UNIVERSITY OF KAISERSLAUTERN

PROJECT WORK

# Discrete Event Simulation of Assembly Lines


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*"Don't water your weeds."*

Harvey MacKay

UNIVERSITY OF KAISERSLAUTERN

# *Abstract*

Project work

**Discrete Event Simulation of Assembly Lines**

by Amita SINGH

This project describes the influence of lean manufacturing in factory planning. It aims to define and discuss the term lean manufacturing as well as to present scenarios for increasing efficiency of the production system. Furthermore, it deals with an existing assembly line and focusses on making different line segments lean. Different ways based are introduced to increase the efficiency of the assembly line. From the presented scenarios, a plausible solutions is achieved through discrete-event simulation. This solution is then implemented on the assembly line.

**Keywords:** Lean Manufacturing, Assembly Line, Simulation, Discrete-Event Simulation

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# Contents

# Chapter 1

# Introduction

## 1.1 Project description

With the increasing demand and high competition in the market continuous improvement towards making the production system more efficient is the key to sustain the business. One of the comprehensive and practical ways is lean manufacturing. Lean manufacturing is a collection of improvement activities which focus on eliminating waste of all forms from the manufacturing processes. This also includes optimizing processes and resources for a line. Not all optimization suggestions or techniques can be implemented directly on assembly line. With the daily production schedule and demand pressure it is important that any optimization suggested is thoroughly discussed and validated. Hence, digital mock-ups and simulations were introduced. Simulation is the imitation of the operation of a real-world process or system over time. It helps not only in the saving time and resources but also allows us to test more scenarios. With the correct and complete data real-time simulation of a process is possible. Simulation also helps in understanding different constraints and results of different processes. Thus, simulation plays a key role in the optimizing a production system.

The project aims at making the assembly line more lean and, thus, increasing efficiency using simulation. In the following chapters, various definitions, concepts and aspects of the project are introduced and discussed. Chapter 4 describes the present scenario and summarizes the challenges of working with an existing assembly line. Based on the constraints, solutions are developed. While finding the solutions the assembly line is studied both statically (Chapter 7) and dynamically. Simulations for different scenarios were performed and results were studied in Chapter 8.

## 1.2 About Deere & Company

Deere & Company is the largest producer of agricultural, construction and forestry machinery. It was founded by John Deere in the year 1837 in Illinois, US. Today, John Deere is a global entity with more than 57,000 employees in a total of 64 factories worldwide. Agriculture & Turf equipment (75%) is still the company's biggest segment. There are two additional business units: construction and forestry (17%) and John Deere Financial (8%). John Deere produces tractors of up to 560 HP power, combines, foragers and a wide range of implements apart from a wide selection of homeowner, commercial mowing and turf products. In addition to supplying to its own factories globally, the company also sells diesel engines and transmission to OEM manufacturers as well as replacement and all-makes parts. Net earnings were $1,9 billion (US dollars) in FY 2015, on total revenues of $26 billion (US dollars).

The project was done on the Operations Simulation Group, a part of the Manufacturing Engineering Department. The simulation group is divided into four sub-groups, namely, North America, southern America, Asia and the region of Europe, Africa and Middle East (EAME). The group responsible for EAME area is located in Mannheim, Germany, in the Deere & Company European Office.

# Chapter 2

# Definitions

## 2.1 Assembly line

Assembly line is a process commonly used for efficient mass production [29]. Assembly line generally consists of $n$ number of work stations arranged in a sequence and linked by a conveyor. These work stations can be fully automated *i.e.* robots perform the complete task at a particular station or semi-automated *i.e.* the operation is performed by a robot maneuvered by a technician or even completely manual which means complete work is done by technicians. The total work content of a product is divided into the $n$ number of stations depending upon the throughput required. Assemblers work on the fitment at a station and the part moves sequentially from one station to another. This minimizes worker movement and thus increases worker productivity. The concept was introduced by Henry Ford.

In order to facilitate assembly line design and analysis, customer demand is the designing parameter. However, given the dynamic nature of production a production system cannot be developed to manufacture a fixed nature and number of products to be produced.

Planning is generally categorized into the green field planning and already existing assembly line planning. Optimization is an ingrained part of planning and focusses on making the process more efficient.

### 2.1.1 Green field planning

The term Green field was originally used in construction and development to reference to land that is never been used. Today, the word is used across disciplines to refer to an imaginary situation in which a concept could be implemented in its pure form; without consideration to existing conditions should be taken. In production Green field planning refers to the planning of a project which is yet to begin. This means that no prior work has been done on the project. This gives planners the opportunity to optimize the assembly line more efficiently as compared to an existing line. For instance, it is easier to install equipment without the constraints of number of stations, conveyor speed, bottleneck *etc*.

### 2.1.2 Existing line planning

This refers to changes on an already built line. It can be both a change in process or product which might result in change in the number of stations or replacement of a resource. With a given layout at times it is difficult to incorporate the changes in the set-up or it might reduce the efficiency of the process. As this project it done for an already existing line; the challenges faced in the modification process of such a line is discussed in detail in Chapter 4.

## 2.2 Takt Time

Takt time is defined as the ratio of time available during production to the demand to be met during that production time [21].

Takt time is the concept to design work, and it measures the pace of customer demand. In terms of calculations, it is available time to produce parts within a specified time interval divided by the number of parts demanded in that interval. The number you get tells you, for instance, one part is to be produced every three minutes to match customer demand.

$$\text{Takt time} = \frac{\text{total time available during a shift}}{\text{number of parts to be produced in that shift}}$$

$$T_k = \frac{T_{TH}}{D} \tag{2.1}$$

where $T_k$ is the Takt time, $T_{TH}$ is the total available time and $D$ is the demand.

It can also be defined as the time interval between two outputs [2]. Takt time means the total available time for production that excludes breaks and equipment downtime.

An assembly line is generally built for a range of Takt time. Demanding on the customer demand Takt time can be adjusted. If cycle time is bigger than Takt time, it means that the time required to complete a task is bigger than Takt time.

## 2.3 Lean Production

Lean manufacturing originated in Japan with the objective of eliminating *muda*, the Japanese term for waste in order to make the process more efficient and to get more value for the end customer product. Today, Lean is an important aspect of many businesses including production. The core principles of lean manufacturing were given by the managers of Toyota Group and thus it is also known as Toyota Production System [4].

Lean cannot be coined as a strategy or technique but rather it is an assortment of philosophies, attitudes and methodologies collectively known as lean. This covers a variety of tools to optimize resources, production time, assets and at the same time product quality and customer satisfaction [23]. The philosophy of lean production is based on the assumptions that lean manufacturing techniques lead to improvement in quality of product and processes. Different tools used to implement lean production are Just-In-time, 5S, Andon, Continuous flow, bottleneck analysis, poka yoke, PDCA, etc. Tools, for instance, Kaizen and Kanban are focused on market demand and waste elimination [5, 8].

Lean production can thus be understood as a comprehensive strategy which takes into consideration and simultaneously attempts to optimize and synchronize them creating a value chain and not as independent subparts with local optimization [1]. This philosophy is built around the desire to manufacture in a continuous flow and without relying on long production and delivery times. One reason for this was the recognition that just small fractions of the total production time add value to the end customer [4]. This led to the idea of one-piece flow and flexible production system without waste. But lean manufacturing not only eliminates waste by controlling the quantity but it also controls the quality of production. It, therefore, strives to achieve the optimum solution between quality and quantity.

In Lean production, waste is defined as any activity which does not add value to the customer. Lean production defines waste into categories depending on whether it can be eliminated from the system or not. There are wastes which cannot be eliminated from the system, for instance, certain minimum level of inventory or maintenance processes, *etc*. Waste can be segregated into the following categories:

- Defects
- Overproduction
- Inventory
- Waiting
- Unnecessary motion
- Transportation
- Overprocessing

All these aspects result in decreasing the variability of the process and thus it results in bottleneck removal. With uninterrupted process, it reduces the cost to company making the product more value stream. Value stream in this case means all linked events or activities which ultimately deliver value to customer [1].

Another approach used in Lean Production to achieve a high level of flow is continuous improvement and knowledge management [10]. Continuous improvement means learning and improving processes iteratively and the latter attributes to knowledge gained from past experiences.These activities resulting in more refined and efficient process.

The main advantages of using this manufacturing philosophy are a high rate of profitability, reduced costs, increased productivity, and customer satisfaction based on high levels of quality and short lead times [4], highlighted that these advantages are even true during periods with slow growth.

With lean production it is important to distinguish between overall guidelines and the tools to be used for implementation [19]. As mentioned, lean tries to reduce waste in the production by defining 3M's – Man (labor), Machine (equipment) and Material – and also tries to balance these aspects to reach a process with no bottlenecks and short lead times. The following steps were defined to achieve the ideal process [6, 4].

- Identify features which create value to customer.
- Identify processes along the value stream
- Make the process uninterrupted
- Customer demand should govern production
- Perfect the process

Lean production assumes that any small improvements made in the product or process will result in overall improvement of production system. These changes can come through Kaizen activities. Kaizen is suitable when a process needs continuous improvement but cannot be used in the scenario where the whole process needs to be changed [24]. Moreover, it also assumes that reducing waste will lead to better performance. These relate to the cost of inventory, resource and bottlenecks. Reducing these will result in better fiscal coefficients making the production system more efficient and thus more lean.

## 2.4 Precedence

There exists a line of action along which tasks are performed while doing an assembly. Precedence chart is a representation of operation sequence and their dependence on each other [13, 11]. This helps in understanding the assembly operations and thus making a decision regarding change in the assembly line. Any change to assembly line that does not conform to the precedence chart is not a viable change in the assembly. Hence, a complete precedence chart should give a clear understanding of the possible solutions.

## 2.5 Constraints

Constraints with respect to an assembly line mean limitation placed on the production of an assembly line [13]. These constraints can be of varied nature, for instance, safety constraint, resource constraint, workplace constraint, line-up constraint.

Safety constraints, generally, describe which actions are prohibited on the assembly line owing to the risk attached to such actions.

Resource constraints deal with specialized machine or operator required to do a task. A machine capacity can be a restraining value; the whole process can be governed by the machine throughput or likewise a skilled labour can be a constraint [14, 3]. If a certain set of skills are required to complete a task, then technicians working on the task should be well versed.

Workplace space can be constraint in some cases. Similarly, work content concerning the production line-up can also be a limiting factor. Consecutive heavy workloads can result in imbalanced line [9, 7].

These are some general constraints with already existing line and thus should be kept in mind while making decisions regarding line design.

## 2.6 Production Scheduling (Line-up)

The aim of production scheduling is to meet customer demands within the proposed time. This demand is to be met along with the optimization of different variables of production, thus making production more efficient [16]. Thus, the goal of production scheduling is to strike a profit-able balance between different parameters of an assembly line. Line-up sequence is the sequence of manufacturing of parts on the assembly line. This sequence is defined depending upon the model and option demands. While deciding the line-up, different parameters are kept in mind, for instance maximizing resource utilization, reducing inventory costs, minimizing work-in-process, short customer lead times coupled with on time product delivery.

# Chapter 3

# Simulation

## 3.1 Definition

Simulation is imitation of any real-world processes over time using computer. The process of interest or subject at hand is commonly known as system and in order to study it scientifically certain assumptions are made about the working of the system. These assumptions usually take form of mathematical relationships which is called model of the system [25]. In simple systems these models can be simple mathematical expressions and can be expressed analytically. But generally real world problems are complex and thus it is not possible to study such models analytically. Therefore, computers are used to evaluate a real world model and gather data in order to estimate the desired true characteristics. Simulation is one of the most widely used operations-research and management-science techniques. Simulation applications are numerous and diverse. Below is the list of some particular kinds of problems for which simulation has been found to be a useful and powerful tool [18]:

- Designing and analyzing manufacturing systems
- Determining ordering policies for an inventory
- Reengineering of business processes
- Designing and operating transportation systems such as airports, freeways, ports, subways, *etc*.
- Evaluating designs for service organizations such as hospitals, post-offices, call centers, restaurants, *etc*.
- Evaluating military weapons systems or their logistic requirements
- Analyzing financial or economic systems
- Determining hardware requirements or protocols for communication networks
- Determining hardware and software requirements for a computer system

## 3.2 History of Simulation

Simulation has proven to be useful in many areas. Over the years simulation has developed in more than one ways. Therefore, it can be seen from many perspectives-application domain or community of use — which leads to different types of simulation-discrete-event, continuous, combined discrete-continuous-these different types of simulations have different environments and programming languages supporting them [22, 12].

From 1945–1970 were the formative years of the computer based simulation. With the construction of first general-purpose electronic computers and the use Monte Carlo method on these computers in order to solve certain problems led to rapid growth in the field of simulation [15]. The increasing availability of general-purpose electronic computers also set the stage for rapid proliferation of simulation techniques and applications in other disciplines.

During the 'Expansion period' (1970–1981), enhanced modeling and analytical tools were developed. In the field of discrete-event simulation specialty simulation products for niche markets were developed [15]. Some advances with respect to analytical work including developments in input modeling, study of modern optimization techniques and contributions to output analysis were also made. Owing to the advancements in technology and computers starting early 1980s simulation has been used in various fields varying from military usage to restaurants.

## 3.3 Simulation of manufacturing systems

Simulation use is widespread from designing to optimizing manufacturing systems. Increased competition has resulted in greater emphasis on productivity and quality [28]. Since these systems are very complex they are usually analyzed by simulation. Equipment and facility costs can be quite high. On the other hand computing costs have decreased owing to the development in software industry. Consequently, improvements in simulation software have reduced model-development time making it feasible for the manufacturing industries to use these softwares.

Simulation helps planner or engineer to obtain a holistic view of the effects of local changes implemented on assembly line. It shows the impact of change made at a particular work station on the performance of the complete line which In turn helps in decision making process. Without the knowledge of this impact, it is difficult to foresee or comprehend such complex situation [27]. If a change is required after, say an installation of a machine retrofitting of such machines can be difficult. Simulation allows the developers and line managers to quickly analyze the system under various operating conditions. Simulation is virtually a necessity to perform any rigorous and meaningful analysis on a modern production line. It is capable of modeling at the required level of detail and it can establish confidence levels around results for a wide range of issues.

In addition to the above benefit, there are a number of potential benefits of using simulation in manufacturing analyses. Below are these benefits [18]:

- Increased throughput (parts produced per unit of time)
- Decreased times of parts in system
- Reduced in-process inventories of parts
- Increased utilizations of machines or workers
- Increased on-time delivery of products to customers
- Reduced operating costs
- Validation of proposed design of manufacturing system
- Validation of production scheduling
- Validation of control strategies
- Validation of quality control, JIT and inventory level
- Helps try more designs

Simulation can create a well-balanced line that has the flexibility to hit targeted throughput consistently. With a simple simulation of the line assembly operations we can identify system bottlenecks, run different production schedules, and evaluate the impact of design and scheduling decisions, such as buffering requirements and product mix. This what-if analysis can be done quickly and accurately to evaluate all the conflicting decision criteria.

## 3.4 Discrete-event simulation

Discrete-event simulation (DES) is a form of computer-based modeling that provides an intuitive and flexible approach to representing complex systems [17]. Though conceptually DES model can be developed on paper but the amount and complexity of data make it impossible to do the calculations without digital computer. DES has increasingly been applied to analyze system with constrained resources where the general aim is to make the production system more efficient or in other words 'lean'.

Discrete-event simulation concerns the modeling of a system as it evolves over time by a representation in which the variables change instantaneously at separate points in time [18]. A DES model consists of finite number of sequential points in time. These points are called variables which change state as soon as an event occurs. An event is defined as an instantaneous occurrence in the system. Between two events no change in system is assumed, so system can jump from one stage to another. This makes the simulation much faster as compared to continuous simulation where system moves without interruptions.

Contrary to discrete simulation, continuous simulation is based on modeling of a system in which the variables change their state continuously with time and thus are typically represented by ordinary differential equations.

Though discrete-event simulation and continuous simulation are used in different scenarios depending on the specific objectives of the study, discrete-event simulation moves in discretized 'steps', and thus takes less time and less computational power.

## 3.5 MIDAS

MIDAS is an acronym for Manufacturing Improvements Design and Analysis Simulator [20]. It is a dynamic analysis simulation tool based on discrete-event simulation. It is used to improve existing processes and validate new processes. It helps in understanding the manufacturing processes in the very early phases of design. By doing so, MIDAS can [20]:

- Identify capital avoidance opportunities by reducing resources (number of machines, buffer sizes, number of technicians, *etc.*) and process complexity.
- Reduce manufacturing cycle times by eliminating bottlenecks, and providing a flexible manufacturing process in terms of volume and mix.
- Improve operating return on assets by increasing throughput, improving utilization of expensive resources (machines, robots, technicians, *etc.*), and reducing inventory.
- Help develop better balanced assembly lines.
- Analyze material flow and equipment usage.

# Chapter 4

# Challenges of an existing line

Re-designing an already built line with so many different and potentially conflicting variables in the production system it might be difficult to predict a new or revised process [26]. The inter-dependencies between process constraints and design objectives are generally complex and difficult to recognize. Re-designing an existing assembly line can result in production loss and overworked or under-worked operators.

The following factors can add complexity to the design of an assembly line:

- Constraints on line
- Mobility of resources/machines
- Precedence of operations
- Material flow on assembly line
- Size of line buffers
- Sequence and mix of product
- Throughput

There are static analytic calculations used to re-design the assembly line, but are limited due to the dynamic nature of the system. It is difficult to incorporate all variables of a dynamic system in static calculations. The impact of buffering, shift patterns, and product sequence quickly confounds this approach for line design and balancing. The challenges faced during the process of re-designing the assembly line for optimizing production are as follows:

**Throughput:** With varying market demand recognizing a new throughput for which the assembly line can be modified is a challenge. A compromise is therefore sought in such cases where assembly line can accommodate the changed number of products to be produced on the line at the same time optimizing resources for both current and future scenarios.

**Mobility of resources:** In an existing line, generally a number of resources which can perform operations only in a given restricted area. For instance, overhead transmissions and robots are already installed. Moving these resources will incur huge costs and therefore are commonly not recommended. Therefore, while re-designing the assembly line fixed resources and hence their area of approach should be treated as a constraint.

**Precedence of operations:** Precedence is an important factor while re-designing any assembly line. Precedence decides the logical sequence of operations in order to efficiently build an assembly. For instance, without battery bracket fitment battery cannot be installed. This means in order to do perform Operation$[B]$ it is necessary to complete Operation$[A]$. In other words Operation$[A]$ is a prerequisite for operation. Though efficiency of assembly line might increase by completing operation before Operation$[A]$ but the precedence does not allow the operation sequence. Hence, while making changes to an existing line it is important to ensure that the changes follow the operation precedence.

**Material flow on assembly line:** In an existing line, there exists the process of material flow and handling. This inflow of material on the required station can be through another sub assembly or material can be routed to this station through an automated process, for instance, a *Power & Free* conveyor might be used to drop a painted cab from paint shop to a station where cab fitment on chassis is performed. Therefore, if the process or line is re-designed it is important to ensure the position of such facilities and the complete material flow process.

**Size of line buffers:** In an existing line, buffer size is predefined and thus any changes made to line or production should keep in mind the inventory allowed on line. On an already built line the space allotted to buffers are generally fixed. Owing to the constraint, it is difficult to increase the size of buffer and consequently the production and therefore is treated as a constraint while re-designing an existing line.

**Sequence and mix of product:** Commonly an assembly line is developed for a range of production sequence and mix. The production schedule is flexible and should be able to accommodate new changes to production. If a new variable is introduced by changing the line as in this case by minimizing the number of stations to make production more lean, then it becomes difficult to maintain the range of sequence and mix of product as the space assigned is less as compared to the former case. For instance, if the number of stations is minimized the two consecutive heavy work content parts are difficult to produce. This might result in a bottleneck and eventually might cause loss of production.

**Constraints on line:** In an existing line, there can be a number of constraints, for instance safety constraints, workers' skills or space allotted to workers, might be treated as a major line designing parameter. While minimizing the number of stations on line, the results of analysis might show that two instead of one worker should be assigned to a particular station but due to safety issue it might not be possible, or due to space constraint two workers might not work simultaneously at a station.

# Chapter 5

# Assumptions

**No re-work:** It is assumed that in the simulation process no part needs re-work. Parts are produced in the first time with no imperfections. There are no stations for repair owing to this assumption.

**No absenteeism:** An assumption is made that the technicians required to execute the process are present and they have the necessary skills. The line does not stop due to unavailability of technicians.

**Material available:** Raw material required for production is always available on the line. There are no problems in the material flow process. The material flow is smooth and uninterrupted.

**No downtime:** Machines are available and work as expected for the whole simulation time. No repair times or preventive action times are considered. This is done to ensure simple calculations without eliminating any important factor influencing the process simulation.

**Technicians share work:** It is assumed that technicians at a particular station can share the work. So a task $p$ can be divided into $n$ smaller sub-tasks, where sub-task $q > 0$ minutes. This sub-task $p$ is user defined. Depending on the work content, a realistic value of $p$ is decided.

$$p = \sum_{i=1}^{n} q_i \tag{5.1}$$

where $i^{\text{th}}$ partition of the task takes $q_i$ minutes. This is one way of sharing work in simulation.

**FIFO:** It is considered that the first part coming in the system will be the first part to go out of system. Technicians will work on the first part and complete it before going to the second part. In other words, technicians cannot work on the second part unless the work assigned to them corresponding to the first part is complete.

**Conveyor stop:** It is assumed that a fixed pace conveyor can move forward iff the work for the parts reaching the end of segments is complete in all respect. If there is an unfinished part reaching the end of a segment then the whole conveyor will stop causing delay to all other parts. It is for this reason that the assumption is made that there are no repairs on the line. Any repair will result in stopping the line and thus decreasing productivity.

**No move time:** It is considered that operator movement does not take a significant part of the operation time and can thus be neglected. Any operator movement between two stations or between station and buffer can be neglected. In the real scenario, this will not always be true. In such cases, walking times and movement times are to be provided for simulation.

# Chapter 6

# Model

## 6.1 Model Description

In this report, a simulation model for an assembly line is developed. This section provides an overview of the model.

The simulation model aims to simulate the assembly line with a special focus on making the production lean by re-allocating the work content and thus consequently minimizing the number of stations. Fixed pace conveyor is chosen as the material handling system. Parts move on a fixed pace conveyor through the system [cf. 6.1]. Moreover, carrier itself moves along unidirectional path from one station to the next. At the segments of the conveyor, different value-added tasks can be done, for instance, machining or assembly. These tasks can be done manually or can be fully or semi-automated.

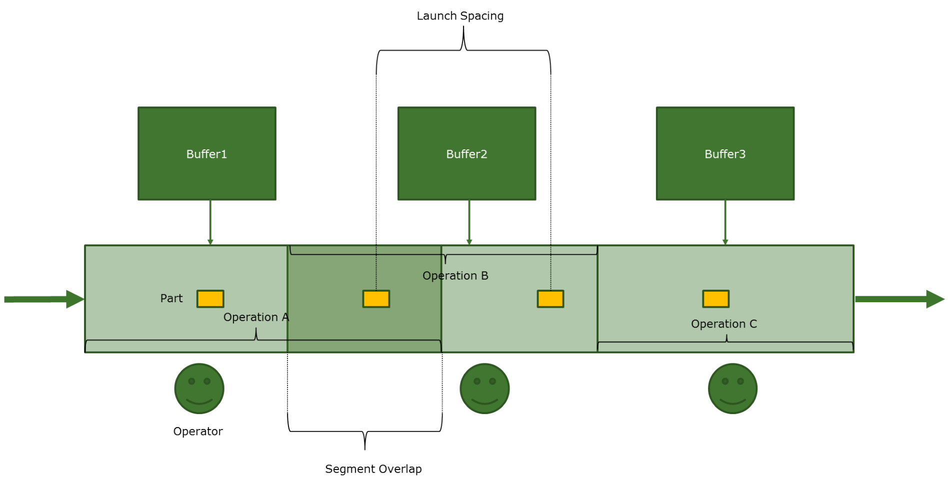


FIGURE 6.1: The model

Furthermore, different part types can be simulated, which vary in shape and size. Moreover, these parts can also vary in the needed operations done along the conveyor; thus, one type can need an additional check on quality, whereas other does not need this operation. The time available for an operation assigned to a segment is determined by the speed of conveyor and the number of technicians working in the particular segment. The following list provides an overview of all different modeling items and their attributes [20].

### 6.1.1 Fixed Pace Conveyor

Fixed Pace Conveyor is used to move parts along a specific path at a constant speed. Technicians work on these parts the segments assigned to them along the moving conveyor. The conveyor is based on the following two major constraints:

- Technicians complete the work to be done on parts in sequence. For instance if part [A] is loaded on line before part [B] then work is executed and completed on part [A] before part [B].
- If a part reaches the end of segment and the work to be executed on the part in the particular segment is not complete, then the conveyor will stop till the work is completed. The conveyor will again start moving when the work is done on the part.

### 6.1.2 Process Parameters

Process is described by the following variables:

1. **Conveyor Segment**: Place where value-added tasks can be done, either by machines or by technicians. Attributes are mainly related to the work, like how many machines or technicians are in the segments. Fixed pace conveyor is divided into one or more segments. These segments defined by a start and an end point and a length. Segments, denoted by Operation$[A]$, Operation$[B]$ and Operation$[C]$ in the Figure 6.1, are the physical workspace in which technicians have to complete the assigned work. The assigned work should be completed by the end of this segment otherwise the conveyor will stop causing the complete assembly line to stop.

   Conveyor segments can overlap that is $(n+1)^{\text{th}}$ segment can begin before $n^{\text{th}}$ segment ends. In other words, technicians on $(n+1)^{\text{th}}$ segment can start working before technicians on $n^{\text{th}}$ segment complete their work, thus in the segment overlap region technicians on both segment can work simultaneously.

2. **Launch Spacing:** Used to measure the distance between the two carriers on the conveyor. Carrier or skid distance is measured from center-to-center. It is important to measure the distance from center-to-center otherwise, for instance, measuring distance between the skids might yield incorrect results.
3. **Parts:** Object on which operations or value-added activities are to be performed. Attributes relate to shape and size and the tasks which need to be done on the part.
4. **Process:** Type of when parts get delivered to the loading station to be entered into the system. Attributes refer to when, what and how parts are generated at the loading station, like in a random or time-stamped way.

5. **Operation:** Task which should be performed on a part in a segment. Attributes refer to the number of tasks, machines used and the number of technicians required and the time needed to complete the tasks.
6. **Buffer:** An excess resource that corrects for misaligned demand and transformations due to inventory, time or capacity. Attributes refer to location and capacity of the excess resource.
7. **Schedule:** Work plan to control operations over time, for instance for technician work times or needed breakdowns.

The simulation model provides the following outputs after the simulation:

- Throughput in terms of parts produced per day and per part type;
- Throughput in terms of loaded parts per day and per part type;
- Buffer utilization during the different schedules and their average, maximum and minimum number of parts during a schedule;
- Part delays per simulation and per station;
- Parts consumed per part type;
- Parts discarded during simulated week;
- Technician utilization during the different simulated weeks according to simulated time per schedule, per day and per work;
- Throughput in terms of parts unloaded as per sequence and per part type.

**Worker flexing** is an important concept used in the process. Worker flexing defined as a process wherein a worker moves between places to complete different tasks. This is significant because a technician might be moving between station [A] and station [B] to complete a part of both the operations by working 30% and 40% task of his total time at respective stations and eliminate another resource.

# Chapter 7

# Static Calculations

Static data analysis are done to detect bottlenecks by analyzing input data of the simulation model, also called input-data analysis [28]. The calculations do not consider any randomness in the system and thus give only a rough overview of the system or simulation behavior. The technique is good for both validation purposes of simulation [1] since it provides first insights into the system as well as leverages static guesses where bottlenecks can be located.

To make educated guess about the bottlenecks it is important to have certain parameters about the system. Below are the parameters up on which the static calculations rely:

**Line-up sequence:** Line-up can be described as the sequence of vehicles produced in an assembly line. This sequence is mixture of different variants of products and consequently different work contents. The sequence of line-up is generally such that the work is distributed equally throughout the process. Therefore, it plays a significant role in balancing the assembly line and smoothing the production process.

So while describing a process it is important to consider the sequence. Though line-up may not have significant effect on the static calculations of the production system, it definitely affects the dynamic process.

**Work Time in Minutes (WTM):** Total minutes available for production. This available time is considered to calculate the Takt time of a process. This time does not include any breaks during a production shift or any machine downtime.

**Takt Time:** As soon as the time horizon of the simulation and the demand of the system are known it is possible to calculate the Takt, in parts per unit time of the system as shown in the equation (2.1), repeated here for completeness:

$$T_k = \frac{T_{TH}}{D}$$

where $T_k$ is the Takt time, $T_{TH}$ is the total available time and $D$ is the demand.

**Operation:** Operation is defined as the work content assigned to a workplace. One or more operations can be assigned to a workplace or in case of a fixed pace conveyor a segment. Operation is further composed of one or more tasks. Task is therefore the smallest unit of work in the system.

**Conveyor Speed:** Conveyor moves at a fixed speed in *metres per second*.

**Technicians:** The number of technicians assigned to a particular segment of the conveyor.

**Time available:** Time available depends on conveyor speed, segment length of the conveyor and the number of operators doing the operations:

$$T_a = \frac{l \times e}{s} \tag{7.1}$$

where $T_a$ is the time available, $l$ is the length of conveyor segment, $s$ is the conveyor speed and $e$ is the operator efficiency.

**Total Time available:** Total time available is expressed in terms of the number of operators working in a conveyor segment. It can be mathematically written as:

$$T_{TA} = T \times N \tag{7.2}$$

where $T_{TA}$ is the time available for one operator and $N$ is the number of operators.

**Technician Utilization:** Technician efficiency is defined as the ratio of the time for which a technician works to the total time available. Technician utilization can be expressed for each part or day, or for the complete line-up. Depending upon the requirement technician utilization is expressed.

**Operator Efficiency Factor:** This is defined as a factor that differentiates a skilled worker from an unskilled worker. Training helps in increasing the operator efficiency factor. The factor is determined by the company as a constant that is used at all factories company wide. Static calculations are made here with sample data. The data has operation times for 4 models of vehicles as shown in Table 7.1. These operation times serves as the basic data. Calculations were done for the line-up of a whole week. This data is generated using random ordering of vehicle models, shown in Table 7.2.

| Model | A time | B time | C time |
|---|---:|---:|---:|
| XJ | 141 | 838 | 233 |
| JZ | 51 | 0 | 319 |
| VN | 603 | 766 | 272 |
| NF | 60 | 0 | 333 |

TABLE 7.1: Operation times required (in seconds).

The number of operators at each station is 1. Converyor segment length for each operation is 7.8 *metres* and operator efficiency factor is taken as 1. Conveyor speed is 1.5 *metres pers second*.

| Model | A time | B time | C time |
|---|---|---|---|
| XJ | 141 | 838 | 233 |
| XJ | 141 | 838 | 233 |
| NF | 60 | 0 | 333 |
| JZ | 51 | 0 | 319 |
| JZ | 51 | 0 | 319 |
| VN | 603 | 766 | 272 |
| XJ | 141 | 838 | 233 |
| NF | 60 | 0 | 333 |
| JZ | 51 | 0 | 319 |
| NF | 60 | 0 | 333 |
| NF | 60 | 0 | 333 |
| VN | 603 | 766 | 272 |
| VN | 603 | 766 | 272 |
| VN | 603 | 766 | 272 |
| NF | 60 | 0 | 333 |

TABLE 7.2: Line-up with operation times (in seconds).

With the given process parameters and operation times, static calculations were done as shown in Table 7.3. The table shows average operation time required for each operation as well as the total time available for the operations. From the table, it can be inferred that Operation$[B]$ is the major bottleneck of the given process. This calculations later serve as base to conform simulation results.

| **Operation Name** | **Operation**$[A]$ | **Operation**$[B]$ | **Operation**$[C]$ |
|---|---|---|---|
| **Average Operation Time** | 219.2 | 371.8 | 293.9 |
| **Total Time Available** | 312 | 312 | 312 |

TABLE 7.3: Static calculations for the line-up.

# Chapter 8

# Simulation results

Simulation was made for the presented scenario and was run for different parameters to find an optimal solution. It gave certain deeper insights which were not obvious from the static math of the model. Also, simulation helped in understanding the bottleneck and its characteristics.

A base model for the proposed future scenario was developed. This base model highlighted a bottleneck in the process. The bottleneck was then eliminated after several scenario simulations. This simulation resulted in a plausible solution for the current bottleneck. The simulation was run for different operator efficiency factors resulting in varied results.

By increasing the operator efficiency factor from base efficiency factor of 1 to 1.112, number of converyor stops can be decreased by 46%. This decreased conveyor segment length helps to accomodate the bottleneck by increasing the segment length of Operation[$B$] by 12.8%. Still the bottleneck was not eliminated so depending upon the company standards operator efficiency factor can be further increased. For the presented simulation, this factor was increased by 22.5%. The simulation was again done for this scenario. The total number of conveyor stops due to bottleneck station decreased by 21%. Therefore, at Operation[$A$] operators should work at higher operator efficiency factor to help eliminate the bottleneck.

The efficiency factor of operator at Operation[$B$] was also increased to meet the demand at Operation[$B$]. Furthermore, one more operator was added to the bottleneck station to increase the efficiency of the assembly line. Both operators at this station work at efficiency factor of 1.225.

Conveyor segment length for Operation[$C$] was validated by running the simulation for all four variants built on the assembly line. These simulations were done for each variant separately by segragating the line-up based on models.

# Chapter 9

# Solutions

The model was simulated with the data of the present scenario to find out the existing bottlenecks, if any. In order to accommodate the future scenario while keeping the process efficient the problem is broken into smaller parts to know the feasibility for each problem segment.

The solution was investigated for the given line-up and conclusions were also drawn for each segment of the conveyor and also alternatively for each variant of the product. Combining all the factors a complete scenario is built and the different parameters of segment lengths, line-up sequence and operator efficiency factor are achieved. The most pragmatic solution was chosen for implementation on the assembly line.

The process is divided into groups of operations clustered and considered as one. Each segment on the conveyor process is then investigated for bottlenecks and process parameters. Later, overall process overview and parameters are developed. These problem portions discussed in the following sections.

1. Finding bottleneck in the process
2. Least segment lengths with no conveyor stops for different operator efficiency factors
3. Finding least segment lengths for all product variants

## 9.1 Finding bottlenecks in the process

Bottleneck operation is the limiting capacity operation of a process and is thus used to define the capacity of the whole assembly line. Therefore, to increase the capacity of a line it is important to increase the capacity of the bottleneck operations.

In this process, Operation$[B]$ is the bottleneck and should be resolved to accommodate more parts for the future scenario.

### 9.1.1 Increase Operator Efficiency Factor

Operator efficiency factor is gives the time available to an operator for an assembly operation. Increase the efficiency factor will lead to more time for the operation. This additional available time may or may not be sufficient to increase the capacity at the bottleneck. So the available time was first increased by 11.2% and then to 22.5% by taking two different efficiency factors. Operator efficiency factor can only be increased to a certain limit. This limit has been set to 22.5% in this case. Though increment by 11.2% is preferred but efficiency can be still further increased to 22.5%, if required. In this case, both the efficiency increment could not accommodate the new operation introduced on line. Thus, another solution should be investigated to find a solution.

### 9.1.2 Increase segment length

Increasing the operation area length generally needs resources, fixed or otherwise, to be move on the line. Costs are incurred in moving the fixed resources. These costs add to the cost to company for parts and therefore are not encouraged. Also with increasing the operation area length will come at the expense of other operation areas. On an existing conveyor, one operation area length can be increased by decreasing the length of adjacent operation areas. It is in this interest that the operation area length of adjacent areas is studied. This is discussed in detailed in the paragraph 9.2. The increment length for operation will be the length by which operation A and operation can be decreased.

### 9.1.3 Increase the number of operators

In the present scenario, one operator is working on Operation$[B]$. One of the simulation objectives was to check if adding an operator to this operation will resolve the bottleneck. The operation tasks were divided into two and assigned to the two operators. The results still yielded a bottleneck. In this case, the segment length can be increased as discussed in the above paragraph and a combination of 9.1.1 and 9.1.2 can give a solution. However, if this solution is implemented, the company will have to incur one one-time cost for moving the fixed resource if it is required and one recurring cost of the additional operator to be employed for this operation. To save these costs the idea is further sub-divided and studied.

### 9.1.4 Decrease work content

Bottleneck can be eliminated by decreasing the work content of this operation by moving some tasks to other operation areas. It is here that precedence plays an important role. There are tasks which cannot be shifted to Operation$[A]$ because only after Operation$[A]$ has been completed Operation$[B]$ can be executed. Same holds for Operation$[C]$, Operation$[B]$ has to be completed before Operation$[C]$ starts. So the work content of this operation cannot be moved to other stations and thus this cannot be considered as a viable solution.

## 9.2 Least segment length with different Operator Efficiency Factor

Segment length for Operation$[A]$ is validated in order to move operation B further up to accommodate the new operation. The simulation of the fixed pace conveyor is based on the fact that the part entering the system first will be processed before the second part. Operator movement of any kind is negligible and is thus not considered in the simulation. These constraints are in-built in the conveyor and they define the conveyor behavior.

The simulation is made for the present scenario and the process is found out to be smooth. Then the minimum length for this operation is to be found out and validated. The number of operators for this operation is 3. Incoming product variants have different work content and depending on the model it is decided if the work can be shared by the three operators. This task list is given as input to the simulation. Further launch spacing plays a vital role here. In the scenario presented launch spacing is taken as 5. This means that every five minutes a new part comes in the system. Hence, at an instant there are two parts in the first conveyor segment because the length of this segment is greater than 5. Therefore, it is important to keep in mind that any operator will work on the second part only after finishing the work assigned to him for the first part is completed. In the process, operator swims between the two consecutive parts.

Here static calculations cannot reflect accurately on the scenario because the second part coming in does not have the time available for the full operation area length. This makes dynamic simulation mandatory.

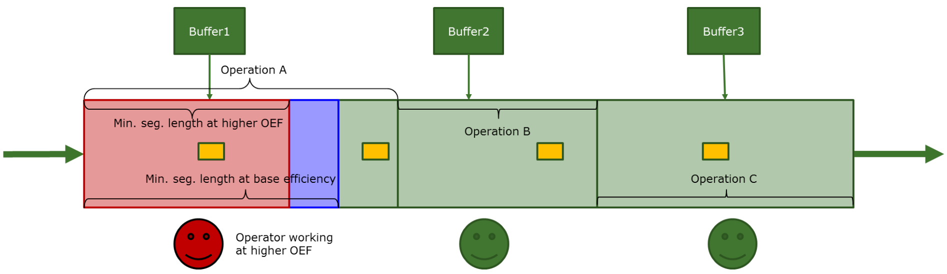


FIGURE 9.1: Minimum segment length for Operation$[A]$

Simulation is made for the future scenario with different operator efficiencies. With the increasing operator efficiency the time available for operation increases and thus the operation area length can be decreased. Simulation is made keeping $x\%$ operator efficiency as the base. The operation area length is decreased to the minimum, just sufficient enough for all the parts to be processed without stopping the conveyor. This is base minimum operation area length that can be used to accommodate new operation. Consequently, the operation B area length can be increased equal to the decreased length of operation A area. The changed scenario did not eliminate the bottleneck in the process.

Therefore, the operator efficiency factor is further increased to by 12 per cent and Operation$[A]$ area length is further reduced x percent giving more available time to Operation$[B]$. With $1.12x\%$ operator efficiency and the necessary changes, the simulation was run to ensure that the conveyor does not stop due to Operation$[B]$. The simulation does not give a smooth process. Therefore, this condition is still not sufficient for the assembly line to run without interruptions.

Further, the operator efficiency factor was increased to $1.225x\%$ in order to provide more time for Operation$[B]$. Simulation is run for the given parameters and analysis is made for the assembly line. The conveyor still stops because of Operation$[B]$.

This validates the fact that the new process cannot be accommodated in the scenario by decreasing the length of adjacent conveyor segments alone. More than one scenario should be combined in order to get the desired outcome from the simulation. Each scenario is weighed by its cost and feasibility. The selection for scenario is made based on the best trade-off between the two factors.

## 9.3 Length segments for all product variants

For Operation$[C]$, the third operation considered in the scenario, operation area lengths corresponding to different product variants are to be found out and validated. There are two operators working in this operation area. Line-up for different product variants is segregated and simulation is run individually for each variant. Work content depending on the variant can be shared between the two operators. This analysis is made for only Operation$[C]$. Thus, the work content of Operation$[C]$ is only considered.

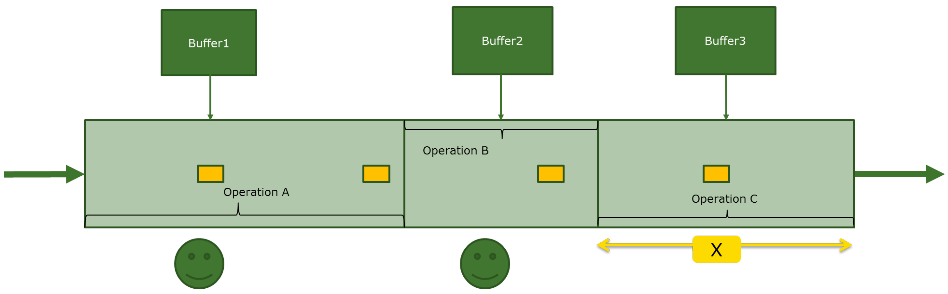


FIGURE 9.2: $X$ is the minimum length of conveyor needed to finish Operation$[C]$ for a particular variant.

There are five product variants considered in the scenario. For each variant length of Operation$[C]$ area for different operator efficiency factor is required. This is done by running the simulation for different values of operator efficiencies and variants. The variants, of course, have different work contents. The work for Operation$[C]$ is divided equally between the two operators. The figure below gives the operation area length for all variants for $1.12x\%$ operator efficiency.

# Chapter 10

# Conclusion

The aim of this project is to make an existing assembly line more efficient by implementing the lean production principles. With regard to the objective, it is highlighted as the first step to thoroughly understand the assembly line and its processes. It is also important to understand different terms and their dependence on each other.

This project is approached by highlighting different aspects of assembly line which can be modified to make the assembly line more lean. There are a number of factors that might affect the line processes. These factors are studied and conclusions have been drawn for different parameters.

The assembly line with different parameters yields insightful results. The line is simulated and validated against the generic results. In the process bottlenecks are identified and are further investigated. It is found that increasing the number of operators at a bottleneck station may lead to increasing the efficiency of the overall line. Increasing the number of operators is not always possible due to space constraints, non-divisibility of tasks owing to the nature of work content, the cost incurred to company due to the additional operator, *etc*.

The efficiency of assembly line can, alternatively, be done by increasing the efficiency of the operator working at the bottleneck station. This is limited by the base efficiency defined for the operator and also by ergonomics of the task. The highest efficiency achieved cannot be greater than a number specified by the company.

Adjacent operation areas of a bottleneck can be modified to increase the overall efficiency of an assembly line. The bottleneck operation area on a fixed pace conveyor can only be increased by reducing lengths of the adjacent operation areas. If there exists such a possibility, it can be validated through simulation and consequently, bottleneck can be eliminated resulting in a more balanced and efficient line.

In conclusion, this project presents a bottleneck elimination approach by proposing different methods and validates them for a generic result.

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