modelling of these inspection stations. The following Figure 4-1, shows

the average stay time at the yard and process time for each option. The average process

lead time for each up-fitting process can be calculated by adding the time together along

every single production line.

From the Figure 4-1, we can calculate the up-fitting lead time for each option, see table

4-3 below:

TABLE 4- 3 THE AVERAGE UP-FITTING PROCESS LEAD TIME FOR EACH OPTION IN PRESENT CASE

Options	Process lead time (minutes)					
	Parking	Queue1	Up-Fitting	Queue 2	Inspection	Total
Option A	257.52	24.84	14.82	1.56	6.78	290.70
Option B	251.88	8.94	38.16	1.56	6.78	307.32
Option C	202.20	0	21.24	1.56	6.78	231.78
Option D	270.24	20.52	66.60	1.56	6.78	365.70

These process lead times in Table 4-3 represent the average process time for each option.

The values will be compared with simulation results of other assumptions to evaluate the

contribution of improved assumptions on the lead time reduction. For the purpose of

protect confidential information of the company, all the time values in the simulation

results are normalized.

Legend:
429.224 /Queue yard for cargo
419.754 /Queue yard for WiFi
336.96 /Queue yard for Thatcham
450.387 /Queue yard for trailer towers
41.415 /Queue for Cargo Vans
14.85 /Queue for WiFi
34.208 /Queue for Trailer towers
32.904 /Combiner cargo 1
16.357 /Combiner cargo 2
63.567 /Combiner wifi
35.414 /Combiner thatcham
206.631 /Combiner1
87.973 /Combiner2
71.921 /Combiner3
80.963 /Combiner4
132.659 /Combiner5
85.891 /Combiner6
2.627 /Queue for inspection
15.223 /inspector1
10.159 /inspector2
8.53 /inspector 3

FIGURE 4- 1 STAY TIME AT THE YARD AND PROCESS TIME AT EACH STATION IN PRESENT CASE

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4.1.1 COST AND BENEFITS ANALYSIS FOR PRESENT CASE MODEL

In the manufacturing world, the costs and benefit analysis is the key index for decision making. It provides the use with an estimate of profit or loss for any change or improvement made to the process. In this project, the selling price for the up-fitters, material costs, labor related costs, and non-labor related costs are listed and profits are calculated. For the present case, as also for the other assumptions, the up-fitter selling price and material purchasing price will be the same. All the annual costs are listed in the table 4-4 and 4-5 with normalized data.

TABLE 4- 4 PROFIT MARGIN FOR EACH OPTION WITHOUT LABOR AND NON-LABOR RELATED COSTS

	Selling Price($)	Material Price($)	Unit profit($)	Yearly production	Total profit($)
Option A	3.33	1.33	2.00	9565	19130.0
Option B	5.17	1.60	3.57	2123	7572.00
Option C	1.00	0.33	0.67	95	63.30
Option D	4.67	1.07	3.60	8790	31644.00
Total					58409.40

TABLE 4- 5 LABOR AND NON-LABOR RELATED COSTS FOR UP-FITTING PROCESS IN PRESENT CASE

	Hourly pay($)	Number of labor ($)	Working hours	Total cost($)
Labor related costs	0.33	16.5	2080	11440.00
Repairs and Maintenance				573.30
Tools				2.00
Supplies				100.00
Building				840.00
Depreciation				1680.00
Others				3838.00
Total non-labor related costs				7033.30
Total				18473.30

In table 4-4, the profit margin without labor and non-labor related costs is given. The labor and non-labor related costs are taken into account in table 4-5. The labor related costs are basic wage, holiday pays, health care etc. The non-labor related costs include repairs and maintenance, tools, supplies, building, depreciation and so on. The profit margin can be calculated as follows:

$$\text{Profit} = \text{Price} - \text{Material costs} - \text{Labor \& Non\_labor cost} = \$58,409.4 - \$18,473.3$$
$$= \$39,936$$

The profit margin is estimated to be around \$40,000. It is a profit making business, which proves from the other side why the plant keeps this up-fitting works inbound. In other production models, the costs analysis should done and compared according to the 'present case' cost analysis.

4.2 SCENARIO 1 MODEL BUILD UP AND RESULTS ANALYSIS

In the Scenario 1, suggestions to eliminate waste are applied through VSM analysis. From the VSM, the operation time for each option has the potential to reduce. Based on the observation, the workers are not utilizing the complete time on the stations. Instead, more time is lost on taking more breaks than allocated. One of the major process time improvements is on option D. In the job description for option D (Chapter 3.1.2), the steel beam needs to be taken out and replaced by a trailer beam with higher strength. This step proves to be a repetition of work. If the position of the steel beam is left open, when the vehicles come to VCC for up-fitting, the beam dissecting time can be saved. After the efficiency improvement suggestions, the process time for option A is reduced from 5.1

minutes to 3 minutes, Option B takes only 15 minutes instead of 16.2 minutes, Option C

takes 15 minutes, and option D takes 24 minutes only. All above is normalized data. The

time saved is calculated in the table below. Based on the hours saved through the whole

year, the number of machines can be reduced and workforce can be adjusted by an

appropriate amount. See table 4-2 a) below with normalized data:

TABLE 4- 6 PROCESS TIME NEEDED FOR EACH OPTION BASED ON ANNUAL PRODUCTION (NORMALIZED DATA)

	process time in present case (mins)	process time in Scenario 1 (mins)	production volume	total time needed in future(mins)	total time needed in future (hours)
Option A	10.2	6	9565	57390	956.4
Option B	16.2	15	2123	31845	531
Option C	18	15	95	1425	24
Option D	34.2	24	8790	210960	3516
Total				301620	5026.8

The table above provides the time needed for up-fitting process. This total time is 5026

hours. A single worker works for 2000 hours in a year, with 70% value added time. 5026

hours equals the work done by 6 laborers. Taking into account other factors such as

walking distance, changeover, part shortage, bad weather conditions etc., two more up-

fitting operators are added in this simulation. This brings the number of up-fitting

operators up to eight. The processing rates provided in table 4-2 confirm that two

inspection stations are not being utilized to their full capacity. This allows for a reduction

in the number of inspection stations being used. The option A station No. 2 is not being

fully used either, and can thus be removed. To summarize, the improvements in Scenario

1 are to: remove option A station No. 2; downsize workforce from the up-fitting stations

which will subsequently cause two more trailer stations to shut down; downsize one

laborer from the inspection station. The scheduled breakdowns are still the same as in the

present case, with 8 hours of working time and 16 hours of down time. The process time

for the inspection stations remains the same as well. This step is evaluates the time and

costs saved by identifying waste and subsequently eliminating it. The results discussion

and cost comparison is introduced in the next chapter. See Figure 4-2 for layout and

Figure 4-3 for process time parameters for each option.
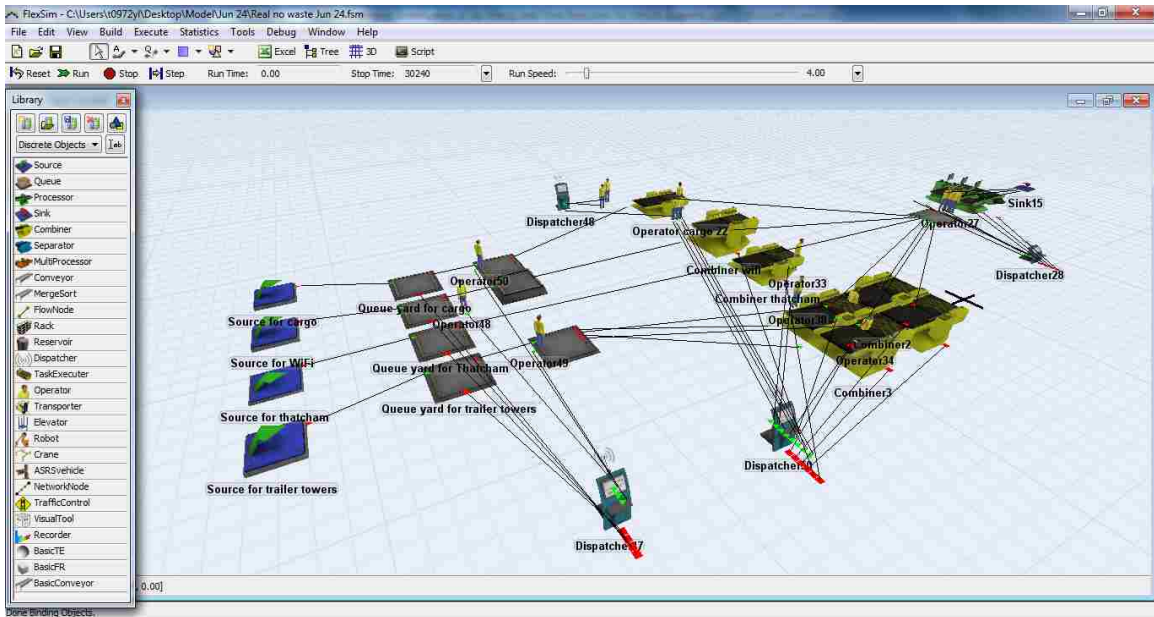
FIGURE 4- 2 PHYSICAL LAYOUT FOR THE SCENARIO 1
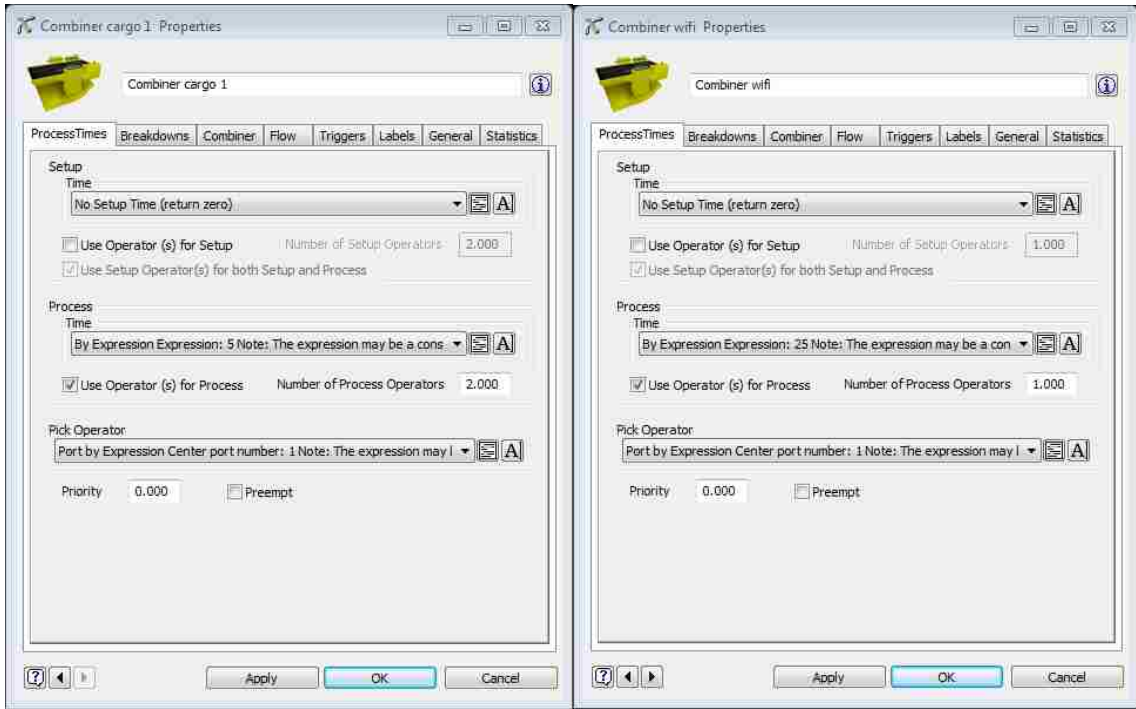
A) PROCESS TIME FOR OPTION A   **B) PROCESS TIME FOR OPTION B**
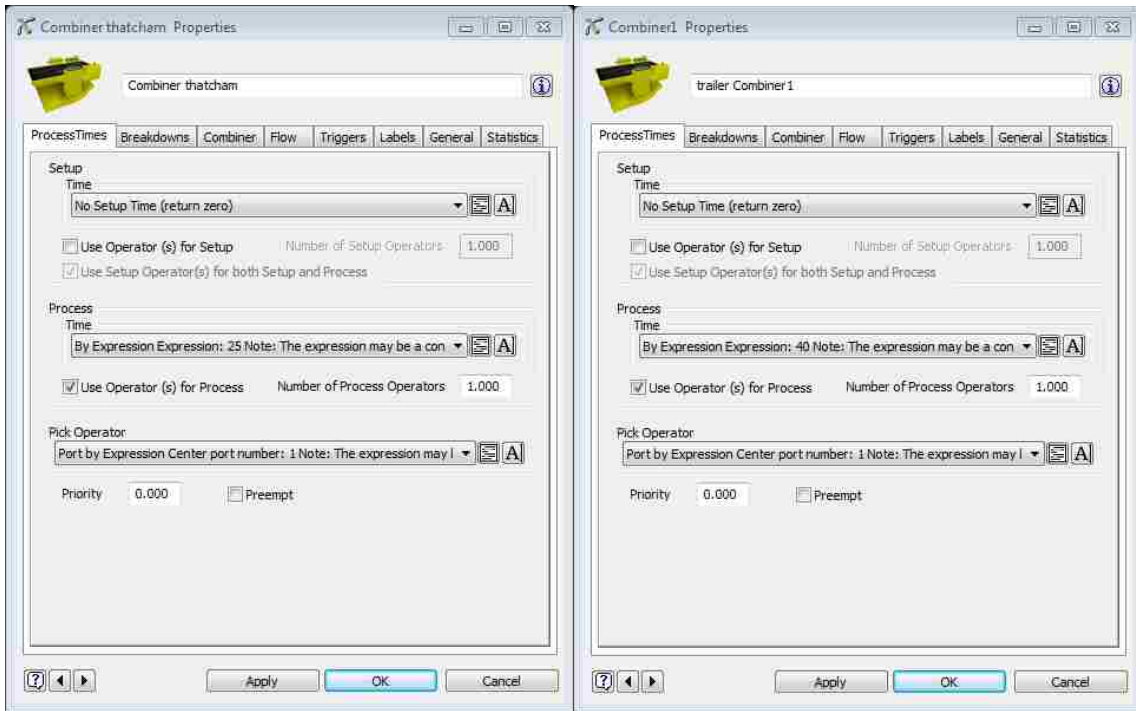
C) PROCESS TIME FOR OPTION C   **D) PROCESS TIME FOR TRAILER**

FIGURE 4- 3 PROCESS TIMES OF THE COMBINING STATIONS FOR EACH OPTION

4.2.1 SCENARIO 1 RESULTS DISCUSSION

The simulation time is set to 30360 minutes. The summary report and state report are given in the following Table 4-7 and 4-8.

TABLE 4- 7 SUMMARY REPORT FOR QUEUE MAXIMUM CONTENT IN SCENARIO 1

Flexsim Summary Report				
Time:	30360			
Object	Class	stats_content	stats_contentmin	stats_contentmax
Queue for Option A	Queue	0	0	4
Queue for inspection	Queue	0	0	5
Queue for Option D	Queue	0	0	5
Queue for Option B	Queue	0	0	1
Queue yard for Option A	Queue	2	0	26
Queue yard for Option C	Queue	1	0	4
Queue yard for Option D	Queue	2	0	24
Queue yard for Option B	Queue	0	0	7

TABLE 4- 8 STATE REPORT FOR COMBINERS AND INSPECTORS IN SCENARIO 1

Flexsim State Report				
Time:	30360			
Object	Class	idle	processing	breakdown
Combiner Option A 1	Combiner	19.00%	10.06%	70.93%
Combiner Option A 2	Combiner	21.39%	2.06%	70.93%
Combiner Option C	Combiner	20.05%	7.33%	70.93%
Combiner Option B	Combiner	14.96%	11.12%	70.93%
Combiner1	Combiner	4.82%	22.32%	70.93%
Combiner2	Combiner	10.72%	16.47%	70.93%
Combiner3	Combiner	13.46%	13.70%	70.93%
Combiner4	Combiner	13.77%	13.31%	70.93%
Combiner5	Combiner	14.80%	11.99%	70.93%
Combiner6	Combiner	15.20%	11.73%	70.93%
inspector 3	Processor	22.23%	6.65%	70.93%
inspector1	Processor	17.67%	11.35%	70.93%
inspector2	Processor	20.10%	8.98%	70.93%

The summary report confirms that the parking capacity is still good to hold enough cars similar to the present case. In the state report, option A has a lower processing rate due to

improved efficiency and constant production volume. To better utilize production

capacities of the station, aggressive strategies for increasing demand can be implemented.

Option B and Option C will always have low processing raters because of the low

production volume. If the trailer station is operated without two workers, much higher

processing rates can be achieved. For the inspection stations, the rates did not change too

much with one worker less. From a statistical point of view, the 'Scenario 1' model has

improved working efficiency, and better utilization of Option D stations with major

process time reduction. Because of order limitation, higher working efficiency does not

improve the utilization of the stations. This assumption led to the reduction of processing

rates for option A, Option B and Option C. Lower processing rates result in labor costs

reduction and equipment reduction, which is beneficial to the company. Subsequently,

the process lead time for each up-fitting option can be calculated from Figure 4-4.
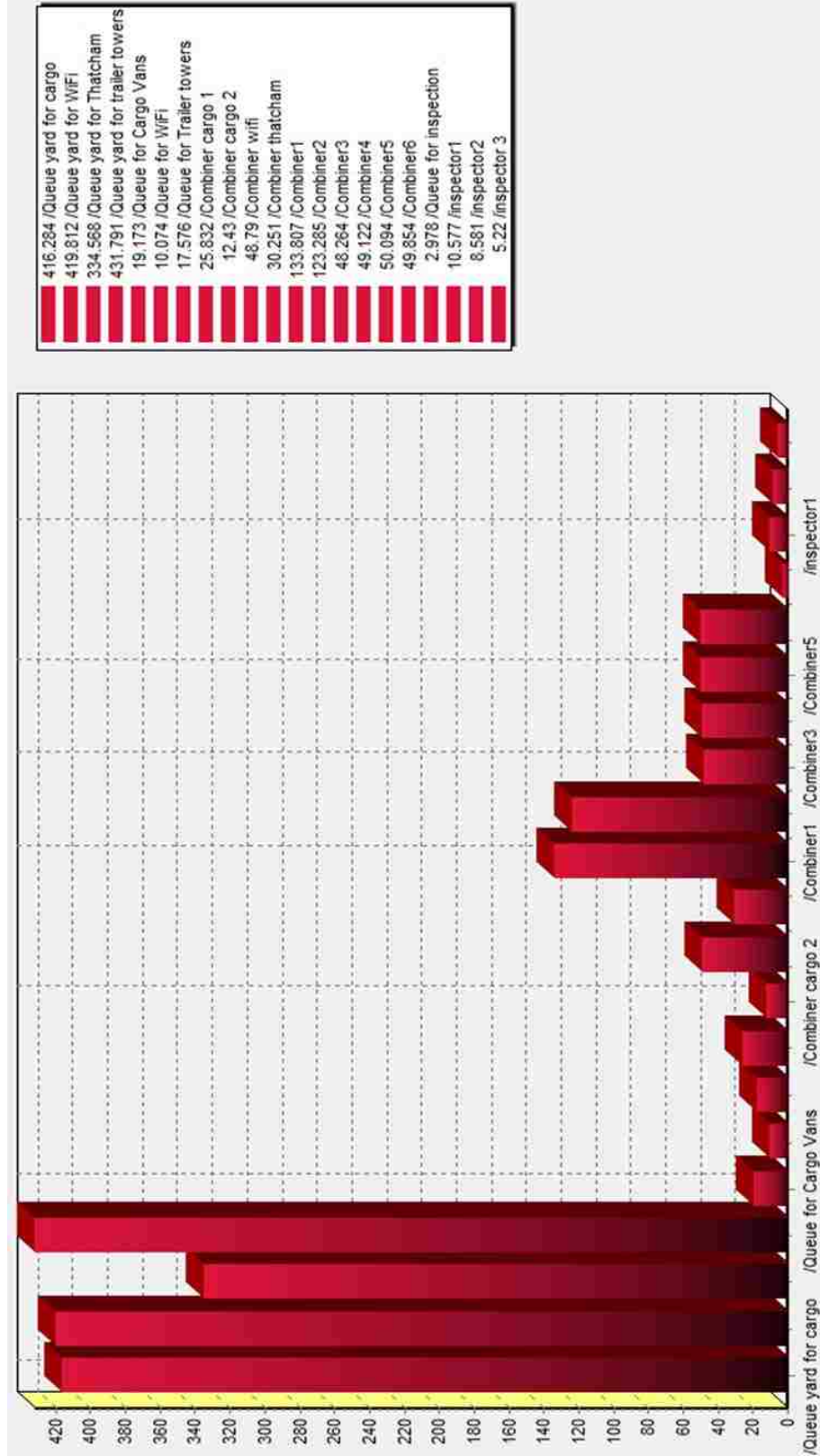
FIGURE 4- 4 STAY TIME AT THE YARD AND PROCESS TIME AT EACH STATION IN SCENARIO 1

By adding the time spent at each section of the up-fitting process, the normalized results

of the process lead times are presented in Table 4-9.

TABLE 4- 9 THE AVERAGE UP-FITTING PROCESS LEAD TIME FOR EACH OPTION IN SCENARIO 1

Options	Process lead time (minutes)					
	Parking	Queue1	Up-Fitting	Queue 2	Inspection	Total
Option A	249.78	11.52	11.46	1.80	4.86	279.42
Option B	252.00	6.06	29.28	1.80	4.86	294.00
Option C	200.76	0	18.18	1.80	4.86	225.60
Option D	259.08	10.56	45.48	1.80	4.86	321.78

Once the results for the 'Scenario 1' model are established, a comparison between the

'present case' and the 'Scenario 1' can be made, as presented in Table 4-10. The results

show that the time efficiency has improved by 12% for stations in Option D. For other

options, the improvements were mainly due to the work rebalance to workers.

TABLE 4- 10 LEAD TIME IMPROVEMENT IN SCENARIO 1 COMPARED TO THE PRESENT CASE

Case	Option A	Reduction	Option B	Reduction	Option C	Reduction	Option D	Reduction
Present case	290.7		307.32		231.78		365.7	
Scenario 1	279.42	3.90%	294	4.30%	225.6	2.70%	321.78	12.00%

4.2.2   COST AND BENEFITS ANALYSIS FOR THE SCENARIO 1

In the Scenario 1, the costs will decrease owing to reduction in working force and

equipment. The revenues will remain unchanged for both the real and the Scenario 1

since the production volume is considered the same for both cases. Based on the results

from 'present case' simulation, three workers are removed in the Scenario 1. Two option

D stations and one option A station were also removed, the repair and maintenance costs

will decrease accordingly. From ten stations to seven, 30% cost reduction of repairs and

maintenance are achieved. As a result, the repair and maintenance costs will decrease by

30% from $573 to $401 (Table 4-5). All relevant costs are listed in Table 4-11:

TABLE 4- 11 LABOR AND NON-LABOR RELATED COSTS FOR UP-FITTING PROCESS IN SCENARIO 1

	Hourly pay($)	Number of labor ($)	Working hours	Total cost($)
Labor related costs	0.33	13.5	2080	9360.0
Repairs and Maintenance				401.3
Tools				2.0
Supplies				100.0
Building				840.0
Depreciation				1680.0
Others				3838.0
Total non-labor related costs				6861.3
Total				16221.3

In the Scenario 1 model, the total labor and non-labor costs are $16,221.3. Compared to

$18,473 in the present case, a total saving of $2,252 was achieved. Thus the total profit

will be $39,936+$2,252=$42,188. In short, all improvements in Scenario 1 has resulted in

an improvement in the overall lead times by 3.9%, 4.3%, 2.7%, 12% respectively.

Although there are considerable benefits, the lead time improvements are not significant.

If lead time is the main concern for a certain period because of the market demands, an

additional shift should be taken into consideration.

4.3 SCENARIO 2 MODEL BUILD UP AND RESULTS ANALYSIS

In the Scenario 1, under one shift working schedule, the lead times cannot change too much. Based on results for the up-fitting process lead time reduction, only option D has a lead time improvement over 10%. Adding one more shift can improve time efficiency under the same conditions for both shifts, but costs control must be taken into consideration. It should also be realized that the same amount of resources cannot be used in both shifts since the order quantities are limited. As such, the attempt is to divide direct workers from future state case into two groups, since the 'Scenario 1 is considered as an efficient model. Four direct workers will be deployed at the up-fitting stations and everyone will have to complete multi-tasks under real time requests. Thus, the workers will go back and forth between different up-fitting processes. One material transporter and one inspection work force will be needed for logistics and final quality inspection. In this case, one more supervisor will be needed which will be equivalent to 1.5 labor force. Additional 0.5 labour cost for union safety and health staff will be incurred. In the present case and Scenario 1, this cost was taken into account in the 'non-labor related cost'. Thus, for Scenario 2, the total labour cost increases to sixteen including up-fitting and administrative costs. The physical layout is presented in Figure 4-5.
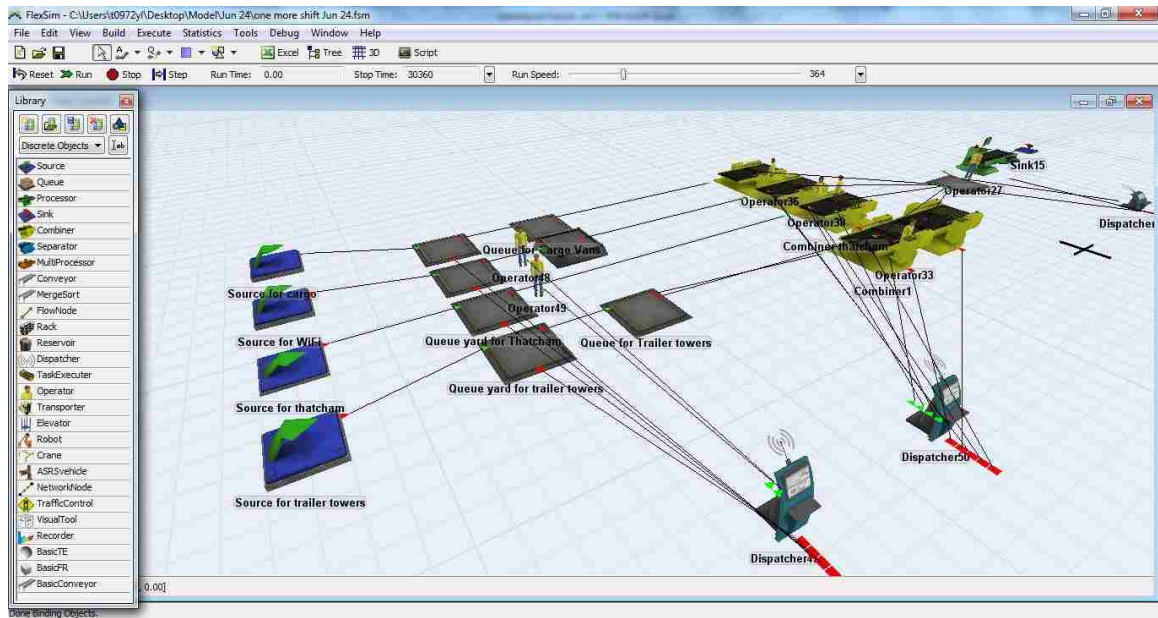
FIGURE 4- 5 PHYSICAL LAYOUT FOR SCENARIO 2

Since there is more working time, the breakdown schedules are changed as well. The working time for each shift is considered to be about seven hours with a total working time of fourteen hours per day. So, the mean time before failure is 840 minutes and the mean time to repair is 600 minutes. See figure 4-6 for details.
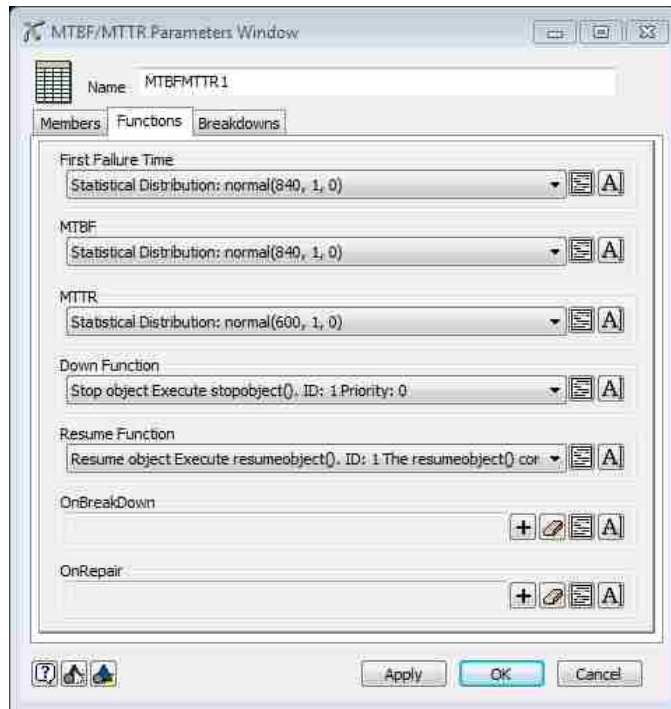
FIGURE 4- 6 BREAKDOWN FUNCTIONS FOR SCENARIO 2 PRODUCTION PLAN

4.3.1   RESULT ANALYSIS FOR SCENARIO 2 ANALYSIS

The simulation time is considered to be twenty two working days in one month, 30360

minutes in the simulation. The summary and state report was recorded during the

simulation process. Please refer to Table 4-12 and 4-13 for details.

TABLE 4- 12 SUMMARY REPORT FOR THE SCENARIO 2 PRODUCTION PLAN

Flexsim Summary Report				
Time:	30360			
Object	Class	stats_content	stats_contentmin	stats_contentmax
Queue for Option A	Queue	7	0	8
Queue for inspection	Queue	0	0	8
Queue for Option D	Queue	5	0	5
Queue for Option B	Queue	1	0	1
Queue yard for Option A	Queue	6	0	17
Queue yard for Option C	Queue	0	0	2
Queue yard for Option D	Queue	6	0	15
Queue yard for Opton B	Queue	0	0	4

TABLE 4- 13 STATE REPORT FOR THE SCENARIO 2 PRODUCTION PLAN

Flexsim State Report				
Time:	30360			
Object	Class	idle	processing	breakdown
Combiner Option A	Combiner	20.51%	11.89%	41.48%
Combiner Option C	Combiner	48.76%	7.33%	41.48%
Combiner Option B	Combiner	41.75%	11.21%	41.48%
Combiner1	Combiner	10.88%	38.98%	41.48%
Combiner2	Combiner	20.16%	29.76%	41.48%
Combiner3	Combiner	29.13%	20.82%	41.48%
inspector1	Processor	31.77%	26.75%	41.48%

From the tables 4-12, the parking lot capacity of 150 units is enough to support the production, since a maximum space for only 38 units is required. According to the state report, the available working time is about 59% with a 41% breakdown time. The processing rates for the Option D combiner 1 and 2 are very good, especially for combiner 1. As for the other options, the processing rates are relatively low mainly because of the order quantity limits. The stations may not be processing all the time, but the workers will always be occupied with tasks. In the pre-running test, if only three workers are assigned to the up-fitting process, they will not be able to complete their work for the day. For the inspection station, the processing rate is only about 26%, which allows the worker to help with other tasks such as subassembly process for parts. Overall, the working force arrangement is considered good in the scenario 2 production plan. The overall lead time reduction for the presented case is shown in Figure 4-7.
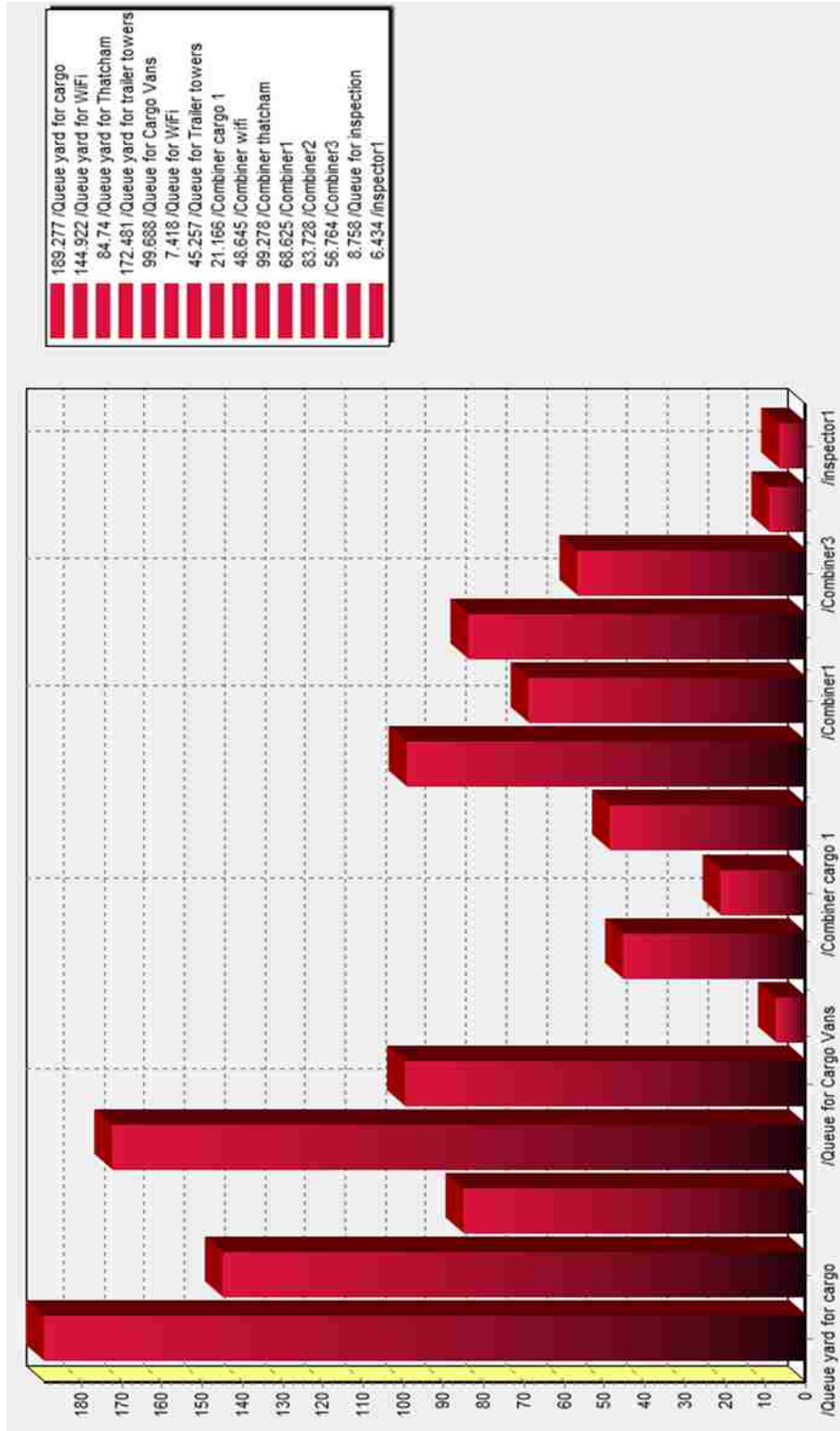
FIGURE 4- 7 STAY TIME AT THE YARD AND PROCESS TIME AT EACH STATION IN SCENARIO 2

Table 4-14 below shows the overall process lead time for each option calculated from the production flow:

TABLE 4- 14 THE AVERAGE UP-FITTING PROCESS LEAD TIME FOR EACH OPTION IN SCENARIO 2

Options	Process lead time (minutes)					
	Parking	Queue1	Up-Fitting	Queue 2	Inspection	Total
Option A	113.58	59.82	12.72	5.28	3.84	195.24
Option B	86.94	4.44	29.16	5.28	3.84	129.66
Option C	50.82	0	59.58	5.28	3.84	119.52
Option D	103.50	27.18	41.82	5.28	3.84	181.62

Similar to the lead time result analysis of 'Scenario 1' model, a comparison between the present case and the proposed case is done to verify how much the lead time can be reduced. See table 4-15 for details.

TABLE 4- 15 LEAD TIME IMPROVEMENT IN SCENARIO 2 COMPARED TO THE PRESENT CASE

Case No.	Option A	Reduction	Option B	Reduction	Option C	Reduction	Option D	Reduction
Present case	290.70		307.32		231.78		365.70	
Scenario 2	195.24	32.80%	129.66	57.80%	119.52	48.40%	181.62	50.30%

From Table 4-15, we can see that major process time reduction has been achieved. The results conformed to expectations, since the working time is doubled, and the production is more synchronized with the plant. From a lead time point of view, this is considered as a good solution. It needs to be further verified from a costs/benefits perspective.

4.3.2 COSTS AND BENEFITS ANALYSIS FOR SCENARIO 2

In this 'Scenario 2' case, the labour cost will be higher than in the Scenario 1. Compared to the present case, only 0.5 working force has been reduced. The equipment maintenance costs remain the same since five stations are used for each shift. A detailed breakdown of the associated costs is presented in Table 4-16.

TABLE 4- 16 LABOR AND NON-LABOR RELATED COSTS FOR UP-FITTING PROCESS IN SCENARIO 2

	Hourly pay($)	Number of labor ($)	Working hours	Total cost($)
Labor related costs	0.33	16	2080	11093.3
Repairs and Maintenance				573.3
Tools				2.0
Supplies				100.0
Building				840.0
Depreciation				1680.0
Others				3838.0
Total non-labor related costs				7033.3
Total				18126.7

The costs form this case should be similar to the present case since it only saves 0.5 labour cost. The total non -material costs are $18,126.7 when compared to $18,473.3 in the present case. A total savings of $346.7 is achieved. From Table 4-1 d), a profit margin of $58,409.4 was determined. Thus, the total profit in the Scenario 2 should be $58,409.4-$18,126.7=$40,282.7. Overall, through all the improvements in Scenario 1, the overall lead times of options A, B, C, and D are improved by 32.8%, 57.8%, 48.4%, 50.3%, respectively. Despite time benefits, the cost saving is lower than the 'Scenario 1'. Hence, the final objective should be to devise a solution for both time and cost. Since

production synchronization is directly proportional to time, a total synchronized production plan is simulated. This is achieved by removing the production back to the plant.

4.4 SCENARIO 3 MODEL AND RESULTS ANALYSIS

The two improvement plans outlined above has its own advantages and disadvantages. That is because the main focus is on the up-fitting process itself. If all the processes can be considered as a whole, and the connection with the plant can be taken into account, other ways can be found to solve the problem. The simulation results from the Scenario 1 and Scenario 2 can only give benefits on one side: for the Scenario 1, the lead time reduction is not significant enough but the costs saving proves to be great; for the Scenario 2, the lead time reduction is good, but the costs did not reduce a lot. A plan to run the up-fitting process 24 hours a day while simultaneously reducing the labour costs would be to move the process back to the plant. It is referred to the 'Scenario 3 model'. The present case model is used as the simulation model to determine the number of stations required for the up-fitting process. The number of stations and labours can be deduced from the simulation results and subsequent cost analysis will be performed. Refer to Figure 4-8 for physical layout of the Scenario 3 working model.
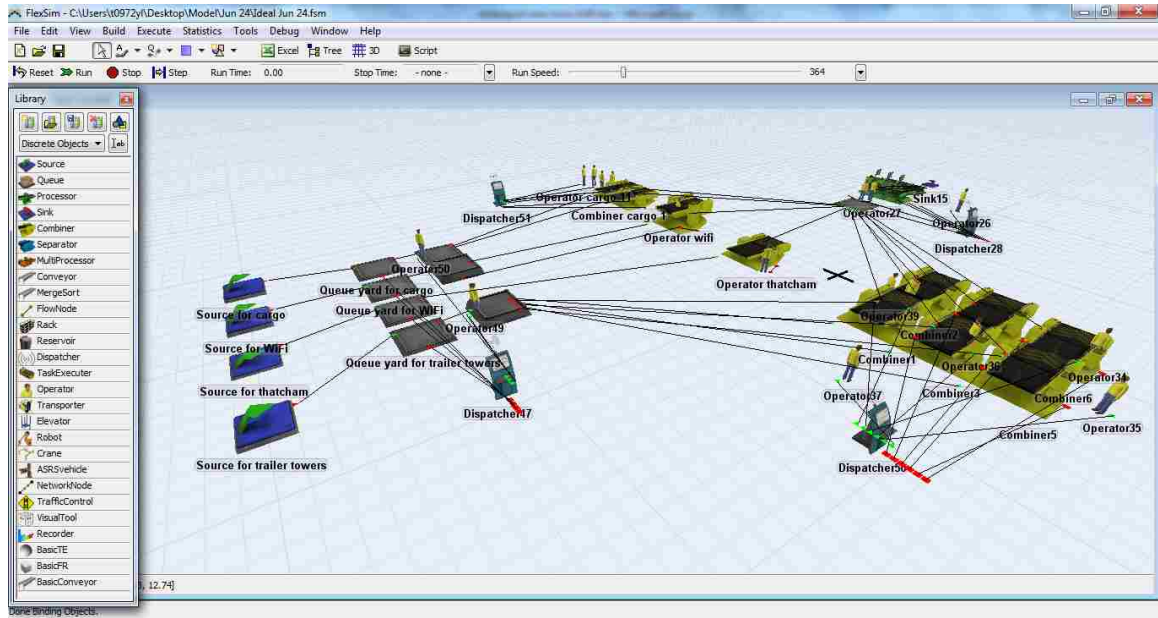
FIGURE 4- 8 PHYSICAL PROCESS LAYOUT FOR THE SCENARIO 3 MODEL

In the Figure 4-9, there are no scheduled breakdowns (16/24 hours in 'present case')

since the process is fully synchronized with the plant.
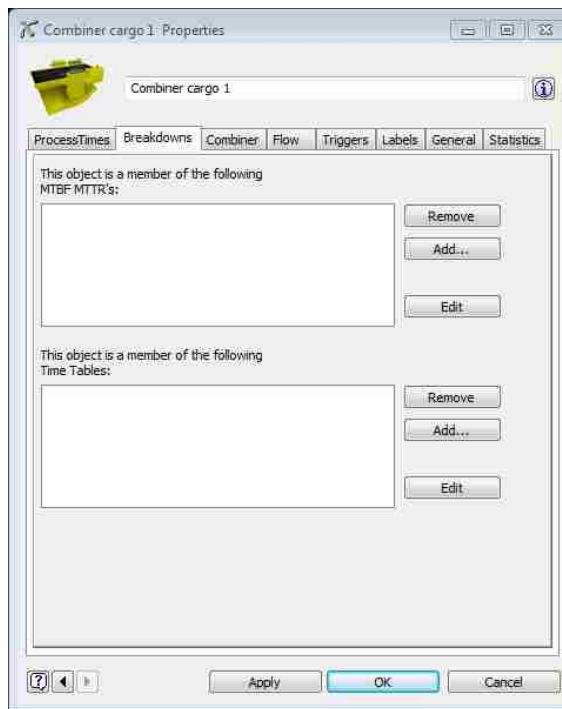
FIGURE 4- 9 BREAKDOWN CRITERIA FOR THE SCENARIO 3 MODEL

4.4.1 SIMULATION RESULTS ANALYSIS FOR THE SCENARIO 3

The simulation time is set to 30360 minutes. The recorded summary and state reports are shown in the following Table 4-17 and 4-18, respectively.

TABLE 4- 17 SUMMARY REPORT FOR THE SCENARIO 3 PRODUCTION PLAN

Flexsim Summary Report				
Time:	30360			
Object	Class	stats_content	stats_contentmin	stats_contentmax
Queue for Option A	Queue	0	0	1
Queue for inspection	Queue	1	0	3
Queue for Option D	Queue	0	0	1
Queue for Option B	Queue	0	0	1
Queue yard for Option A	Queue	0	0	1
Queue yard for Option C	Queue	0	0	1
Queue yard for Option D	Queue	1	0	1
Queue yard for Option B	Queue	0	0	2

TABLE 4- 18 STATE REPORT FOR THE SCENARIO 3 PRODUCTION PLAN

Flexsim State Report				
Time:	30360			
Object	Class	idle	processing	breakdown
Combiner Option A1	Combiner	87.66%	12.34%	0.00%
Combiner Option A2	Combiner	100.00%	0.00%	0.00%
Combiner Option C	Combiner	92.59%	7.41%	0.00%
Combiner Option B	Combiner	88.88%	11.12%	0.00%
Combiner1	Combiner	31.23%	68.77%	0.00%
Combiner2	Combiner	78.13%	21.87%	0.00%
Combiner3	Combiner	100.00%	0.00%	0.00%
Combiner4	Combiner	100.00%	0.00%	0.00%
Combiner5	Combiner	100.00%	0.00%	0.00%
Combiner6	Combiner	100.00%	0.00%	0.00%
inspector 3	Processor	99.60%	0.33%	0.00%
inspector1	Processor	78.59%	21.41%	0.00%
inspector2	Processor	94.07%	5.60%	0.00%

As observed in Table 4-17, the maximum number of vehicles waiting in line is one, which eliminates the need for parking. The developed model proves that the work can be done in the plant from the inventory point of view. Also as shown in Table 4-18, only one option A station, one Option B station, one Option C, and two Option D stations are needed for the work load. Based on the processing rates and the working load calculation presented in Table 4-6, 2.6 workers are needed for each shift. Based on the projected workload, the workers would not be able to finish their tasks if there are only two workers are present during one shift. Taking this into consideration, three workers are chosen to meet the requirements for the up-fitting process for each shift; therefore, nine labourers will be required for the Scenario 3 model.

To further maximize space utilization, Option B and Option C stations can be merged into one station. These two types of up-fitting processes do not need a lot of space for the parts (each one needs only one part of a size 40mm×30mm with some fasteners) and the production volume is very low as well, as shown in Figures 1-3 B) & 1-3 C) (2123 and 95 units annually). After the adjustments, only four stations will be needed for each shift. The lead time can be calculated according to Figure 4-10 below:
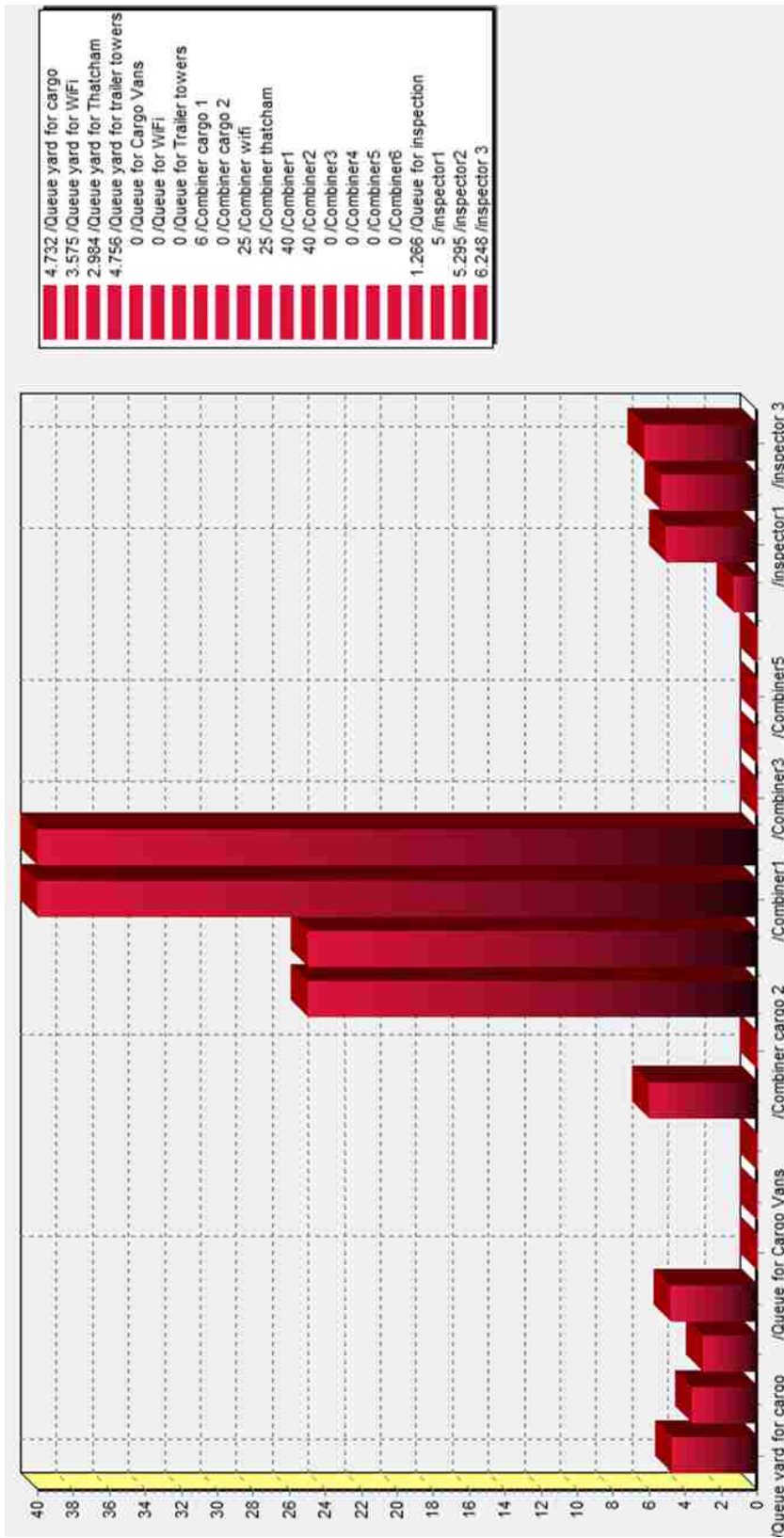
FIGURE 4- 10 STAY TIME AT THE YARD AND PROCESS TIME AT EACH STATION IN SCENARIO 3

Table 4-19 below shows the overall process lead time for each option calculated from the production flow:

TABLE 4- 19 THE AVERAGE UP-FITTING PROCESS LEAD TIME FOR EACH OPTION IN SCENARIO 3

Options	Process lead time (minutes)					
	Parking	Queue1	Up-Fitting	Queue 2	Inspection	Total
Option A	2.82	0	3.6	0.78	3.3	10.5
Option B	2.16	0	15	0.78	3.3	21.24
Option C	1.8	0	15	0.78	3.3	20.88
Option D	259.08	0	24	0.78	3.3	30.96

Following the same procedure, the lead time comparison is given in the Table 4-20 below:

TABLE 4- 20 LEAD TIME IMPROVEMENT IN SCENARIO 3 COMPARED TO THE PRESENT CASE

Case No.	Option A	Reduction	Option B	Reduction	Option C	Reduction	Option D	Reduction
Present case	290.7		307.32		231.78		365.7	
Scenario 3	10.5	96.40%	21.24	93.10%	20.88	91.00%	30.96	91.50%

Upon the comparison, the up-fitting lead times were seen to be reduced by more than 90%. Transportation and storage time via WC is removed from the process. By doing so, the vehicles with up-fitters can be shipped on the same day as the regular vehicles. From the lead time point of view, the only better solution is to conduct the up-fitting process on the line. However, this is not feasible due to the operation complexity. The solution can be considered acceptable if the cost analysis for the model is justified.

4.4.2 COST AND BENEFITS ANALYSIS

In this 'Scenario 3 model', three operators for each shift were considered. All

supervising, material handling, and inspection work can share the same resources in the

plant, so these-expenses as in the 'present case' will be eliminated. Based on the

observation in the plant, the stations can be located in the repairing department. Since,

there are more than twenty stations available for repairing in the plant, four stations can

be allocated for up-fitting process. Four stations for one shift equals twelve station for

three shifts. Compared to ten stations in the present case, the maintenance fees increase in

the developed model. Table 4-21 presents a breakdown for the costs:

TABLE 4- 21 LABOR AND NON-LABOR RELATED COSTS FOR UP-FITTING PROCESS SCENARIO 3

	Hourly pay($)	Number of labor ($)	Working hours	Total cost($)
Labor related costs	0.33	9	2080	6240.00
Repairs and Maintenance				688.00
Tools				2.00
Supplies				100.00
Depreciation				1680.00
Others				3144.70
Total non-labor related costs				5614.70
Total				11854.70

Upon careful observation, it can be seen that tremendous labour costs have been reduced.

Only nine workers instead of 16.5 (in present case) are needed. The maintenance fees will

be 20% higher than the present case due to the increased number of stations used. The

building cost can also be eliminated since the up-fitting process will share the same

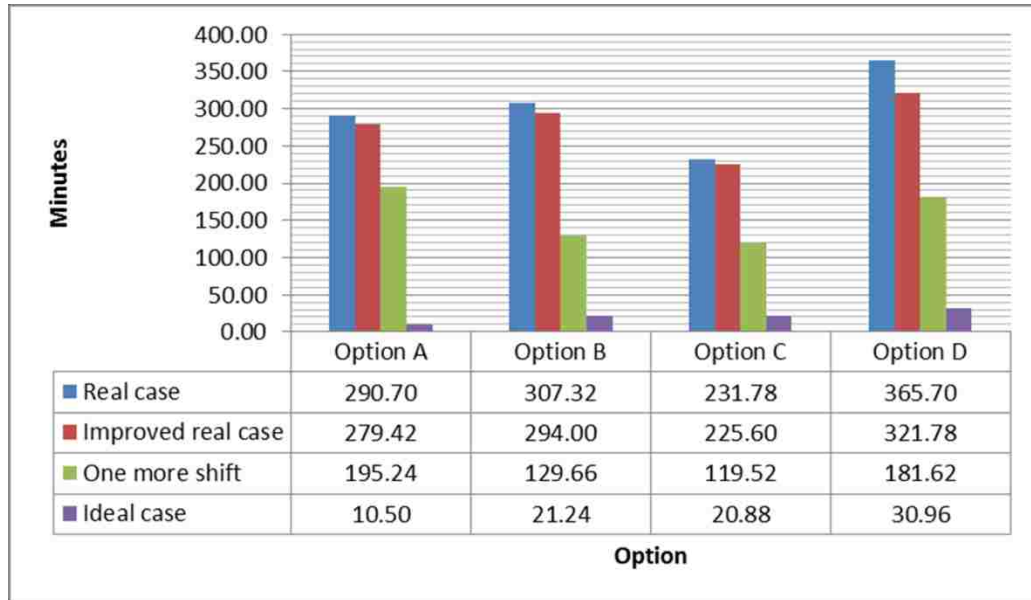building with the assembly plant. As shown in Table 4-4, the profit margin considered for

the material costs is $58,409.4. Thus, the total profit can be calculated to be $58,409.4-$11,854.7=$46,554.7. Implementation of the proposed model can result in a total savings of about 6.6 thousand dollars for one year. The model has been optimized to reduce both lead time and cost of the process.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The main purpose of the project is to reduce the lead time for the up-fitting process for

the vehicles with special requirements ordered by the customers, without introducing a

negative cost impact. To understand the present state an investigation of the production

process was performed. Then alternative scenarios are proposed, simulated using the

Flexsim^{TM} tool, and evaluated. The 'present case' production has been simulated and

validated by comparing the model results to actual production data. Three production

plans have been proposed and verified using the simulation tools. The 'Scenario 1'

scenario is to assume that the efficiency of the current process can be improved. The up-

fitting procedure for the option D was also updated (by reducing the parts that has to be

assembled) to reduce the process time. The results showed that the costs benefits are

positive, with an reduction of about 17% compared to the 'present case', however, the

reduction in lead time is not as significant. Only in option D was the up-fitting time

improved by more than 10%. In the 'Scenario 2 model', the reduction in lead time is

obvious since there is more working time at VCC and the process is more synchronized

with the plant. The cost reduction, however, is worse than the 'Scenario 1' which stated

with an improvement of only about 1%, since this case required adding one more shift

which resulted in a higher labour cost. Lastly, the solution to reduce both the lead time

and costs has been brought up in the 'Scenario 3', where the solution is to move the

whole up-fitting program back to the plant. Under the current order quantities, there is

enough space to complete the work in the plant. This method saves transportation,

material handling, inspection and supervising costs, so the waste is eliminated to its

maximum extend. In Figure 5-1, the lead time reduction for each option in different

production plans has been listed:

	Option A	Option B	Option C	Option D
■ Real case	290.70	307.32	231.78	365.70
■ Improved real case	279.42	294.00	225.60	321.78
■ One more shift	195.24	129.66	119.52	181.62
■ Ideal case	10.50	21.24	20.88	30.96

FIGURE 5- 1 THE SUMMARY FOR LEAD TIME REDUCTION FOR EACH OPTION IN DIFFERENT PRODUCTION CASES

From this table, the time saving in the 'Scenario 3' is obvious since every option has a

lead time reduction of more than 90%. It is the best solution under the current production

volume. In the Figure 5-2, the costs/benefits comparison between different solutions is

shown to support the conclusion that 'the Scenario 3' is the best choice.
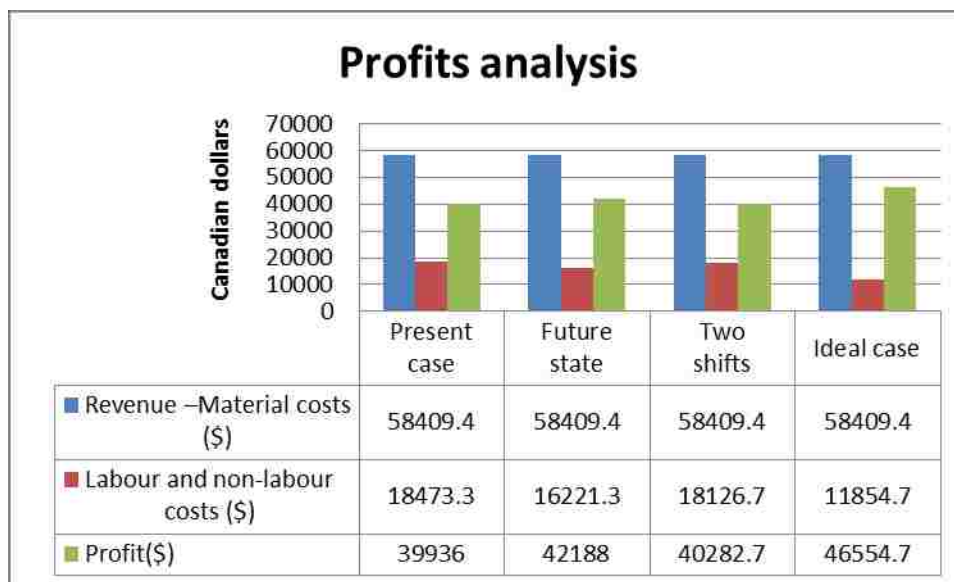
FIGURE 5- 2 SUMMARY OF COSTS ANALYSIS FOR DIFFERENT PRODUCTION PLANS (NORMALIZED DATE)

From the Figure 5-2, all proposed cases have higher profit margins than the present case and by the numbers it is easy to say that the 'Scenario 3' is the best solution. It saves nearly 6.6 thousand dollars for the company.

Even though the proposed plans have different benefits for the company, they all have their own limitations. For the 'Scenario 1', which is also the base for the other cases, the working load increase may cause issues from the union and workers, since no one is willing to work additional time under the same paying rates. However, this solution only requires a minor change to the working and management schedule. A changeover of labour is suggested and this solution makes it easier to assign the work to new employees rather than the old ones. This is important since most the current workers have more than 30 year seniority in the plant and most of them are ready to retire, all they require is the incentive of a buy-out from the company. In 'Scenario 2', the same problem will happen as in the 'Scenario 1', since the working load will increase. There could also be a

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problem at the administrative level, since two shifts will increase the management and logistical costs. In addition, the production volume is not high enough and two shifts would leave a lot of equipment unused. From the resource management point of view, this is not a good solution. Lastly the 'Scenario 3' is the best solution under the current production volume but like any option it has its own set of limitations. If the production increases, there might not be enough space in the plant for the up-fitting stations. Another limitation is that all the data used for the simulation is based on a monthly average production volume, but there can be extreme cases and fluctuations in future productions. Additional runs have been done to validate the model under the extreme production volume and results have shown that the work still can be finished with no excess of inventory at the end of the day. The average data was chosen using comparisons which were done under the same production volume for all assumptions.

In conclusion, 'Scenario 1' is necessary from a cost control point of view. If the plant has expansion plans for the up-fitting processes, it should be kept at VCC for future space and equipment requirements concerns. If the plant has no expansion plans for the up-fitting processes, the program should be moved back to the plant to save time and costs. However formal, rigorous layout assessments along with material flow evaluations should be performed to determine the optimal benefits. In future, the simulation models should be further verified with data that has distributional properties. This can be conducted by collecting more statistical production data for the up-fitting options in the plant. Furthermore, a formal time study needs to be performed inside the company to better understand the work load and necessary resources to be invested. Lastly, the up-fitting capacity inside the plant (repair bay) needs to be further investigated to find out

the relocation break-even point for the up-fitting process. If the company intends to

expand the up-fitting process in future, this point can be adopted as a reference.

APPENDICES

APPENDIX A: LEAD TIME REDUCTION SUMMARY

Case No.	Option A	Reduction	Option B	Reduction	Option C	Reduction	Option D	Reduction
Present case	290.7		307.32		231.78		365.7	
Scenario 1	279.42	3.90%	294	4.30%	225.6	2.70%	321.78	12.00%
Scenario 2	195.24	32.80%	129.66	57.80%	119.52	48.40%	181.62	50.30%
Scenario 3	10.5	96.40%	21.24	93.10%	20.88	91.00%	30.96	91.50%

APPENDIX B: COST SUMMARY

	Revenue –Material costs ($)	Labour and non-labour costs ($)	Profit($)
Present case	58409.4	18473.3	39936.0
Scenario 1	58409.4	16221.3	42188.0
Scenario 2	58409.4	18126.7	40282.7
Scenario 3	58409.4	11854.7	46554.7

APPENDIX C: LEAD TIME REDUCTION SUMMARY COMBINED WITH COST/BENEFITS SUMMARY

Case No.	Option A	Reduction	Option B	Reduction	Option C	Reduction	Option D	Reduction	Profits
Present case	290.70		307.32		231.78		365.7		39936.00
Scenario 1	279.42	3.90%	294.00	4.30%	225.60	2.70%	321.78	12.00%	42188.00
Scenario 2	195.24	32.80%	129.66	57.80%	119.52	48.40%	181.62	50.30%	40282.70
Scenario 3	10.50	96.40%	21.24	93.10%	20.88	91.00%	30.96	91.50%	46554.70

REFERENCES/BIBLIOGRAPHY

1. Chwen Sheu and J.G. Wacker, "The Effects of Purchased Parts Commonality on Manufacturing Lead Time," International Journal of Operations & Production Management 17, no. 7–8 (1997): 725–45.

2. B. Fahimnia et al., "A Heuristic Method to Optimise Manufacturing Lead Time," in Annals of DAAAM for 2006 & Proceedings of the 17th International DAAM Symposium "Intelligent Manufacturing & Automation: Focus on Mechatronics and Robotics", 8-11 Nov. 2006, (Technical Univ. Wien, 2006), 119–20.

3. Rajaniemi Joonas, "Measuring and Defining Lead Time in a Telecommunication Production " University of Oulu ,2012

4. Richard Weber, "Stochastic Scheduling, Research Interests, Statistical Laboratory" 2002

5. Rer. Nat, "Algorithms for deterministic and stochastic scheduling" vorgelegt von Dipl.-Math. Marc Uetz, aus Munster (Westfalen) 2001

6. K.M. Chandy and P.F. Reynolds, "Scheduling Partially Ordered Tasks with Probabilistic Execution Times," in Proceedings of the 5th Symposium on Operating Systems Principles, 19-21 Nov. 1975, vol. 9, Oper. Syst. Rev. (USA), 1975, 169–77.

7. M. Pfund, J.W. Fowler, and J.N.D. Gupta, "A Survey of Algorithms for Single and Multi-objective Unrelated Parallel-machine Deterministic Scheduling Problems," Journal of the Chinese Institute of Industrial Engineers 21, no. 3 (May 2004): 230–41.

8. Lin Ling, Tan Zhi-yi, and He Yong, "Deterministic and Randomized Scheduling Problems Under the Lp Norm on Two Identical Machines," Journal of Zhejiang University (Science) 6A, no. 1 (January 2005): 20–6, doi:10.1631/jzus.2005.A0020.

9. Ying Ma, Chengbin Chu, and Chunrong Zuo, "A Survey of Scheduling with Deterministic Machine Availability Constraints," Computers & Industrial Engineering 58, no. 2 (March 2010): 199–211, doi:10.1016/j.cie.2009.04.014.

10. Lin Lin et al., "Network Modeling and Evolutionary Optimization for Scheduling in Manufacturing," Journal of Intelligent Manufacturing 23, no. 6 (December 2012): 2237–53, doi:10.1007/s10845-011-0569-6.

11. Mitsuo Gen, Runwei Cheng, and Lin Lin, Network Models and Optimization Multiobjective Genetic Algorithm Approach (London: Springer, 2008)

12. M. Gen, Lin Lin, and Haipeng Zhang, "Evolutionary Techniques for Optimization Problems in Integrated Manufacturing System: State-of-the-art-survey," Computers & Industrial Engineering 56, no. 3 (April 2009): 779–808, doi:10.1016/j.cie.2008.09.034.

13. Gyula Vastag and D.Clay Whybark, "Global Relations Between Inventory, Manufacturing Lead Time and Delivery Date Promises," International Journal of Production Economics 30–31 (July 1993): 563–569, doi:10.1016/0925-5273(93)90121-Z.

14. Jin-Shan Yang and J.C.-H. Pan, "Just-in-time Purchasing: An Integrated Inventory Model Involving Deterministic Variable Lead Time and Quality Improvement Investment," International Journal of Production Research 42, no. 5 (March 1, 2004): 853–63, doi:10.1080/00207540310001632448.

15. R.N. Route, M.R. Lambrecht, and B. Van Houdt, "Performance Evaluation of a Production/inventory System with Periodic Review and Endogenous Lead Times," Naval Research Logistics 54, no. 4 (June 2007): 462–73, doi:10.1002/nav.20222.

16. A. Kokangul, T. Khaniyev, and J.K. Cochran, "Optimal Control of Work-in-process Inventory of a Two-station Production Line," Optimal Control Applications and Methods 31, no. 3 (May 2010): 201–11, doi:10.1002/oca.896.

17. H. Jodlbauer, "Range, Work in Progress and Utilization," International Journal of Production Research 43, no. 22 (November 15, 2005): 4771–86, doi:10.1080/00207540500137555.

18. Jiang Wei, "Intelligent Control on Work-in-progress Inventory Based on Biological Modulation Mechanism," in 2009 International Workshop on Intelligent Systems and Applications, ISA 2009, May 23, 2009 - May 24, 2009, 2009 International Workshop on Intelligent Systems and Applications, ISA 2009 (IEEE Computer Society, 2009), Hubei University of Technology; Huazhong University of Science and Technology; Huazhong Normal University; IEEE Harbin Section, doi:10.1109/IWISA.2009.5072920.

19. P. Kaminsky and O. Kaya, "Inventory Positioning, Scheduling and Lead-time Quotation in Supply Chains," International Journal of Production Economics 114, no. 1 (July 2008): 276–93, doi:10.1016/j.ijpe.2008.02.006.

20. Dong Tang, "Managing Finished-goods Inventory Under Capacitated Delayed Differentiation," Omega 39, no. 5 (October 2011): 481–92, doi:10.1016/j.omega.2010.10.006.

21. Liuxin Chen, Youyi Feng, and Jihong Ou, "Joint Management of Finished Goods Inventory and Demand Process for a Make-to-stock Product: a Computational Approach," IEEE Transactions on Automatic Control 51, no. 2 (February 2006): 258–73, doi:10.1109/TAC.2005.863484.

22. S. Wadhwa, K.S. Rao, and F.T.S. Chan, "Flexibility-enabled Lead-time Reduction in Flexible Systems," International Journal of Production Research 43, no. 15 (August 1, 2005): 3131–62, doi:10.1080/00207540500076530.

23. S. Wadhwa, K.S. Rao, and F.T.S. Chan, "Comparative Influence of Three Flexibility Types on Manufacturing Lead-time Performance," International Journal of Advanced Manufacturing Technology 29, no. 9–10 (2006): 1002–7, doi:10.1007/s00170-005-2603-3.

24. J.M. Pinilla and F.B. Prinz, "Lead-time Reduction through Flexible Routing: Application to Shape Deposition Manufacturing," International Journal of Production Research 41, no. 13 (September 10, 2003): 2957–73, doi:10.1080/0020754021000032040.

25. Yi-Chi Wang, "Evaluating Flexibility on Order Quantity and Delivery Lead Time for a Supply Chain System," International Journal of Systems Science 39, no. 12 (December 2008): 1193–202, doi:10.1080/00207720802298939.

26. Mark A Nash and Poling, Mapping the Total Value Stream: a Comprehensive Guide for Production and Transactional Processes (Boca Raton: CRC Press, 2008).

27. A. Esfandyari et al., "Application of Value Stream Mapping Using Simulation to Decrease Production Lead Time: a Malaysian Manufacturing Case," International Journal of Industrial and Systems Engineering 8, no. 2 (2011): 230–50, doi:10.1504/IJISE.2011.041371.

28. T. Edtmayr, P. Kuhlang, and W. Sihn, "Methodical Approach to Designing Workplaces and Increasing Productivity Based on Value Stream Mapping and Methods-time Measurement," Transactions of Famena 35, no. 1 (2011): 91–9.

29. P. Singh and H. Singh, "Application of Lean Tool (value Stream Mapping) in Minimisation of the Non-value Added Waste," Applied Mechanics and Materials 110–116 (2012): 2062–6, doi:10.4028/www.scientific.net/AMM.110-116.2062.

30. B. Singh, S.K. Garg, and S.K. Sharma, "Value Stream Mapping: Literature Review and Implications for Indian Industry," International Journal of Advanced Manufacturing Technology 53, no. 5–8 (March 2011): 799–809, doi:10.1007/s00170-010-2860-7.

31. "Windsor assembly plant", Chrysler 2013

32. "Vehicle completion center in Windsor", Chrysler 2011

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