IMPROVEMENT OF EFFICIENCY FOR PRODUCTION LINE BY APPLYING LINE BALANCING TECHNIQUES AND SIMULATION A CASE STUDY FOR ADIDAS COMPANY

By

NGUYEN TAN THANH

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ABSTRACT

The purpose of paper is improving efficiency KPI in shoes production companies. A case study of Adidas Vietnam was adopted. The aim of this paper is improving the KPI efficiency that related to the working time, number of worker existing on production line and productivity (output). Two phases for improvement were generated, the first one is Improving the cycle time to be below takt time and keeping number of workstation using direct observation method base on concept of eliminating, combining, simplifying the assembly process without any additional machine and manpower and Arena software. Next phase is modifying the initial improvement to generates the second improvement by minimize number of workstation. Lingo software is used for that purpose. All the required data was measured and the parameters such as elapsed time at each work station, efficiencies, number of workers, time of each of the workstations etc. was calculated from the existing line.

Keywords: Efficiency, Line balancing, Simulation process design, Optimization, Minimize workstation, Lingo.

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Author

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CHAPTER 1 INTRODUCTION

1.1 Background of the study

Balancing assembly lines becomes one of the most important parts for an industrial manufacturing system that should be supervised carefully. The success of achieving the goal of production is influenced significantly by balancing assembly lines. Since then, many industries and for sure researchers, attempt to find the best methods or techniques to keep the assembly line balanced and then, to make it more efficient. The typical problems facing with manufacturing usually are: short product cycle for fashion articles, long production lead-time, bottlenecking, and low productivity.

To balance an assembly line, some methods have been originally introduced to increase productivity and efficiency. These objectives are achieved by reducing the amount of required manufacturing time to produce a finished product, by reduction in number of workstations or both of them.

Assembly line balancing problems can be classified into two groups: stochastic and deterministic assembly lines. In this thesis, we study the shoe manufacturing process in Adidas Company. Just like majority of shoe manufacturers, it is manual labor intensive, which means tasks performed inherit stochastic characteristics.

1.2 About Adidas Company

Adidas is a German international corporation that designs and manufactures sports clothes and accessories. Adidas is holding a big share of Adidas Group that consists of Reebok Sportswear Company, Taylor Made-Adidas Golf Company, Rockport and 9.1% of FC Bayern Munich. Beside sports footwear, Adidas also produces bags, shirts, watches, eyewear and other clothing related goods. Adidas is the largest sportswear manufacturer in Germany and Europe and it is obviously that Adidas is also one of the top leading companies in sportswear manufacturer in the world.

In Vietnam, Adidas has 7 factories producing high quality products to be distributed to every continent. Most of them are producing shoes with varieties of models like: sport, classic, football, tennis, running, etc. Adidas Company uses the PPH indicator likes KPI (key performance indicator) efficiency to evaluate the line performances in production line of factories.

PPH (Pair/ Person/ Hour) is a KPI of production line that using to evaluate the efficiency of work of each line in the factory. PPH also is the efficiency one person can make product in one hour. Pairs are units Adidas's business generates as an output. A man-hour is a type of input that is equal to one hour of work an employee performs in making pairs. Regarding production line, there are 4 main stages to produce the shoes: Cutting, Stitching, Stock-fitting and Assembly. Factories of Adidas are almost manual-operations oriented system. Thus, utilization manpower plays an important role to improve productivity as well as efficiency.

1.3 Current issues

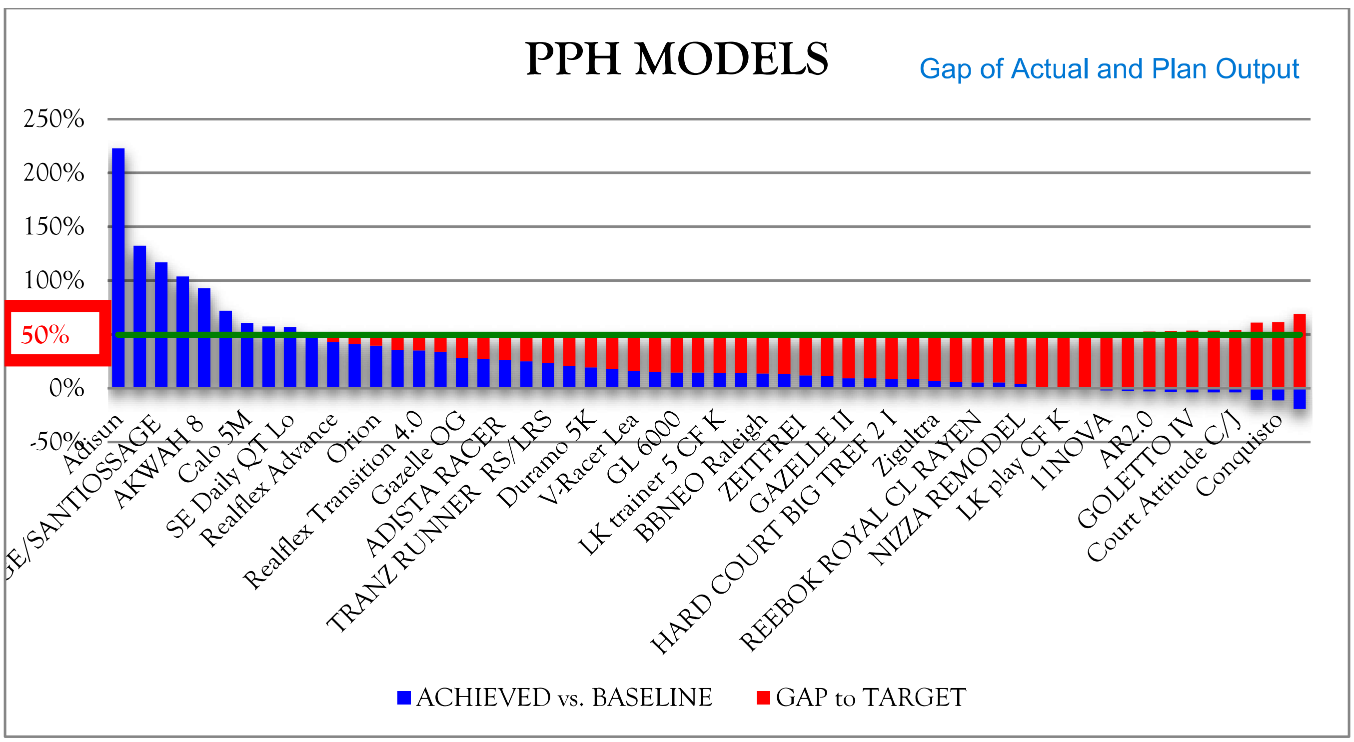


Figure 1-1: The PPH performance line achieved of all models in shoes manufacturing (Fall-Winter season)

Current PPH performance Line: Season Fall – Winter (FW), with current monthly data show that 8 models reach the target or higher, 10 models achieved an increment of over 25% in PPH, 38 models has increment of less than 25% in PPH, and PPH of 10 models are lower than baselines.

Requirement from Top Management: Increasing 50% of the PPH performance line of top 5 models, which have biggest volume in this season.

Larger than 50%

Most of models achieved PPH efficiency though their performances are not equal. Some models reach the target and other had low performance even under the baseline.

1.4 Research Objectives

- Find the root-causes that hinder PPH improvement
- Propose solutions
- Confirm the solution by simulation

1.5 Scope and limitation

Two models with the lowest PPH among the top 10 models with top biggest volume were chosen to study.

CHAPTER 2 LITERATURE REVIEW

2.1 What is KPI efficiency?

Define the KPI

PPH (Pair/ Person/ Hour) is a KPI of production line that using to evaluate the efficiency of work of each line in the factory. PPH also is the efficiency one person can make product in one hour. Pairs are units Adidas's business generates as an output. A man-hour is a type of input that is equal to one hour of work an employee performs in making pairs.

Output (pair): The amount of output a firm generates compared to a certain input.

Labor (person): A production worker's function is to process a product or service. Processing a product or service can include shipping, assembling, sorting, testing or inspecting. Depending on what type of environment they work in, they're given production goals to meet on a daily basis.

Production workers can work in a variety of environments. They can be technically skilled, or perform basic functions. Some are required to work in a clean environment for medical, pharmaceutical, or food production industries. In most cases, a production worker will perform one or several tasks repetitively.

A production worker performs repetitive tasks to complete a product or service in a consistent and correct manner. She may also be required to input information into a system, reporting the amount of work or problems with products or services.

Time (Hour): The production time for a manufacturing process is primarily determined from the cycle time, but must also account for the defect rate, machine uptime, and machines used.

How to calculate PPH?

We can calculate company's productivity by determining the number of pairs we make per man-hour. Producing a greater number of pairs per man-hour represents a higher level of productivity, which may help our firm lower costs and increase profits.

Step 1 Define demand or requirement in a certain period of time

Determine the number of pairs or units produces in a certain period of time, such as one month. For example, assume produces 50,000 pairs in one month.

Step 2 Define the resource available in a certain stage

Determine the number of workers that the Factory employed during the same time period and the number of hours each employee worked. In this example, assume you employed 10 workers who each worked 160 hours during the month.

Step 3 Calculte productivity ratio

Multiply the number of workers by the number of hours each one worked to calculate the number of man-hours your business used during that time period. In this example, multiply 10 workers by 160 hours per worker to get 1,600 man-hours. This means that you produced 50,000 pieces using 1,600 man-hours.

Step 4

Divide the number of pairs produced by the number of man-hours to calculate the pairs produced per man-hour. Continuing with the example, divide 50,000 pairs produced by 1,600 man-hours to get 31.3 pieces produced per man-hour.

2.2 Assembly line balancing

2.2.1 Basic theory Min cycle time or number of resource

Balancing assembly lines is a very important mission for manufacturing industries in order to improve productivity by minimizing the cycle time or the number of workstations. The balancing problems manage the assignment of tasks to workstations to achieve the purpose objectives. The general practice in the assembly line balancing is to assign tasks to workstations in such a way that each total time of assigned tasks to each workstation has an equal line cycle time Assign job in the proper schedule, have an equal line

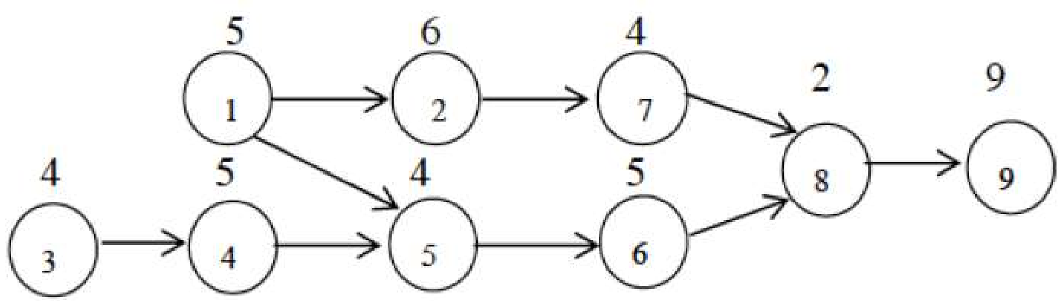
An assembly line consists of workstations usually arranged along a conveyor belt or similar material handling equipment. The jobs are consecutively launched down the line and are moved from station to station. At each station, certain operations are repeatedly performed regarding the cycle time. In general, the line-balancing problem consists of optimally balancing the assembly work among all stations with respect to some objective. For this purpose, the total amount of work necessary to assemble a work piece (job) is split up into a set $V = \{1 \dots n\}$ of elementary operations named *tasks*. Performing a task j takes a *task time* t_j and requires certain equipment of machines and/or skills of workers. The total workload necessary for assembling a work piece is measured by the sum of task time's Σt. A precedence diagram can summarize these elements. It contains a node for each task, node weights for the task times, arcs the direct and paths for the indirect precedence constraints. Figure 1 shows a precedence diagram with $n = 9$ tasks having task times between 2-9 in time unit. (The assembly tasks cannot be sub-divided and must be completed at their assigned workstation.) Line balancing operates under two conditions:

- **Precedence Constraint.** The priority of job or map of nodes

Products can't move to other station if it doesn't fulfill required task at that station. It shouldn't across other station because certain part needs to be done before others.

- **Cycle time Restriction**

Cycle time is maximum time for products spend in every workstation. Different workstation has different cycle time.



2.2.2 *Types of Assembly Line*

An assembly line can be classed into three categories based on numbers of models assembled on the line and according to the line pace which are:

➢ ***Single - model line:***

A single – model line can be described as a line that assembles a single model that type of assembly line in which assemblers work on the same design of the same product.

➢ ***Mixed – model line:*** Require the difference between machines

Mixed – model line is producing more than one model that type of assembly line in which assemblers work on all different models of a product in the same assembly line.

➢ ***Batch model line:***

This line produces each model in batches that type of assembly line in which products are assembled in groups at a time.

There are two types of optimization problems for the line-balancing problem (Ajenbit, 1998). **[1]** In Type I, the cycle-time (maximum amount of time units that can be spent at each workstation) is $\boxed{\text{fixed}}$ and the objective is to minimize the required number of workstations. The Type II attempts to minimize the maximum cycle-time given a fixed number of workstations. This study will adopt the Type I problem. The overall objective of this research is to improve productivity through line balancing by minimizing both labor and idle times on the production line. [14] This paper intends to investigate and evaluate the line-balancing problem in a production line of shoes manufacturing .The paper seeks to:

Job shop schedule, min Cmax

pallarel machine with job shop

min labor and idle time

I. Identify the line-balancing problem.

ii. Identify the idle time at each workstations and how it can be reduced.

iii. Assess the workstations on the production lines in order to minimize the number of workstations.

have the same with lean, but it can understand remove some stage in production line. Do this make sense in quality requirement ?

2.2.3 Objectives of line balancing

Like lean production

1	To minimize the total amount of unassigned or idle times at the workstation.
2	To eliminate bottlenecks, ensuring a smoother flow of production.

3	To determine the optimal number of workstations and operations in each station.
4	To maintain the morale of workers since the work content of the different workers will not be of great difference.
5	To maximize the manpower utilization by minimizing the idle times of the operators.
6	To minimize intermediate stock or work-in-progress (zero inventory or just-in-time concept). very hard to achieve.
7	To improve the quality and productivity of the assembled products.
8	To reduce waste of production and delay.

Identify the relevant factors.

2.2.4 Factors affecting on line balancing and problems encountered

1	There are constraints in operations in terms of size of machines, location, space, jigs and fixtures, building structure, etc.
2	The workers in the line have great variations in level of skill and aptitudes for certain jobs. Thus, it is difficult to synchronize the time.
3	Some work content cannot be broken down further into elements. Some specific job cannot break down.
4	Long machining times can become bottlenecks.
5	The design of parts, shape and size of materials may pose constraints (e.g., bulky materials).
6	Special processes, such as electroplating, curing and baking by batch, have fixed sequences. It follow by sequence so reduce some elements are not valid.
7	Long set-up times. Set up time
8	Small production volumes do not justify the use of line balancing. Refer to MOQ

2.2.5 Line balance loss percentage (%)

Statistics to monitor production effectiveness

Balancing loss is the quantification of the lack of balance in a production line, defined as the percentage of time not used for productive purposes with the total time invested in making a product. The importance of this measure lies in its ability to assess perhaps the most problematic of all the detailed design decisions in product layout, namely that of line balancing. Achieving a perfectly balanced allocation of activities to workstations is nearly always impossible in practice and some imbalance in the work allocation between stages results. So the effectiveness of the line- balancing activity can be measured by balancing loss. In effect it is the time wasted through the unequal allocation of work. Line balancing loss and system loss are also found in some line assembly (Roy and Khan, 2010) **[2].**

The LBL percentage is presented to identify the seriousness of the problem. LBL is calculated as follows:

$$\%\boldsymbol{LBL} = \frac{\boldsymbol{nT_{max} - \sum ti}}{\boldsymbol{n\,T_{max}}}\ \boldsymbol{x\ 100\%}$$

Where: LBL : Line balance Loss : % watsed time.

n = Number of workstation

T_{max} = Value of the highest cycle time

$\sum t_i$ = Total cycle time

There are a lot of research papers for line balancing problems: (Lim Chuan Pei, 2002) **[3]** describes a case study conducted at a manufacturing company aimed at improving productivity using line balancing. Two alterative were generated using different assignment rules. Johnson **[4]** expresses the problem of line balancing as 'a set of non-divisible tasks to be performed, each task has a known deterministic performance time. A partial ordering of tasks by precedence constraints is specified. The problem is to assign these tasks to assembly stations, so that the necessary number of station is minimized.' The step is to line balancing has been detailed out by Hoffman **[5].**

Literature review

Assembly lines are still a crucial problem to get the smoothing of production system (Rajenthirakumar et. al, 2011) **[6].** Many studies have been done under several perspectives achieving its performance. The problem can occur in many aspects, such as task, integration concept, or layout arrangement. These disruptions will take effect in line assembly and decrease the line efficiency. The effect of task deterioration in assembly line results increasing the number of workstations depending on the task deterioration rates (Noushabadi et.al, 2011) **[7]**.

Two main problem are less accuracy of standard time, and poor work arragement.

Forecast, estimate standard time is required firstly.

(Johan Oscar Ong and Yosi Twentiarani, 2012) **[8]** Research was mainly focused on increasing the line efficiency of dress sewing W1234. Less accuracy of standard time and poor work arrangement are identified as the root cause of having low efficiency. Hand-to-mouth system and additional cost are occurred as the side effect of this situation. In order to overcome the root cause, a time study is the first and foremost method to be done. By having accurate standard time, it is expected that the number of operators is adequate, and also the work arrangement can be designed smooth without violating takt time. Thus line balancing is the next method used after time study. There are many improvements can be achieved. The target output can be achieved and overtime can be removed.

(Hasbullah bin Mat Isa, 2010) **[9]** The main objective of his project is to demonstrate the use of simulation in analyzing the existing production floor performance and in evaluating various alternatives to overcome the existing problem. Results of the study revealed that the current production floor was suffering from time working handling. From here, a total of 3 alternative layouts were proposed and they were simulated to determine their effect on the production performance

2.2.6 Optimization

Solving *NP*-hard discrete optimization problems to optimality is often an immense job requiring very efficient algorithms, and the B&B paradigm is one of the main tools in construction of these. A B&B algorithm searches the complete space of solutions for a given problem for the best solution.

Using discrete input to analyze in worst case ?

Branch and Bound

General of purpose method is to solve discrete optimization problems. Takes exponential time in the worst-case is useful to solve small instances of hard problems

Applegate and Cook (1991) **[10]** developed variables of lower bound to optimize the cutting plane and "brand and bound" procedure. "Brand and bound" procedures are updated by Brucker et al. in 1994 **[11]**. These have the advantage that gives us an optimal solution.

2.3 Simulation Basic theory

2.3.1 Simulation theory

2.3.1.1 Definition of Simulation

According to J. Banks, J. Carson, B. Nelson, D. Nicol (2001) **[12]**, "Simulation is the imitation of the operation of a real-world process or system over time". Simulation is often run on computer with proper software.

2.3.1.2 Purpose of simulation

Simulation of a real system is usually run on a computer with proper software to analyze and estimate a plan, which influences on simulated real system.

Simulation is used in various fields such as:

- Design and analyzes production system
- Define strategy of purchase in warehouse.
- Analyze financial system.
- Evaluate and design service system…

2.3.1.3 Benefit of simulation

- Perform test on a running system without interrupt system.
- Analyze a present system to understand its abnormal changes.
- Adjust time to accelerate or slow down process.

- Find out important changes of system.
- Define bottleneck of system.
- Help to understand working process of system.
- Control working conditions.
- Study system in a longtime.

2.3.1.4 Disadvantages Limitation: Require deeply variable : Difficult to formulate.

- Building of model requires a strict training because this is science as well as art. Sometimes it is difficult to explain simulation result cause it's based on accidental character of system.
- Require much time and cost.
- Simulation is not an optimum tool but very effective in comparison the changes of models.

2.3.1.5 Trick point

- Target to simulate is not clear at the beginning of studying.
- Simulation level is not appropriate
- Built model is too complex at the beginning
- Using many simulation software without understanding about them..
- Exploit animation.
- Not successful in explaining of accidence of real system.
- Perform and analyze result after just one single running....

2.3.1.6 Definition of system

A system is defined as a collect of many objects like people, machine…that interact with each other on purpose finishing the goal reasonably [Schmidt, Taylor (1970)] **[13]**.

System' status is a collect of necessary variables to describe system at a certain time. This is related to the goal of studying. A system can be built by many ways. Generally based on character of variables in a system we can divide them in three kinds:

Interrupt system: a system with status variables, which change immediately at different time.

Continuous system: a system where status variables change continuously currently.

Combined system: a system with an interrupt part and a continuous part.

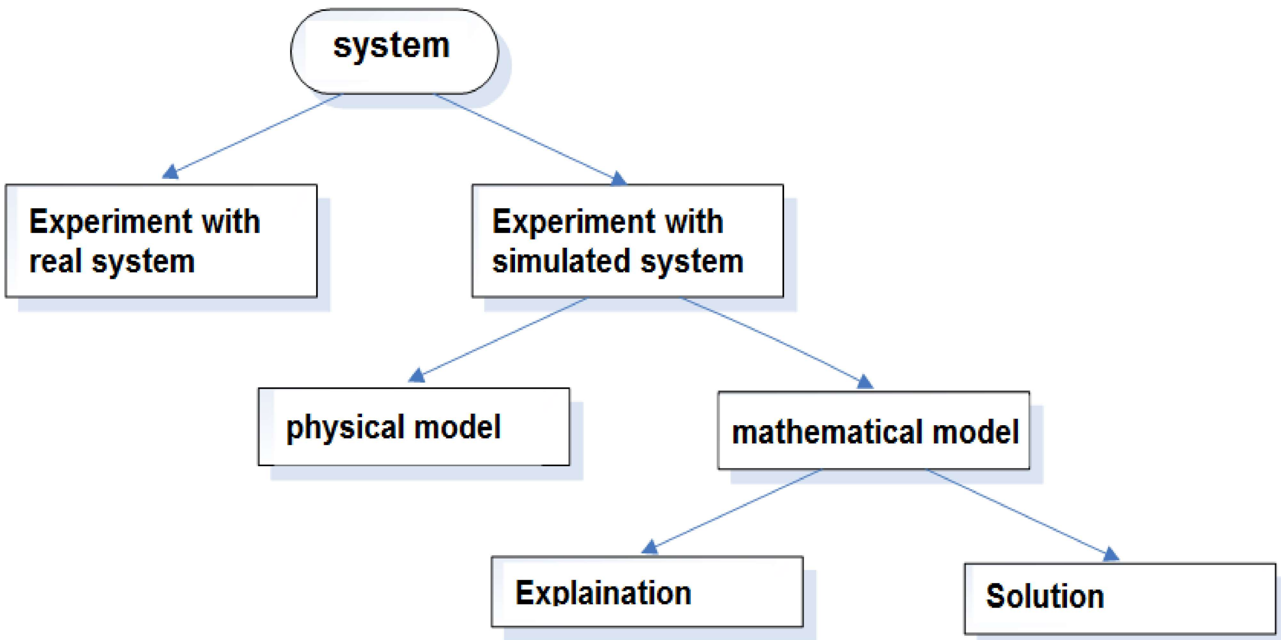


Figure 2-1: Studying method

2.3.1.7 *Sequence of studying simulation*

OK. Sequence of method.

1. **Describe the problem and plan to study:**

First step of studying simulation is to define clearly state of the problem. If the problem is not defined, there is little chance to success in studying. When a system is changed, it requires a plan and criteria to evaluate the effect of this change. Studying should be planned based on resource, cost and time.

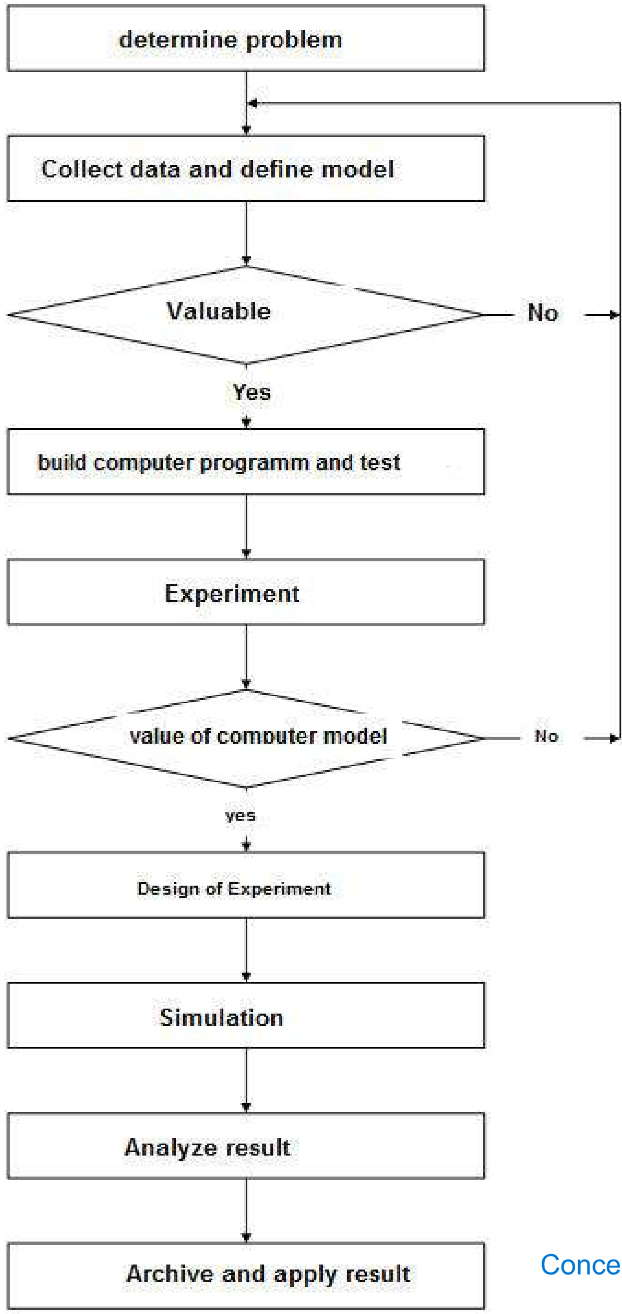
What is problem and requirement plan & criteria ?

2. Collect data and define model: From conceptualize model, propose what data needs to be collected and analyze.

Information and date should be collected at watched system. It is recommended that work process, statistic distribution and accidental variables have to be defined in detail before. Building a logical and mathematical system of a real system with given goals is an art of science. A model has to have enough details to reflect character of a system but it's not necessary to perform every couple of elements of system and model.

3. Value of a model: Validation and Verification: Check the accuracy and percision of the data and model

Value of a model is evaluated through simulation process by support of decider. Using of methods to evaluate the completeness and precision of statistic distribution, which is used to create accidental variables, also enhances the value of model.



Conceptualization model

Figure 2-2: Process of simulation studying

2.3.1.7 Building computer program and test

Tool to test.

There are many available program languages like: FORTRAN, PASCAL or C, or specific programs, which are used in simulation like: GPSS, SIMAN, SIMSCRIPT II.5, SLAM II. This makes simulated model much more reliable as well as saves time and cost. Besides inspection technique and software problem solving technique should be concerned. After these steps are finish, it's ready for a test-run.

1. Test:

This step is for checking model and evaluate model in next step.

2. Value of a computer running model:

Test-run is used to test the sensibility of the output in model when there is a small change of input.

3. Design experiment:

Design of changes in simulated model. For every model the design has to determine begin conditions of simulation, length of warm-up phase, length of a simulation run and amount of single simulation for every design.

4. Perform Simulation:

This step is used to give data for presenting designs, which are concerned by the.

5. Analyze result:

Using statistic technique to analyze simulation results. Normally is to build a trust area for designing detail system.

2.3.1.8 Achievement and implement of results:

This is the last step of simulation process. Because simulated model is used for many applications, presumptions have to be archived in model and computer program. If a simulation studying cannot be applied, it means failure. The more reliable the results from the models are, the bigger chance they can be applied.

2.3.1.9 Method of building valuable simulated model

To build valuable model, the person who makes simulation should:

- Communicate with system: It is recommended to work with people who know deeply about the system. They can provide necessary information in building model.
- Watching system.
- Using available theory about statistic distribution
- It is allowed to use results of other similarly studying in building model
- Equip experience and knowledge to testify how a complex system works, especially when that system has not existed yet.
- Test theories of model: some input data can follow theoretical distribution. Test of suitability is conducted by diagram or other test methods.
- Test of simulation results with real system: If the simulation result is similar to reality, the simulated model will be developed and the précised simulation result will be compared to the existent system. In case these two data are not much different, the simulated model is evaluated as "valuable" Then the model will be adjusted as recommence.

2.3.1.10 Determine distribution of input data in simulated model

- **Method 1:**

Using discrete data. Input directly from excel or CSV to ARENA.

Collected data is used directly in simulated model. This method is called simulation based on trace. However this simulation just repeats what has happen in the past and cannot perform a simulation as wish cause of lack of data.

- **Method 2:**

From raw data, test the polulation

Data is built in a distribution experiment. This method will remove the disadvantage of the first method. But method 1 helps us to evaluate the model simply by comparison simulation results with real system.

- **Method 3:**

Fit the dataset

Statistic techniques are used to fit the data in a distribution theory like: Normal, Poisson … after that using testifies method to make sure that data are suitable to selected distribution. This method is conducted through three steps:

- Determine how the collected data is distributed
- Estimate parameter of that distribution
- Testify the suitability of distribution theory for collected data.

In simulation Arena the tool Input Analyzer is integrated. It allows us to do this quickly. With Input Analyzer we can fit the data in experimental or theoretical distribution and evaluate the suitability based on parameter of Chi-square, testified value p of Kolmogorov-Smirnov. Value p is acceptable value to remove data, which follow another distribution if it is equal or bigger than 0,05.

2.3.1.11 Methods to determine distribution

Fit the dataset

- **Method of experience**

- Method of development of diagram and comparison of frequency.
- Method of distinguishes distribution by diagram.

- **Method of statistical diagram**

- Check suitability.
- Chi – Square test
- Kolmogorov – Smirnov test.
- Anderson – Darling test.
- Test of Poisson process.

More popular statistic for testing

2.4 General about the software

Arena is discrete event simulation software simulation and automation software developed by Systems Modeling and acquired by Rockwell Automation in 2000. In

Arena, the user builds an experiment model by placing modules (boxes of different shapes) that represent processes or logic. Connector lines are used to join these modules together and specify the flow of entities. While modules have specific actions relative to entities, flow, and timing, the precise representation of each module and entity relative to real-life objects is subject to the modeler. Statistical data, such as cycle time and WIP (work in process) levels, can be recorded and outputted as reports.

Arena can be integrated with Microsoft technologies. It includes Visual Basic for Applications so models can be further automated if specific algorithms are needed. It also supports importing Microsoft Visio flowcharts, as well as reading from or outputting to Excel spreadsheets and Access databases. Hosting ActiveX controls is also supported. The next figure shows the home screen of Arena:

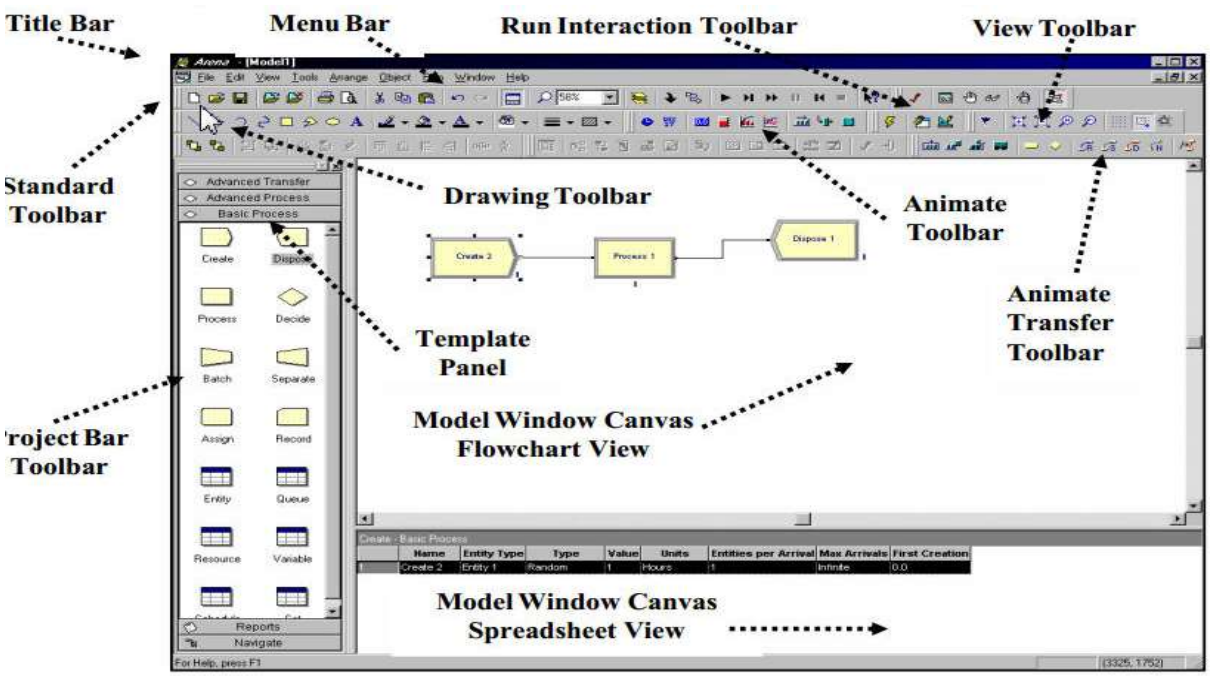


Figure 2-3: Arena Home screen

Features:

- Modeling of the given process to determine or to give information about them
- Simulation of the process in future to study on complex relationships and determine possibility of optimization
- Visualization of activities by animation graphics

- Analyze how the system works, how much reliable a plan is, to give a best decision for our works
- Besides Arena allows us to modify the input parameter as well as parameter in the model and supplies various tools helping us on solving the problem quickly.

Some basically modules:

- **Assign**

This module is used by entities to assign value to attributes. A single module Assign can make a multiple assignment

Usage:

- Accumulative addition of sub-components to a machining component.
- Change of attribute.
- Set up a priority for customer.

- **Create**

This module is used to create at begin for entities in the simulated model. The Create module generates a stream of arrivals of Arena entities (jobs, people, messages, etc.)

Usage:

- Begin of the components in manufacturing line
- A document of the arriving event (e.g., order, test, application) in a trading process
- Arriving event of a customer at a service process (e.g. retail sale, hotel, check-in desk).

- **Decide**

The Decide module is used by entities to make branching decisions, based on chance or the truth/falsity of prescribed conditions. The dialog box below makes a two-way probabilistic branching decision

Usage:

- Isolate a defect component to repair
- Distinguish approved or declined test
- Send customer with priority to special service area

❖ **Process**

This module is the main process in simulation. Moreover it can be used as a sub-model and determine definition based on logical level

Usage:

- Machining of a component
- Check a document
- Ordering
- Serve customer

❖ **Dispose**

The Dispose module implements a "sunset" mechanism for entity.

Usage:

- Customers leave from supermarket
- Components leave from manufacture
- An end of trading process.

❖ **Record**

The Record module is used by entities to collect statistics at selected locations in the model. The statistics include time between two entities going through module, statistic about entities (time, cost). The dialog box below the list of statistics types in a Record module.

Usage:

- The Count option maintains a count with a prescribed increment (any real value, positive or negative), which may be defined as any expression or function, and the counter is incremented whenever an entity enters the Record module

- The Entity Statistics option provides information on entities, such as time and costing/duration information

- The Time Interval option tallies the difference between the current time and the time stored in a prescribed attribute of the entering entity

- The Time Between option tallies the time interval between consecutive entries of entities in the Record module (these intervals correspond to inter-departure times from the module, and the reciprocal of the mean inter-departure times is the module's throughput)

- The Expression option tallies an expression, whose value is recomputed whenever an entity enters the Record module.

2.5 Model validation

Check model run correctly with conceptualization model

After getting the result from simulated model we test to determine whether the model is different from the real system. It is conducted by compare result from simulation and from the reality.

This method is Turkey's pairwise comparison with 95% confident level.

X_j : Average output from simulation model

Y_j : Average output of real system

A new method to test in model validation

With $Z_j = Y_j - X_j$, then:

$$Var\left[\overline{Z}(n)\right] = \frac{\sum_{j=1}^{n}\left[Z_j - \overline{Z}(n)\right]^2}{n \times (n-1)}$$

Check the variation of model and real system.
Another test using time series errors.

n = Size of sample

Within 95% confident level the average declination between the simulated and real system is:

The average declination rate.
This rate near 0, good model

$$\overline{Z}(n) \pm t_{n-1,1-\frac{\alpha}{2}} \sqrt{Var\left[\overline{Z}(n)\right]}$$

If the reliability area includes 0, we can conclude there is no difference between real system and simulated model. Of course it is based on statistic perspective.

2.6 Lingo

Like Cplex

LINGO is a software tool designed to make building and solving Linear, Nonlinear, Quadratic, Stochastic, and Integer optimization models easier and more efficient (Lingo User's Guide, 1999). Its modeling language enables users to express their problems in a natural manner that is very similar to standard mathematical notation. For multi-period fixed charge problems, LINGO categorizes it under PINLP class. It solves the problems by using branch and bound manager. LINGO optimization model has two attributes: objective function of problem and constraints of problem. Stating "min" for minimization problem or "max" for maximization problem can specify the objective function. After stating the objective function, constraints are specified on next lines. The points on LINGO reveal the following:

- LINGO is very much useful to solve hard optimization problems.
- It solves the problems by using branch and bound methodology.
- It can be used to verify and compare the results with the traditional and meta-heuristic optimization methods.
- It performs better than meta-heuristic algorithms in certain linear programming problems.
- The CPU time to find optimal solution using LINGO is very much slower when compared to the time taken by the heuristic procedure particularly in case of NP-hard problems.
- On the above considerations, the mathematical formulations of all the four models have been solved using LINGO to find its capability of providing optimal solutions and time taken for solution convergence.

CHAPTER 3 METHODOLOGY

The aim of this thesis is improving the KPI that related to the working time, number of worker existing on production line and productivity (output). This chapter explains the steps that were used to address the research goals. The first part includes analysis of the current performance of the production lines via data collection, simulation modeling. The second part proposes solutions via two phases. One is improving the cycle time to be below takt time and utilization manpower using Arena software. Second phase is modified initial phase to minimize number of workstation by using optimal theory. Lingo software is used for that purpose. The parameters such as processing time at each workstation, efficiencies, number of workers, etc. were measured from the existing line.

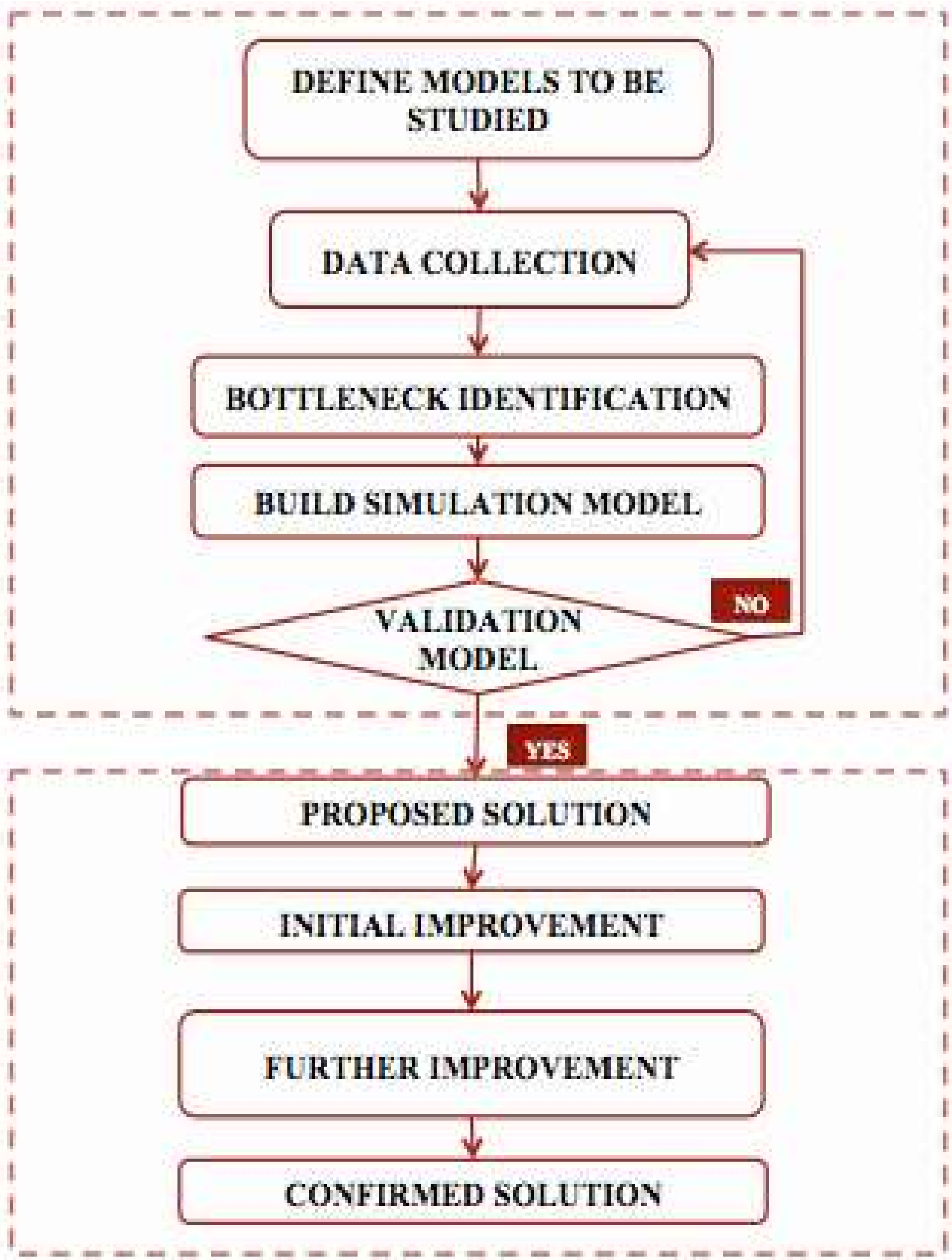


Figure 3-1: Methodology diagram

3.1 Define shoes model to be studied

Review the main products need to investigate.

At the beginning, we need to review the report of the last seasons from all factories, Select one factory had lowest PPH efficiency, and models run on production of this factory. Next, this study will be researching on the improvement of 2 models. One is the model with the lowest PPH, and another is highest (achieved target) PPH efficiency, which belong to the top 5 models (the model has biggest volume and is supported by high technology in production floor).

This way can illustrate that sometime % small not mean worst. highest % not sure best performance. Remember that.

3.2 Data collection

Record actual output, number of tasks, workstation

In this term, we recorded the total actual output per day, number of tasks and workstations to build the layout of production line, identifying a material flow, process flow, the routing that connect locations and the resources such as: real manpower, equipment, machines, etc. In each model is divided into 5 main areas: Cutting, pre-fit, stitching, stock-fit and assembly.

Identify resource need.

Identify process flow

Input in run setup in ARENA

- Duration of data collecting: from 05.03.2014 to 10.03.2014 and 14.05.2014 to 16.05.2014
- Time of collecting during a day: 08:00 AM - 14:00 PM
- Instrument used by collecting: Stop-watch, mobile phone
- Cutting area: To determine the cycle time in this area, we collect the output (by batching) of each workstation and then divided them by total working time of each workstation.
- All areas remain: Using stopwatch to measure cycle times that one by one process.

3.2.1 Cycle time

Value-added (VA): Any part of the production process that improves the product for the customer. For a process to be value-added, a customer must be willing to pay for it.

Non-value-added (NVA): Activities that do not contribute to the product or the process and should therefore be eliminated. Customers don't willing to pay for it. Non-value added steps are waste.

Non-value-added necessary (NVAN): Production activities that ensure the value-added steps have been properly completed. For example, inspection does not contribute to the product, but it is necessary until the process can be improved to the point where inspection can be eliminated.

Cycle time formula:

$$\boldsymbol{Cycle\ time} = VA + NVA + NVAN$$

Category the element of cycle time.

3.2.2 Allowance (%)

Differ with normal time and standard time
Differ with takt time and cycle time

- In all of the work measurement techniques, the normal time is adjusted by an allowance factor to obtain the standard time.
- Allowances are used because there will be periods during the regular work shift when the worker is not working.
- The purpose of the allowance factor is to compensate for this lost time by providing a small increment of "allowance time" in each cycle. This way, even with the time losses, the operator will still be able to complete a day's work during the hours of the shift.
- Normal time is adjusted by an allowance factor $\boldsymbol{A_{pfd}}$ to obtain the standard time

(Assume that takt-time, Allowance (%) is available, reported from company)

3.2.3 Standard cycle time

Most workers are paid on the basis of time. The common work shift is 8 hours per day, and the worker is paid an hourly rate.

The standard time for a given task is the amount of time that should be allowed for an average worker to process one unit using the standard method and working at a normal pace. The standard time includes some additional time, called the **allowance**, to provide for the worker's personal needs, fatigue, and unavoidable delays during the shift.

The standard time is sometimes referred to as the **allowed time**, because it indicates how much time is allowed for the worker to process each unit so that by the end of the shift a fair day's workload has been accomplished, despite the various interruptions that may occur.

This step we will focus on how to determine the standard cycle time and manpower requirement, they will be compared with actual system.

Fomular of standard cycle time

Standard cycle time formula:

$$\boldsymbol{standard\ cycle\ time} = (\,Cycle\ time\ \times\ allowance) + cycle\ time$$

Depend on standard cycle time and takt-time, we easily determine the manpower requirement:

$$\boldsymbol{Manpower\ requirement} = \frac{Standard\ cycle\ time}{takt\ time}$$

3.2.4 Balance cycle time

The balance cycle time is a parameter that balance between standard cycle time with actual manpower existing on production line, it's determined by:

Based on cycle time, can identify which stages is bottleneck

$$\boldsymbol{Balance\ cycle\ time} = \frac{standard\ cycle\ time}{actual\ manpower}$$

After analytical calculation of parameters needed, the next step is comparing the processing time, capacity and human resource of each workstation. Some workstations tend to be the cause for bottlenecks as these stations handled more workload as compared to other stations that meaning is workstations have cycle time are larger than Takt time

3.2.5 Determine line balancing loss percentage

Balancing loss is the quantification of the lack of balance in a production line, defined as the percentage of time not used for productive purposes with the total time invested in making a product. The importance of this measure lies in its ability to assess perhaps the most problematic of all the detailed design decisions in product layout, namely that of line balancing.

After collect data and information of two models, we applying line balancing loss theory and equation to determine the percentage of balance loss for each areas of two models above

$$\%\boldsymbol{LBL} = \frac{\boldsymbol{nT_{max}} - \sum \boldsymbol{ti}}{\boldsymbol{n\,T_{max}}}\ \boldsymbol{x\ 100\%}$$

Where:

n = Number of workstation

T_{max} = Value of the highest cycle time

$\sum t_i$ = Total cycle time

Ok

3.2.6 Comparison between line balancing loss percentage of two models

Depending on the data have been collected as well as calculated the percentage loss balance above. In this step, we will focus on comparison between two models, which one is the model with the lowest PPH, and another is highest (achieved target) PPH efficiency. Finding the same or difference points between them and explain why having one model achieved target and another is not.

3.3 Build simulation model

Rule: From basic to complex, check error

After understanding the situation and analysis the problem, we develop the simulation model in computer by using ***Arena® software*** (offered by Rockwell Automation) base on the procedure of flow chart.

To build a simulation model and to carry out simulation runs with Arena, a user performs the following steps:

1. Construction of a basic model. Arena provides the model window flowchart view, which is a flowchart-style environment for building a model. The user selects and drags the flowchart module shapes into the model window and connects them to define process flow of the model.

2. Adding data to the model parameters. The user adds actual data that collected processing times, resource demands to the model.

3. Performing a simulation run of the model. The user runs the simulation and examines the results.

4. Analysis of the simulation results provided by the automatic reports of Arena. The user can expand the statistics.

5. Modifying and enhancing the model according to the user needs.

3.3.1 Arena Input Analyzer

From discrete data, construct the distribution of dataset by input analyzer.

Arena's Input Analyzer is a powerful tool that allows you to analyze different type of data; it is used to fit probability distributions to data and/or to evaluate the fit. Input Analyzer performs two goodness-of-fit tests for any distribution you attempt to fit: the chi-squared test and the Kolmogorov-Smirnov test. For each test it prints the p-value, telling you how well the distribution fits your data. We collect real data in production line following some model as the **model inputs**: number of parts per hours, the processing time of each task.

3.3.2 Arena Output Analyzer

Report by output analyzer.

Arena Output Analyzer is used for some of the plotting that it facilitates; it's true usefulness is the ability to easily construct an auto-correlation plot and other kind of plots. An auto-correlation plot allows dependence in the data to be quickly examined. Creating Histograms, Process analyzer will give as results all the needed data to discuss, read and understand the plot. The output variables were the number of products per hours/day.

3.3.3 Arena Process Analyzer

Check the system response with different cases

The Arena Process Analyzer is a tool that supports parametric analysis of Arena models by allowing the modeler to create, run and compare simulates scenarios, and thus observe the effect of prescribed responses.

The term parametric analysis refers to the activities of running a model multiple times with a different set of input parameters for each run, and then comparing the resultant performance measures. Its purpose is to understand the impact of parameters changes on system behavior (sensitivity analysis), often in the process of seeking the optimal configuration (parameter set) with respect to one or more performance measures or combination thereof.

In Process Analyzer input parameters are called controls, and the resultant performances values are called responses. Controls may consist of variables and resources capacities, while responses include both variables and statistics.

3.4 Verify, and Validate the Simulation Model

Rule: Make sure model run properly before run mass hours.

1. Validate and evaluate the model.
2. Compare the model input-output transformations to corresponding input-output transformations for the real system.

❖ There are several variations on this test.

After getting the result from simulated model we test to determine whether the model is different from the real system. It is conducted by compare result from simulation and from the reality.

This method is Turkey's pairwise comparison with 95% confident level.

X_j : Average output from simulation model

Y_j : Average output of real system

With $Z_j = Y_j - X_j$, then:

$$Var\left[\overline{Z}(n)\right] = \frac{\sum_{j=1}^{n}\left[Z_j - \overline{Z}(n)\right]^2}{n \times (n-1)}$$

n = Size of sample

Within 95% confident level the average declination between the simulated and real system is:

$$\overline{Z}(n) \pm t_{n-1,1-\frac{\alpha}{2}} \sqrt{Var\left[\overline{Z}(n)\right]}$$

If the reliability area includes 0, we can conclude there is no difference between real system and simulated model. Of course it is based on statistic perspective.

3.5 Proposed solution

From the defined bottleneck, we will propose solution to solve or improve these problems.

Some solutions will be proposed for main purpose to improve productivity, utilization labor force that can be increased the PPH efficiency performance.
In this term, two phases for improvement will be proposed:

The first phase, in order to all workstation have cycle time below takt time, the concept of eliminating, combining, simplifying the assembly process without any additional machine and manpower (line balancing theory) should be considered. Direct observation is approached as the method to find out the potential solution existing on production line.

- Recording the processing time of each task that we will concern
- Understanding fully the task to be assign for each workstation
- Analyzing the skill of worker for each task through observation

Observe constraint and condition must need for this process.

And then run simulation to get a result.

- The output will be appeared after improving bottleneck
- Determining PPH efficiency compare with PPH target
- Decreasing the percentage of loss balance

Analyze output and determine the PPH, output target.

Whereas, modifying the first improvement generates the second phase: the optimum number of workstation is found by linear programming. Lingo software is used for that purpose.

CHAPTER 4 ANALYZE CURRENT STATE

The major step is to identify a bottleneck of workstation in current layout, which has longest processing time. Simulation model is built to analyze the current situation, and determine the bottleneck. We validate the simulation model by comparing the results from simulation and from the reality.

4.1 Selecting models

This study will be researching on the improvement of 2 models. One is the model with the lowest and highest (achieved target) PPH efficiency model.

Table 4-1: Selecting shoes model

	Productivity	Mean	Target	Achieved	Gap
TOP MODEL Products	**PPH (weighted Ave)**	**Baseline**	**Target PPH**	**Achieved**	**Gap to Target**
PRINCESS WIDE D	**1.40**	**0.92**	**1.38**	**52%**	**#N/A**
REEBOK SUBLITE PRIME	1.04	0.83	1.25	25%	25%
REALFLEX TRANSITION 5.WR	0.95	0.76	1.14	24%	26%
REEBOK ROYAL COMPLETE LOW	**0.67**	**0.73**	**1.09**	**-19%**	**69%**
SPEEDFUSION RS L	0.87	0.83	1.25	5%	45%
CL NYLON R13	0.94	0.76	1.14	24%	26%
REALFLEX ADVANCE 2	1.10	0.76	1.14	45%	5%
CL NYLON SLIM POP	0.94	0.76	1.14	23%	27%
RECORD FINISH RS 2	0.94	0.83	1.25	14%	36%
ZIGULTRA CRUSH	0.85	0.76	1.14	12%	38%

Explanation:

- Column 1: Top model name
- Column 2: PPH weighted average that models have PPH achieved for each month and then average monthly PPH we will get the PPH of season (table is in last season (Summer – Spring 2014)
- Column 3: Baseline is standard efficiency for each model if we get the baseline that we will achieve 100% PPH (efficiency)
- Column 4: From the top management of Adidas Company, they have set the target that increasing 50% compare with baseline
- Column 5: the percentage PPH achievement
- Column 6: Gap to target

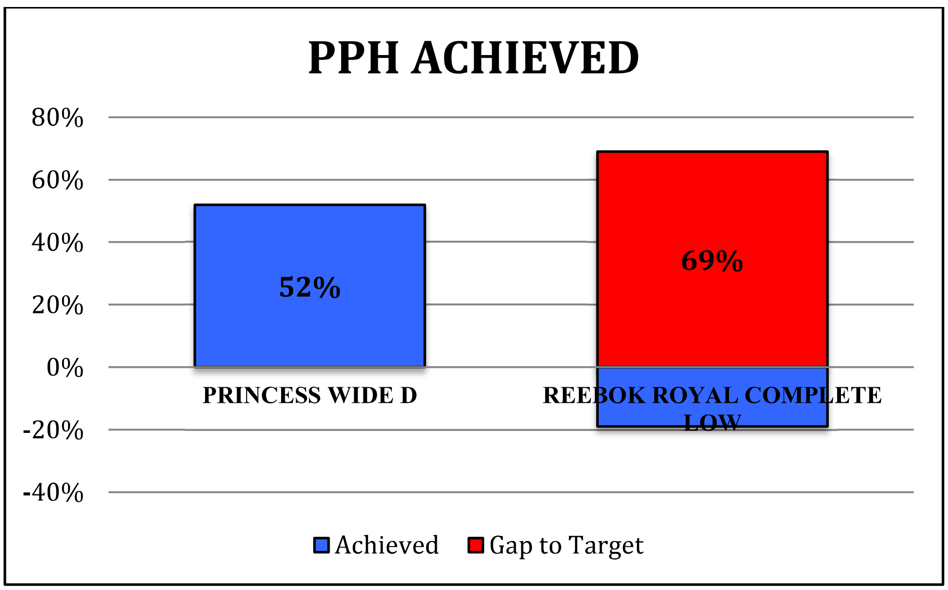


Figure 4-1. PPH Achieved

The red color (high-light in table) is the models we have to consider of this study:

1. Princess Wide D model have achieved the PPH target with 52% increased
2. Reebok Royal Complete Low model was not achieved the PPH target, even under the base line by -19%

4.2 Data collection

Firstly, before drawing the flow chart of two above models, we have to consider the construction of each model. Below the table shows all details that makes clear understanding.

Princess model:

Table 4-2: Princess model information

PRINCESS					
Areas	**No. Of tasks**	**No. Worker**	**Takt time**	**Target output (1hour)**	**Target output (8hour)**
Cutting	11	3	30	120	960
Pre-fit	12	8	30	120	960
Stitching	15	17	30	120	960
Stock-fit	10	5	30	120	960
Assembly	30	22	30	120	960
Total	78	55			

No.of Task: Based on working instructions or Mapping line or observe directly in the factory.

Takt time is like perfect time for each worker. It can understand like KPI to achieve.

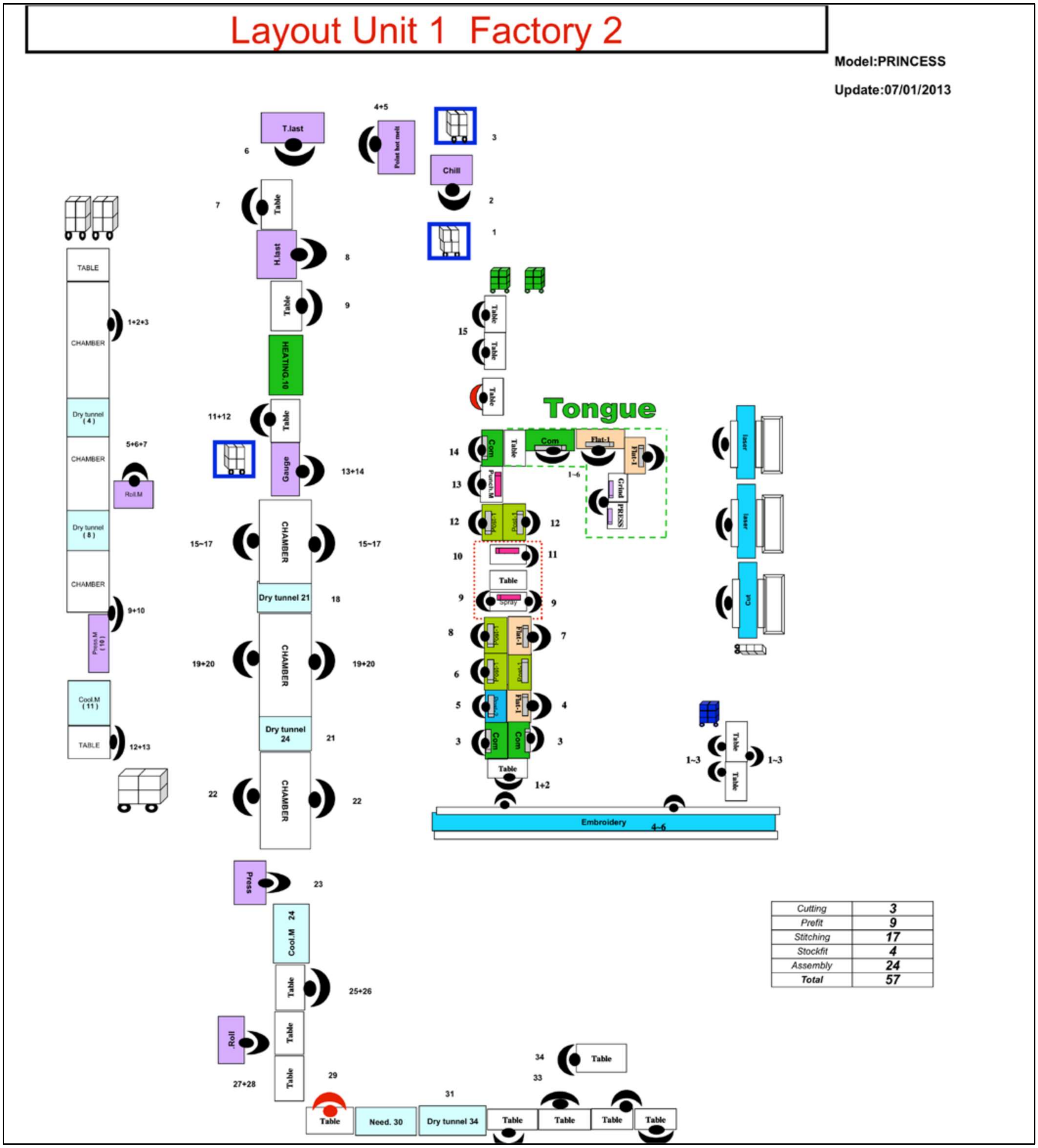
Model Reebok Royal CL:

Table 4-3: Model Reebok Royal CL model information

REEBOK ROYAL CL					
Areas	**No. Of tasks**	**No. Worker**	**Takt time**	**Target output (1hour)**	**Target output (8hour)**
Cutting	18	5	30	120	960
Pre-fit	6	6	30	120	960
Stitching	26	43	30	120	960
Stock-fit	15	20	30	120	960
Assembly	34	34	30	120	960
Total	99	108			

After approaching to the real production line, we conducted that both models have the same as tatk-time within 30 seconds and target output per one hour is 120 products. The total number of task in Princess model just are 78 while Reebok model having 99 tasks.

Description the layout of Princess and Reebok Royal CL models:



Cutting	3
Prefit	9
Stitching	17
Stockfit	4
Assembly	24
Total	57

Figure 4-2. Princess model Mapping line in the factory.

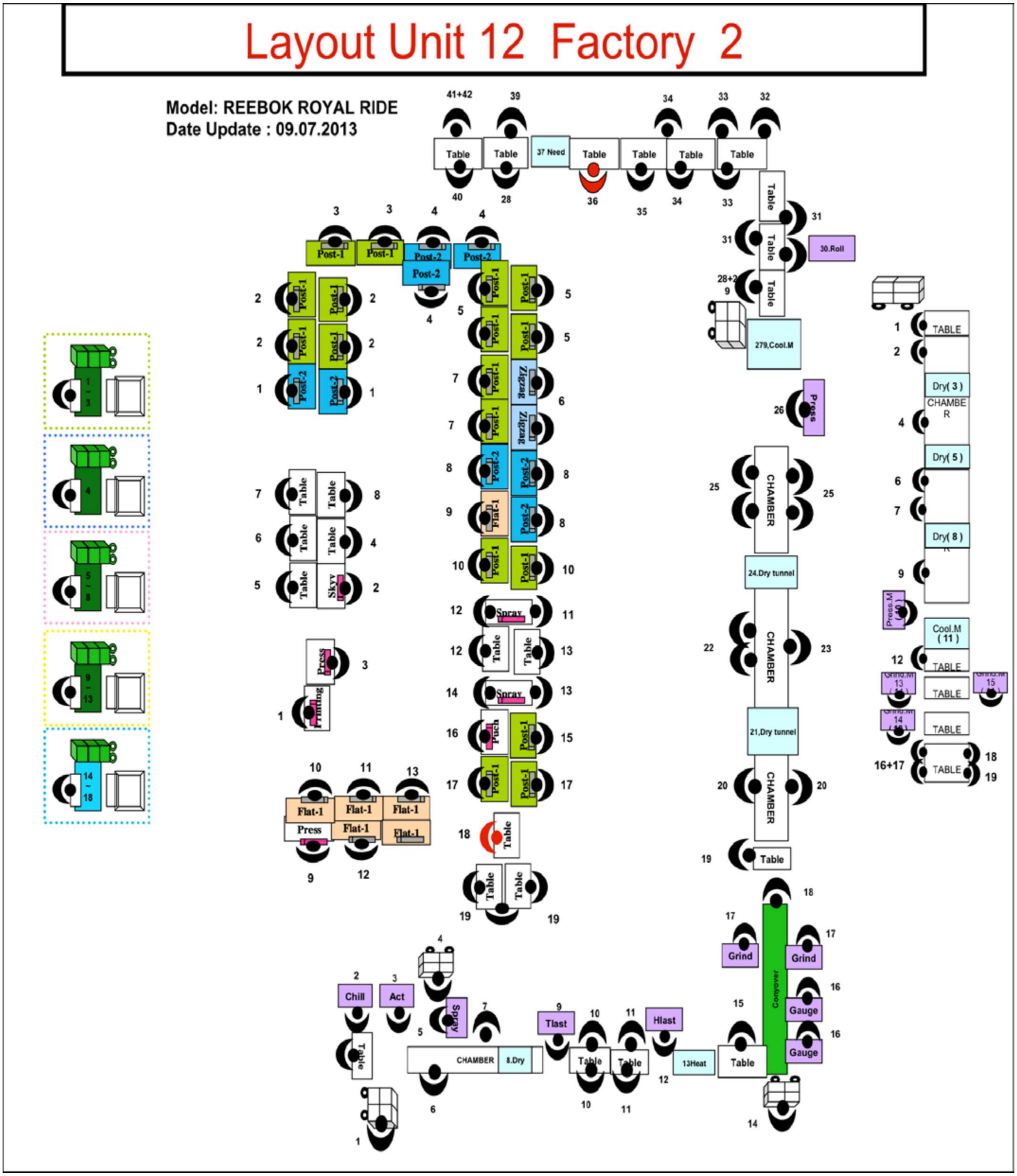


Figure 4-3. Reebok Royal CL model layout

4.2 Comparison line balance loss percentage between two models

The LBL percentage is presented to identify the seriousness of the problem. LBL is calculated as follows:

$$\%\boldsymbol{LBL} = \frac{\boldsymbol{nT_{max}} - \sum \boldsymbol{ti}}{\boldsymbol{n\,T_{max}}}\ \boldsymbol{x\ 100\%}$$

Where:

n = Number of workstation

T_{max} = Value of the highest cycle time

$\sum t_i$ = Total cycle time

Table 4-4: LBL (%) Model comparison

LINE BALANCE LOSS PERCENTAGE (% LBL)		
AREAS	**PRINCESS MODEL**	**REEBOK ROYAL CL MODEL**
CUTTING	**17.1%**	**2.2%**
PRE-FIT	**26.3%**	**10.3%**
STITCHING	**23.2%**	**48.6%**
STOCK-FIT	**23.3%**	**21.4%**
ASSEMBLY	**39.1%**	**55.7%**

Overall, the result shows that the line balance loss percentages of two models are more than 40% of unbalance. Specifically, Princess and Reebok Royal CL are 35.5% and 53.4% respectively. Thus, some effective actions must be taken to balance the assembly line, as well as increasing the productivity of the assembly line.

Take average loss >= 40%

The major step is to identify bottleneck areas in current layout. In each area the line balance loss percentage (LBL%) is different with highest areas consumption percentages will be identified as a bottleneck or considering.

Looking at the line balance loss percentage of each area of two models, we easily recognize that the highest percent focus on assembly area for both models: Princess (39.1%) and Reebok (55.7%). However, the stitching area of Reebok model surprisingly account for 48.6% unbalance while the Princess just only makes up less than 25%. Totally, although the princess model has 41.5% unbalance, it also reaches a target that increasing 50% PPH performance line almost contrasts to the Reebok Royal CL model, just occupies by only 2% PPH increase.

Therefore, there is two areas in currently will be considered that are: (Reebok Royal CL model)

- Stitching area
- Assembly area

Identify bottleneck base LPL

Beside the LBL (%) we mention above, we have to pay more attention for design of shoes, especially is complex tier level. In general, Reebok Royal CL model has a higher level of difficulty than Princess model: CTL (*) of Reebok Royal CL model is 4.1, while only 2.0 for Princess model that why Princess model has saved more simple production Reebok Royal CL model, as an evidence to show that Reebok has more stations than the other one.

We can conclude that Princess model has saved more simple manufacturing process. It explain why in the same period Princess model has a higher output Reebok Royal CL model, of course achieved PPH targets.

(*) CTL is complex tier level of shoes (confidential value)

4.3 Reebok Royal CL model analysis

Both areas currently will be considered as:

- Stitching area
- Assembly area

4.3.1 Analytical calculations

4.3.1.1 Cycle Time

Cycle time formula:

$$\boldsymbol{Cycle\ time} = VA + NVA + NVAN$$

4.3.1.2 Standard cycle time

This step we will focus on how to determine the standard cycle time and manpower requirement, they will be compared with actual system.

Standard cycle time formula:

$$\boldsymbol{standard\ cycle\ time} = (\,Cycle\ time\ \times\ allowance) + cycle\ time$$

4.3.1.3 Manpower requirement

Depend on standard cycle time and takt-time, we easily determine the manpower requirement

$$\boldsymbol{Manpower\ requirement} = \frac{Standard\ cycle\ time}{takt\ time}$$

4.3.1.4 Balance cycle time

The balance of cycle time is a parameter that balance between standard cycle time with actual manpower existing on production line, it's determined by:

$$\boldsymbol{Balance\ cycle\ time} = \frac{standard\ cycle\ time}{actual\ manpower}$$

Table 4-5: Stitching areas data To fulfil this table, must need work flow.

No.	Operation	VA	NVA	NVAN	Total (cycle time)	Standard Total Cycle time	Actual manpower	Manpower Requirement	Balance Cycle time
P3	Attach + Press Toe box to Toe cap	13.0	0.0	4.0	17.0	18	1	1	18
P4	Attach eyestay rienf to eyestays	9.0	0.0	3.0	12.0	13	1	1	13
P6	Attach heel tab rienf to heel tab	8.0	0.0	3.0	11.0	12	1	1	12
P10	Stitch computer Tongue lace loop to Tongue	11.0	0.0	2.0	13.0	14	1	1	14
P11	Stitch Tongue to Tongue lining	22.0	0.0	6.0	28.0	30	1	1	30
P12	Stitch binding tongue	10.0	0.0	3.0	13.0	15	1	1	15
P13	Stitch tongue bottom	22.0	0.0	6.0	28.0	30	1	1	30
P14	Stitch Tongue label to Tongue	10.0	0.0	2.0	12.0	13	1	1	13
S1	Stitch imation decora heel upper	40.0	0.0	6.0	46.0	50	2	2	25
S2	Stitch side stripe (l/m) to vamp	80.0	0.0	12.0	92.0	100	4	4	25
S3	Stitch side check (med) to vamp	48.0	0.0	6.0	54.0	58	1	2	58
S4	Stitch Toe cap to vamp	76.0	0.0	6.0	82.0	89	3	3	30
S5	Stitch Eyestay to vamp	90.0	0.0	6.0	96.0	104	3	4	35
S6	Zigzag Stitch back tab to heel upper	42.0	0.0	6.0	48.0	51	1	2	51
S7	Stitch heel cap to upper 1st	20.0	0.0	6.0	26.0	28	1	1	28
S8	Stitch heel cap to upper 2st	75.0	0.0	6.0	81.0	88	3	3	29
S9	Stitch collar lining egds	15.0	0.0	6.0	21.0	22	1	1	22
S10	Stitch collar lining to upper	43.0	0.0	6.0	49.0	53	2	2	27
S11	Spray hot melt Attach to toecap	22.0	0.0	4.0	26.0	28	1	1	28
S12	Spray hot melt + Attach internal counter to upper	45.0	0.0	8.0	53.0	57	2	2	28
S13	Attach Collar foam + Invert Collar lining	21.0	0.0	5.0	26.0	27	2	2	14
S14	Spray hot melt + Attach Collar lining	25.0	0.0	2.0	27.0	29	2	2	14
S15	Stitch Upper bottom	10.0	0.0	6.0	16.0	13	1	1	13
S16	Punched holes eyestay	8.0	0.0	4.0	12.0	13	1	1	13
S17	Stitch tongue to upper	44.0	0.0	6.0	50.0	54	2	2	27
S19	Shoe lacing + Putting upper on the trolley	74.0	0.0	8.0	82.0	87	3	3	29

Table 4-6: Assembly areas data

No.	Operation	VA	NVA	NVAN	Total (cycle time)	Standard Total Cycle time	Actual manpower	Manpower Requirement	Balance Cycle time
A3	Chilling & Heating	15.0	5.0	4.0	**24**	26	1	1	**26**
A4	Prepare last	16.0	0.0	3.0	**19**	21	1	1	**21**
A5	Point hot melt + Attach Texon to last	20.0	0.0	3.0	**23**	25	1	1	**25**
A6	Apply latex C 310 to Upper	24.0	0.0	3.0	**27**	29	1	1	**29**
A7	Apply latex C 310 to Texon	20.0	0.0	3.0	**23**	25	1	1	**25**
A9	Toe lasting	16.0	0.0	8.0	**24**	26	1	1	**26**
A10	Side lasting	42.0	0.0	6.0	**48**	52	2	2	**26**
A11	Tighting shoes lacing	30.0	0.0	6.0	**36**	39	2	2	**19**
A12	Heel lasting	14.0	0.0	9.0	**23**	25	1	1	**25**
A14	Prepare sole	0.0	0.0	20.0	**20**	22	1	1	**22**
A15	Pointing marking toe	20.0	0.0	4.0	**24**	26	1	1	**26**
A16	Gauge marking Q'ter	46.0	0.0	3.0	**49**	53	2	2	**26**
A17	Grinding bottom marking upper	44.0	0.0	6.0	**50**	55	2	2	**27**
A19+A18	Primer PR 505 on sole	30.0	0.0	23.0	**53**	57	1	2	**57**
A20	Primer W-104 L on upper	49.0	0.0	6.0	**55**	59	2	2	**30**
A22	Cement SW -07 on upper	20	0	6	**26**	28	2	2	**14**
A23	Cement SW -07 on sole	24.0	0.0	3.0	**27**	29	1	1	**29**
A25	Attach sole to upper	98.0	0.0	10.0	**108**	118	2	4	**59**
A26	Universal pressing + Transfer line	13.0	10.0	3.0	**26**	28	1	1	**28**
A28	Unlace	10	0	5	**15**	16	1	1	**16**
A29	Delast + Arrange last	8	0	4	**12**	13	1	1	**13**
A30	Rolling hot melt Sockliner + Insert Sockliner on shoes	10	0	2	**12**	13	1	1	**13**
A31	Cleanning	45.0	0.0	6.0	**51**	55	2	2	**28**
A32	Crumple tissue paper + Insert tissue paper on shoes	11	0	2	**13**	14	1	1	**14**
A33	Tighting shoes lacing	49.0	0.0	6.0	**55**	59	2	2	**30**

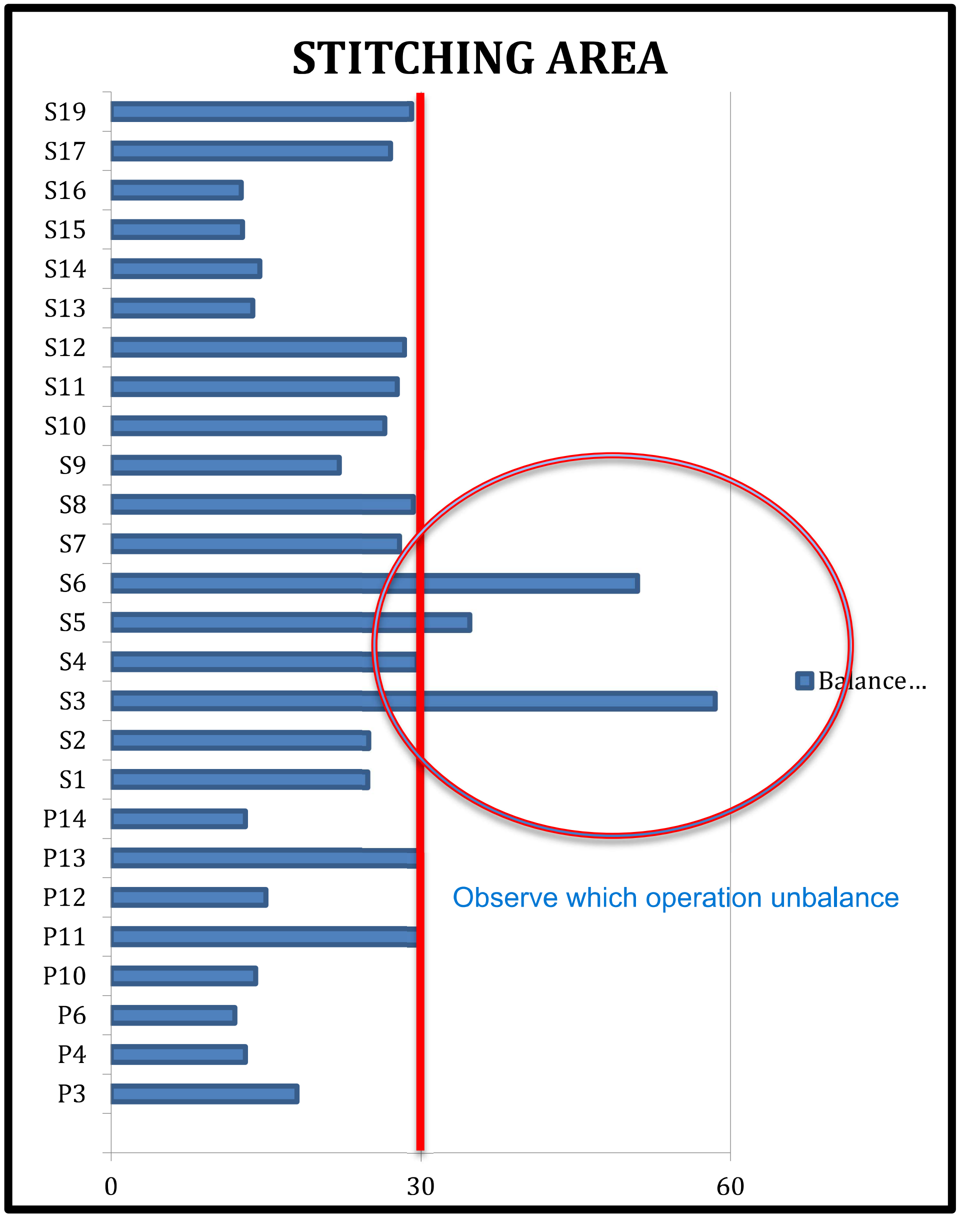


Figure 4-4. Balance cycle time at stitching area

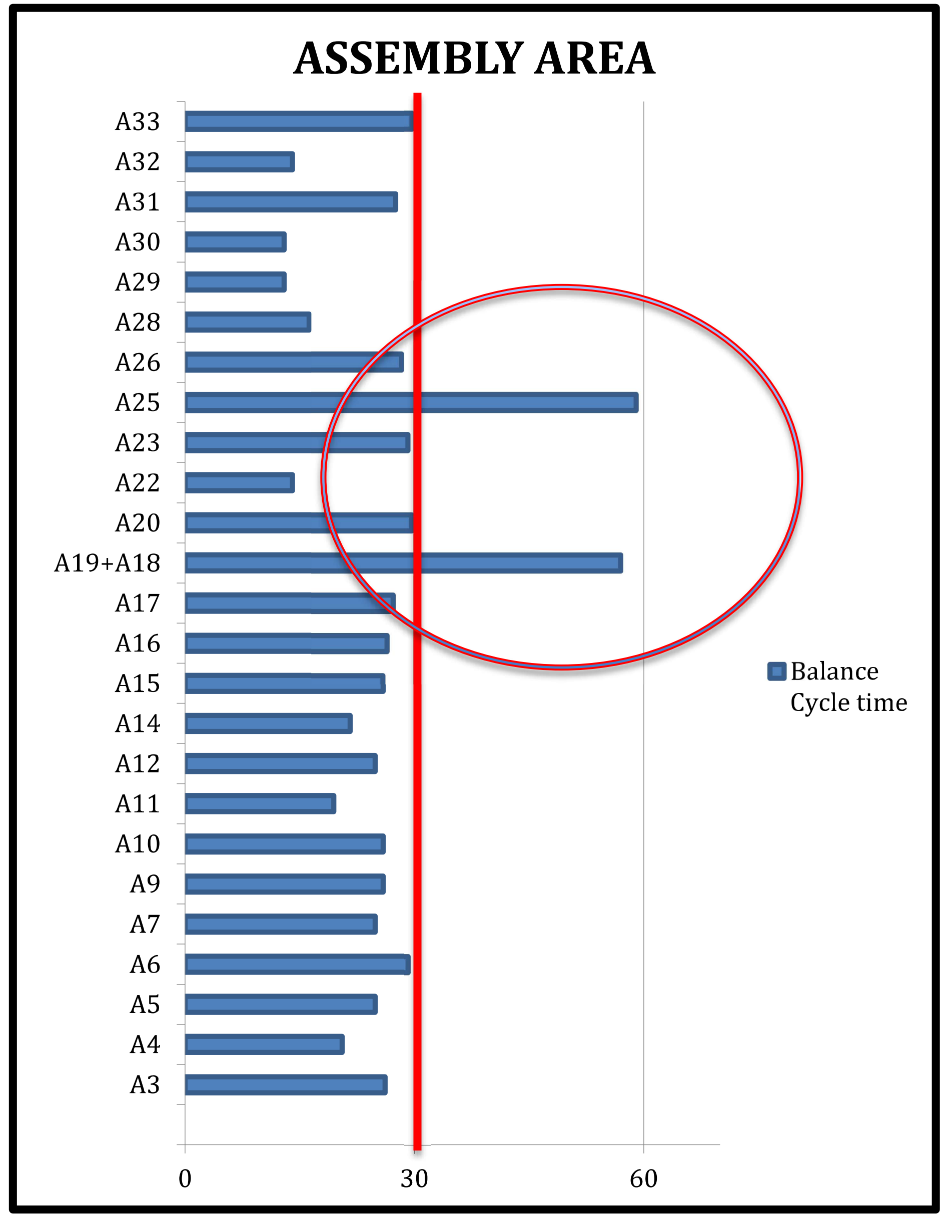


Figure 4-5. Balance cycle time at assembly area

4.4 Bottleneck specification

As the red circles color from figure 4-4 and 4-5 shows that some workstations tend to be the bottlenecks as these stations handled more workload than other stations. After bottleneck analysis we just focus mainly on 2 specific areas:

- The workstations 3, 5, 6 belong to **stitching area**.
- The workstation (18, 19), 25 belong to **assembly area**.

Table 4-7: Standard manpower vs. Actual manpower Estimate head count

No.	Operation	VA	NVA	NVAN	Total (cycle time)	Standard Total Cycle time	Actual manpower	Manpower Requirement
S3	Stitch side check (med) to vamp	48.0	0.0	6.0	**54.0**	58	1	2
S5	Stitch Eyestay to vamp	90.0	0.0	6.0	**96.0**	104	3	4
S6	Zigzag Stitch back tab to heel upper	42.0	0.0	6.0	**48.0**	51	1	2
A19+A18	Primer PR 505 on sole	30.0	0.0	23.0	**53**	57	1	2
A25	Attach sole to upper	98.0	0.0	10.0	**108**	118	2	4

Standard manpower is the least number of workers required for a production line, which is determined by standard cycle time and allowance. However, the actual manpower is insufficient to meet standard manpower, which leads to the cause of cycle time of workstation 3, 5, 6 (stitching area) and 18, 19, 25 (assembly area) higher than takt-time.

4.5 Conceptual model

After observing and analyzing the real operation systems of production line, the conceptual model is developed. Conceptual model quite involves some degree of abstraction of the system operations, or some amount of simplification of actual operation. In order to assure that the conceptual model is reflected accurate the operational model, the model is confirmed by the production manager.

4.5.1 Flow chart for production line (Reebok Royal CL model)

FLOW-CHART (STITCHING AREA)

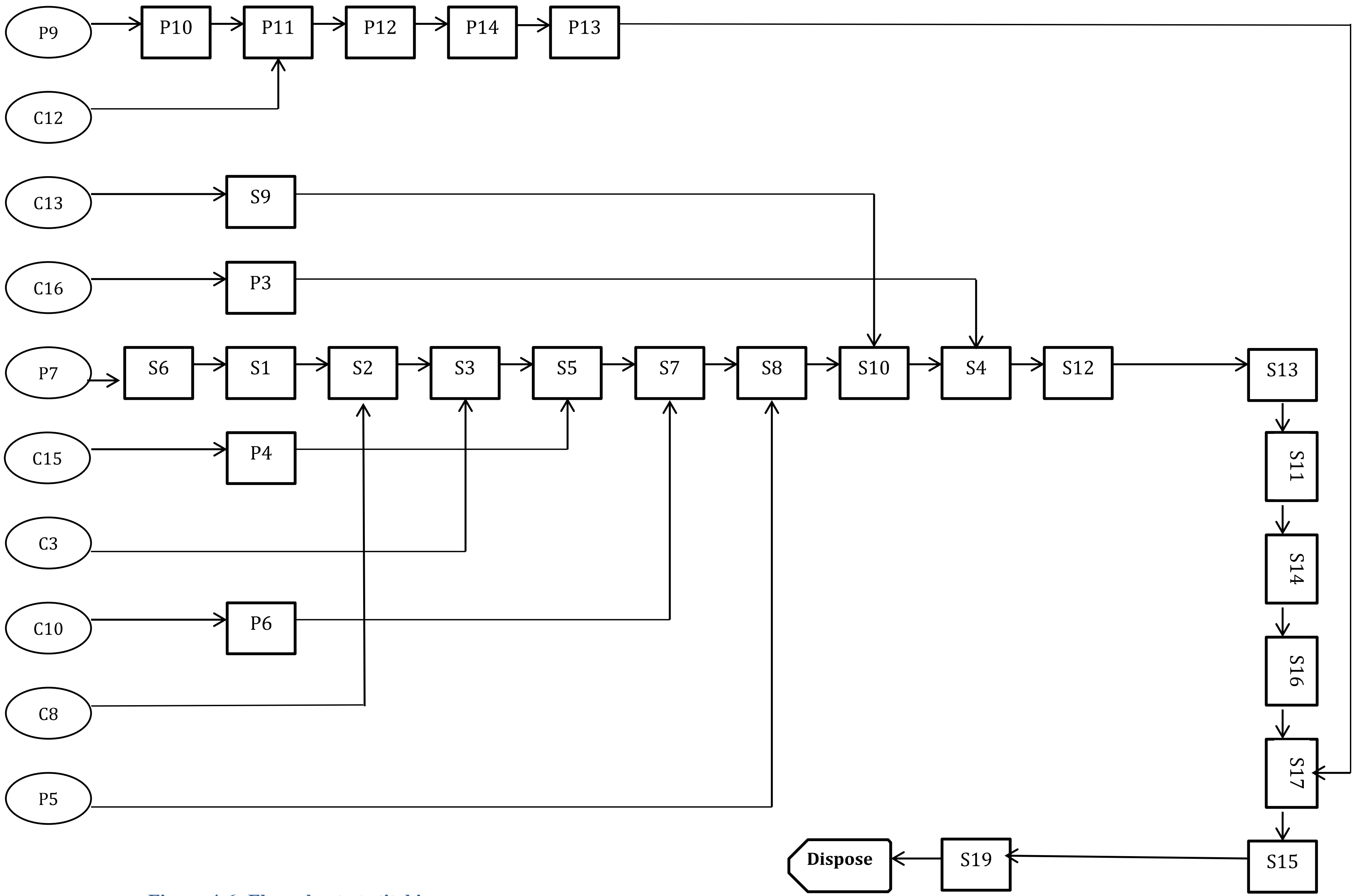


Figure 4-6: Flow-chart at stitching area

FLOW-CHART (ASSEMBLY AREA)

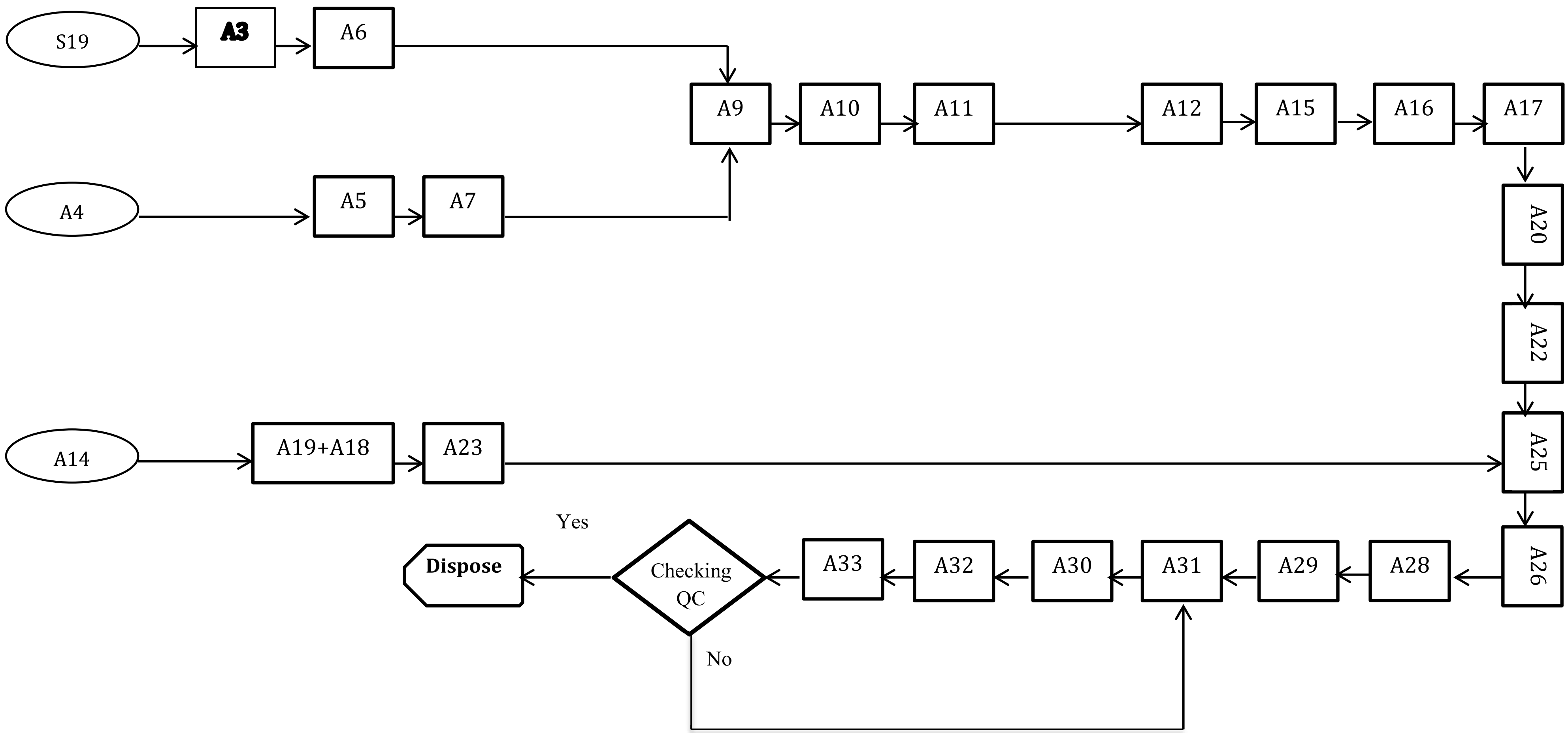


Figure 4-7: Flow-chart at assembly area

4.5.2 Input analyzing

The author focus on process bottleneck

The input data is analyzed by input analyzer of **Arena® program** (offered by Rockwell Automation). The chosen probability distribution & associated parameter for goodness of fit are evaluated by input analyzer software (figure 4-8, table 4-8 and 4-9).

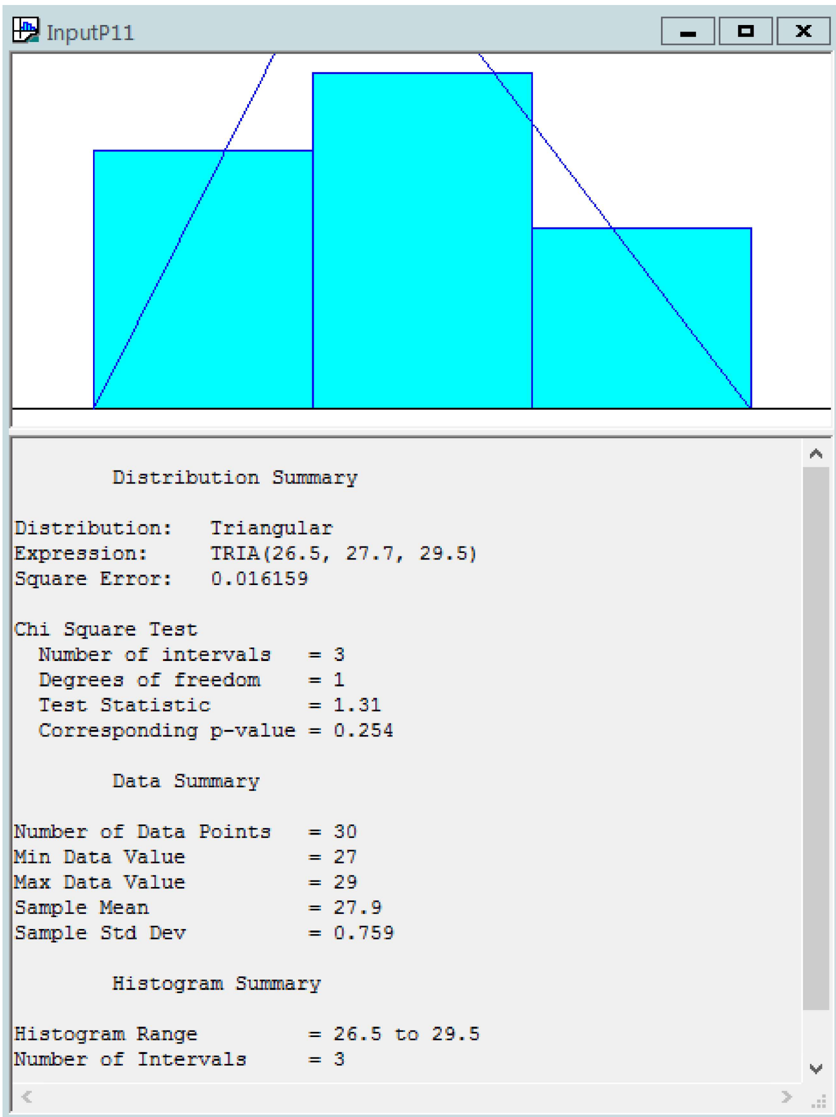


Figure 4-8: Testing the model parameter

By analyzing this data, we see that the expression TRIA (26.5, 27.5, 29.5), (Triangular distribution) will be applied to the attach eyestay rienf to eyestays process module.

Table 4-8: Distribution of processing time at stitching area

No.	Operation	Distribution			
P10	Attach + Press Toe box to Toe cap	Triangular	11	12	13
P11	Attach eyestay rienf to eyestays	Triangular	27	28	29
P12	Attach heel tab rienf to heel tab	Triangular	13	15	16
P14	Stitch computer Tongue lace loop to Tongue	Triangular	11	12	13
P13	Stitch Tongue to Tongue lining	Triangular	27	28	29
S9	Stitch binding tongue	Triangular	19	20	22
P3	Attach + Press Toe box to Toe cap	Triangular	14	16	17
S6	Stitch Tongue label to Tongue	Triangular	46	47	49
S1	Stitch Imation decora heel upper	Triangular	44	46	47
S2	Stitch side stripe (l/m) to vamp	Triangular	90	91	93
P4	Attach eyestay rienf to eyestays	Triangular	13	15	16
P6	Stitch Toe cap to vamp	Triangular	10	12	13
S3	Stitch Eyestay to vamp	Triangular	52	53	55
S5	Zigzag Stitch back tab to heel upper	Triangular	94	95	97
S7	Stitch heel cap to upper 1st	Triangular	24	25	27
S8	Stitch heel cap to upper 2st	Triangular	79	80	82
S10	Stitch collar lining edges	Triangular	47	48	50
S4	Stitch collar lining to upper	Triangular	80	81	83
S12	Spray hot melt Attach to toecap	Triangular	51	53	54
S13	Spray hot melt + Attach internal counter to upper	Triangular	27	28	29
S11	Attach Collar foam + Invert Collar lining	Triangular	24	26	27
S14	Spray hot melt + Attach Collar lining	Triangular	27	28	29
S16	Stitch Upper bottom	Triangular	11	12	13
S17	Punched holes eyestay	Triangular	48	50	52
S15	Stitch tongue to upper	Triangular	13	14	15
S19	Shoe lacing + Putting upper on the trolley	Triangular	80	82	83

Table 4-9: Distribution of processing time at assembly area

No.	Operation	Distribution			
A3	Chilling & Heating	Triangular	22	24	26
A4	Prepare last	Triangular	17	20	21
A5	Point hot melt + Attach Texon to last	Triangular	21	23	25
A6	Apply latex C 310 to Upper	Triangular	25	26	29
A7	Apply latex C 310 to Texon	Triangular	21	23	25
A9	Toe lasting	Triangular	22	24	26
A10	Side lasting	Triangular	46	48	50
A11	Tighting shoes lacing	Triangular	34	36	38
A12	Heel lasting	Triangular	21	23	25
A14	Prepare sole	Triangular	18	20	22
A15	Pointing marking toe	Triangular	22	24	26
A16	Gauge marking Q'ter	Triangular	47	49	53
A17	Grinding bottom marking upper	Triangular	48	50	52
A19+A18	Primer PR 505 on sole	Triangular	53	55	58
A20	Primer W-104 L on upper	Triangular	53	55	57
A22	Cement SW -07 on upper	Triangular	27	28	29
A23	Cement SW -07 on sole	Triangular	25	27	29
A25	Attach sole to upper	Triangular	115	117	118
A26	Universal pressing + Transfer line	Triangular	24	26	28
A28	Unlace	Triangular	14	15	16
A29	De-last + Arrange last	Triangular	12	13	14
A30	Rolling hot melt Sock liner + Insert Sock liner on shoes	Triangular	11	12	13
A31	Cleaning	Triangular	12	13	14
A32	Crumple tissue paper + Insert tissue paper on shoes	Triangular	9	11	12
A33	Tighting shoes lacing	Triangular	53	55	57

4.6 Developed simulation model

4.6.1 Simulating the input

Base on the logical model and collected data, the simulation model of stitching and an assembly area developed using arena software.

Firstly, the model created by inserted information such as the distribution of Time Between Arrivals of parts, are used and shown following table:

Can construct from maximum output plan per shift

Table 4-10. Standard Manpower vs. Actual Manpower

Create	Distribution	Max Arrival
Create C3	TRIA(6 , 7 , 8)	979
Create C4	TRIA(18 , 19 , 20)	979
Create C8	TRIA(6 , 7 , 8)	1057
Create C10	TRIA(5 , 6 , 7)	979
Create C12	TRIA(4 , 5 , 6)	979
Create C13	TRIA(4 , 5 , 6)	979
Create C15	TRIA(9 , 10 , 11)	979
Create C16	TRIA(9 , 10 , 11)	979
Create P5	TRIA(25 , 26 , 27)	1035
Create P8	TRIA(25 , 26 , 27)	1035
Create P9	TRIA(21 , 22 , 23)	1212
Create A4	TRIA(17 , 20 , 21)	1404
Create A14	TRIA(18 , 20 , 22)	1333

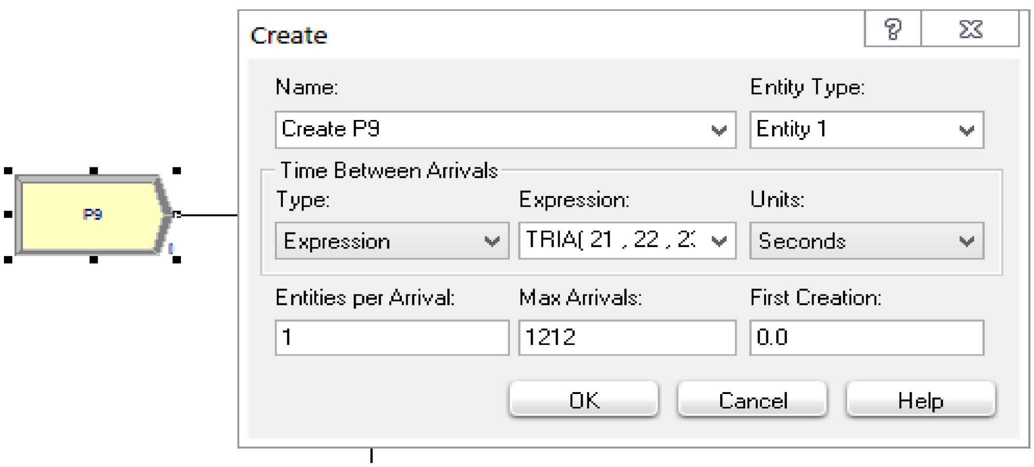


Figure 4-9: Create module

The “create module” generates a stream of arrivals of Arena entities. Considering the above distribution table

About from 21s to 23s, there is average 1 part coming to production line within 22 seconds, so the triangular distribution should be used “TRIA (21,22,23)” to represent for this number.

Secondly, we use the “assign module” to assign the percentage of each kind of part.

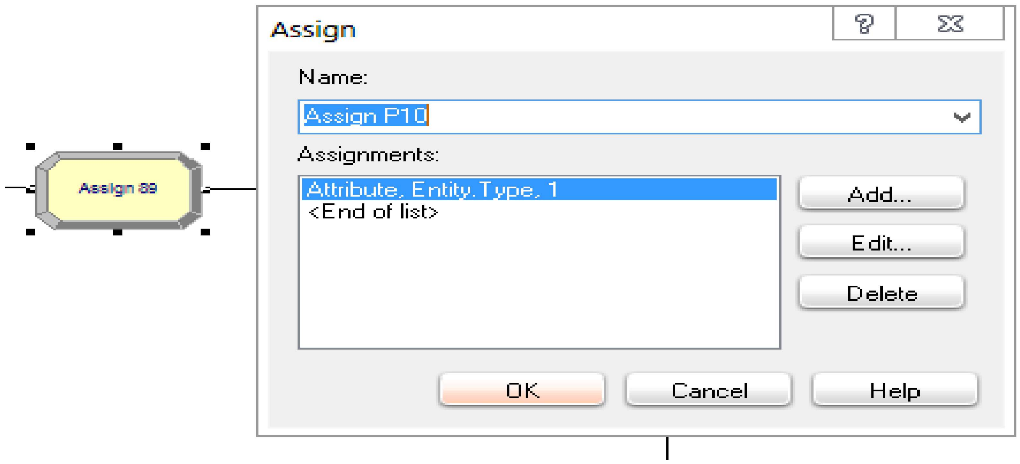


Figure 4-10: Assign module

This module is used for assigning attributes and variables for any parts or items passing through.

4.6.2 *Simulating the output* Connect with files

At the output step, the "read-write module" is used to record all the needed information such as the total time of the whole process or the total moving items, which are very important for data analyzing, and exporting those information into an Excel file.

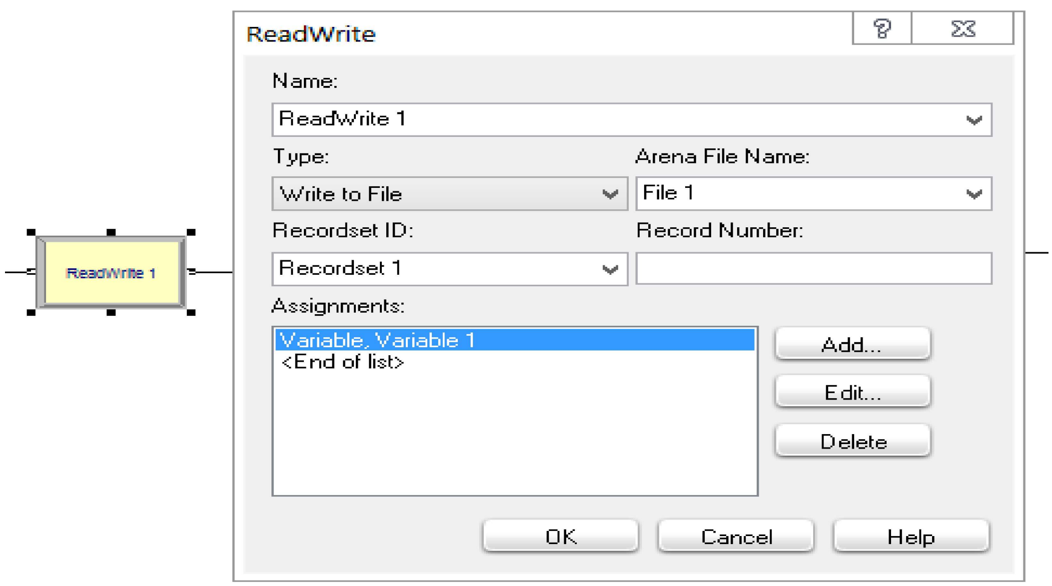


Figure 4-11: Read-write module

After capturing all the needed information, the “dispose module” is used to express the final step of the whole process and complete the model.

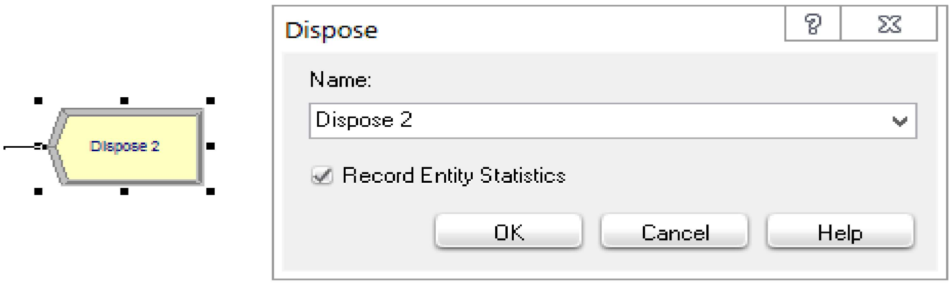


Figure 4-12: Dispose module

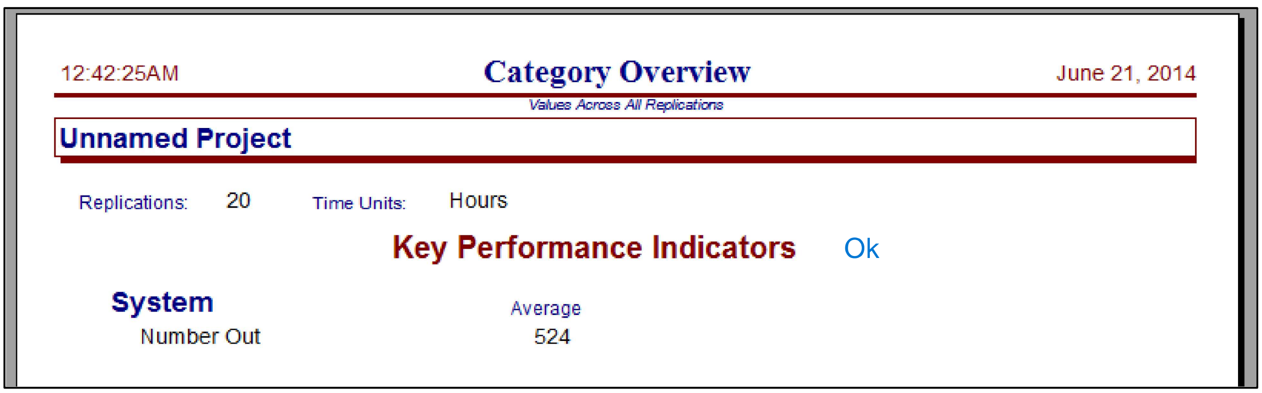


Figure 4-13: Average output per day of stitching area

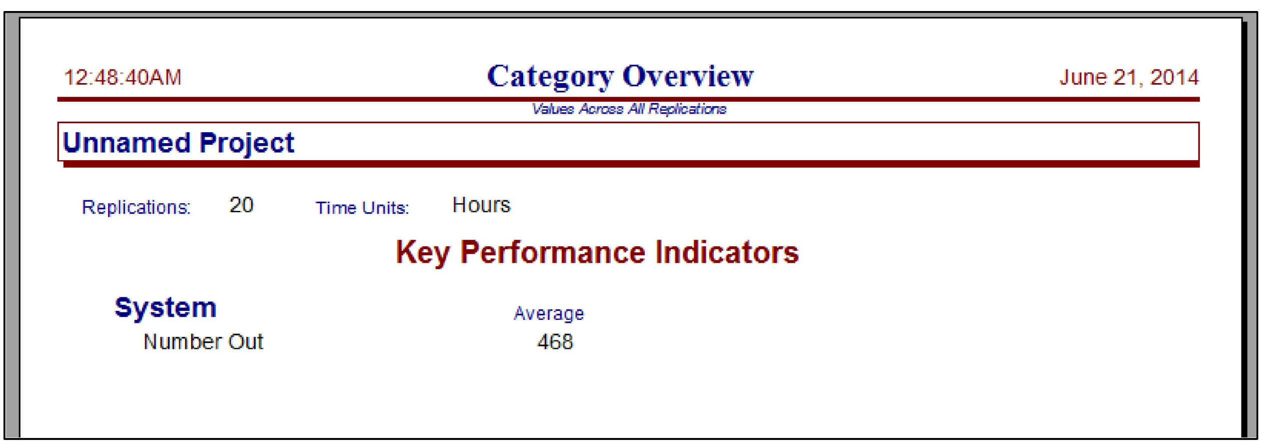


Figure 4-14: Average output per day of Assembly area

4.7 Validation

After getting the result from simulated model we determine whether the model is different from the real system. It is conducted by comparing result from simulation and the reality. This method is Turkey's pairwise comparison with 95% confident level. By using **Minitab 14.0 program**, we get the below result: Using minitab to check the variance of output.

4.7.1 Validation at Stitching Area

STITCHING AREA	OUTPUT (SIMULATION)	ACTUAL OUTPUT
REPLICATION 1	524	518
REPLICATION 2	540	526
REPLICATION 3	525	520
REPLICATION 4	539	533
REPLICATION 5	524	536
REPLICATION 6	540	550
REPLICATION 7	525	520
REPLICATION 8	539	529
REPLICATION 9	525	532
REPLICATION 10	540	533
REPLICATION 11	524	528
REPLICATION 12	540	529
REPLICATION 13	525	530
REPLICATION 14	540	550
REPLICATION 15	524	545
REPLICATION 16	541	550
REPLICATION 17	524	533
REPLICATION 18	541	543
REPLICATION 19	525	529
REPLICATION 20	539	533

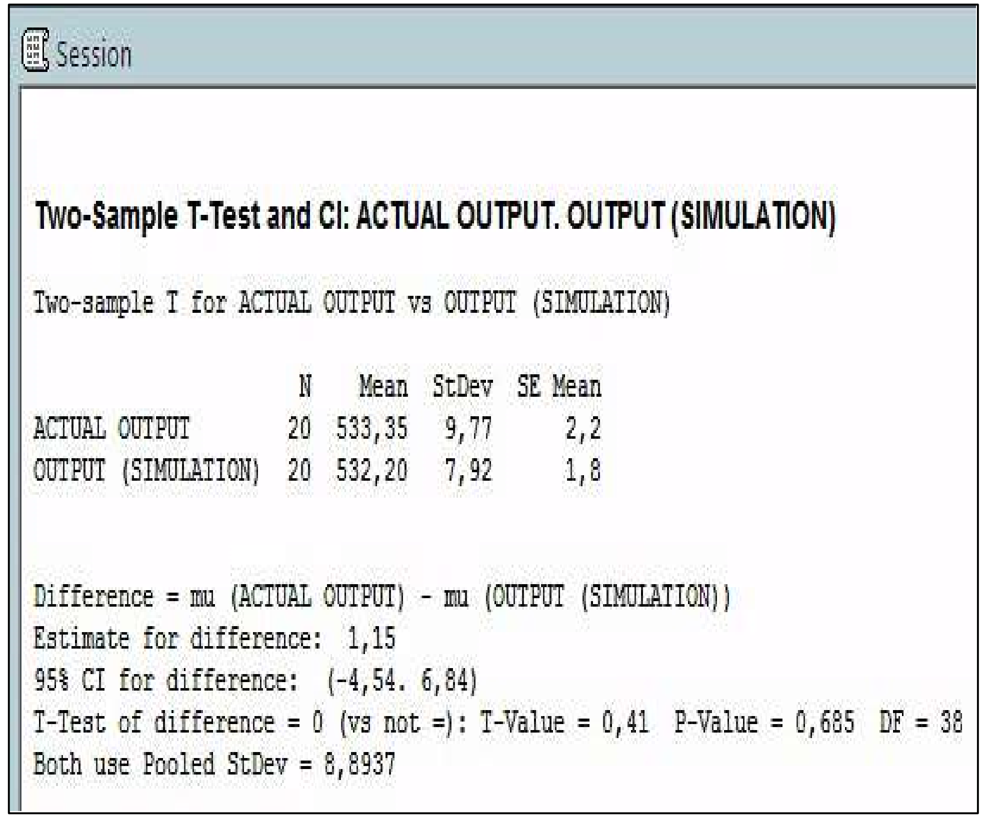
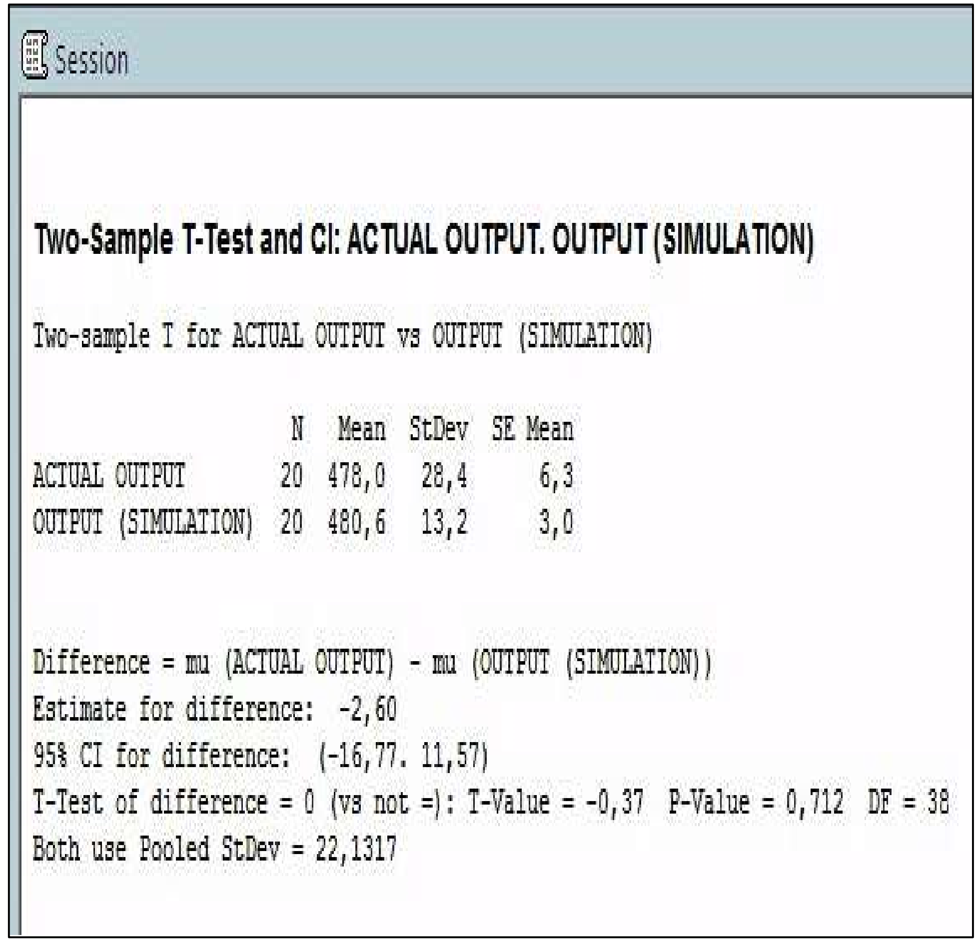


Figure 4-15: Validation at Stitching Area

4.7.2 Validation at Assembly Area

ASSEMBLY AREA	OUTPUT (SIMULATION)	ACTUAL OUTPUT
REPLICATION 1	468	399
REPLICATION 2	493	408
REPLICATION 3	467	470
REPLICATION 4	494	476
REPLICATION 5	468	488
REPLICATION 6	494	490
REPLICATION 7	468	473
REPLICATION 8	493	479
REPLICATION 9	468	488
REPLICATION 10	493	510
REPLICATION 11	468	466
REPLICATION 12	494	487
REPLICATION 13	467	488
REPLICATION 14	494	477
REPLICATION 15	468	470
REPLICATION 16	493	488
REPLICATION 17	468	494
REPLICATION 18	493	499
REPLICATION 19	467	509
REPLICATION 20	494	501


Session

Two-Sample T-Test and CI: ACTUAL OUTPUT. OUTPUT (SIMULATION)

```
Two-sample T for ACTUAL OUTPUT vs OUTPUT (SIMULATION)

                     N   Mean  StDev  SE Mean
ACTUAL OUTPUT       20  478,0   28,4      6,3
OUTPUT (SIMULATION) 20  480,6   13,2      3,0


Difference = mu (ACTUAL OUTPUT) - mu (OUTPUT (SIMULATION))
Estimate for difference:  -2,60
95% CI for difference:  (-16,77. 11,57)
T-Test of difference = 0 (vs not =): T-Value = -0,37  P-Value = 0,712  DF = 38
Both use Pooled StDev = 22,1317
```

Figure 4-16: Validation at Assembly Area

Based on 95% confident interval for difference between the simulated output and actual output is a range $[-4.54, 6.48]$ in stitching area which contains the number zero, corresponding to this result we can draw a conclusion that the simulated model similar to the real system.

Similarly, the validation process are apply for assembly area in range $[-16.77, 11.57]$ which contains the number zero, corresponding to this result we can recognize that the simulated model similar to the real system. Contain zero, similar with real system

To sum up, the two models were chosen, they are the Princess Wide D models, which has achieved the PPH target, and Reebok Royal Complete Low model has not achieved the PPH target. The Princess has 35.5% line balance loss and Reebok Royal CL is 53.4%, which evidences are given above. Therefore, we focus on Reebok Royal CL models to find out the root causes existing in production line. In fact, the actual manpower is insufficient to meet standard manpower. It leads to the cause of cycle time of workstation 3, 5, 6 (stitching area) and 18, 19, 25 (assembly area) higher than takt-time… Then, we build the model on simulation software and validate that the simulated model is similar to the real system.

CHAPTER 5 PROPOSED AND VALUATED SOLUTION

The assembly process involves a set of workstations; each carries out a specific task or tasks in a restricted sequence. It is important that tasks are allocated to each workstation as evenly as possible to avoid bottlenecks and excessive idle time. Line balancing involves assigning and balancing tasks between workstations of the assembly line in order to minimize balance delay, labor force and ultimately minimizing workstation.

After we have built simulation model that similar with real system, we was proposed solutions for improving the cycle time below takt-time based on the concept of eliminating, combining, simplifying the assembly process without any additional machine manpower by direct observation method. Increasing the PPH efficiency performance by generating to utilize manpower existing in the real system can be the second improvement.

5.1 Initial improvement

The cycle time is improved below takt time by direct observation, concept of eliminating, combining, simplifying the assembly process without any additional machine and manpower and Arena software.

The improvement is then confirmed by simulation by direct observation. We've realized some process that should be reconsidered:

Table 5-1: Consideration of station

No.	Operation	Cycle Time (Sec./Prs)				Standard Total Cycle time	Takt time	Actual manpower
		VA	NVA	NVAN	Total			
S13	Attach Collar foam + Invert Collar lining	21	0	5	26	27	30	2
S14	Spray hot melt + Attach Collar lining	25	0	2	27	29	30	2
P12	Stitch binding tongue	10	0	3	13	14	30	1
P14	Stitch Tongue label to Tongue	10	0	2	12	13	30	1
A22	Cement SW -07 on upper	20	0	6	26	28	30	2
A28	Unlace	10	0	5	15	16	30	1
A29	Delast + Arrange last	8	0	4	12	13	30	1
A30	Rolling hot melt Sockliner + Insert Sockliner on shoes	10	0	2	12	13	30	1
A32	Crumple tissue paper + Insert tissue paper on shoes	11	0	2	13	14	30	1

5.1.1 Workstation S13 (stitching area)

At the workstation S13, it includes 2 tasks: Attach collar foam and invert collar lining. The table below shows the processing time of each task and total processing time of workstation S13 is recorded (10 replications) by stopwatch: Not clear, but combine task is a good idea

Table 5-2: Workstation S13 – Attach collar foam and invert collar lining

Workstation S13		Description	Processing Time (second)	Total	Actual worker
Task 1:	Attach collar foam	Check components	1	12	1
		Attach foam	9		
		Check components after attach	2		
Task 2:	Invert collar lining	Check upper	1	15	1
		Turn over the collar lining to back side	13		
		Transfer to next process	1		

At this workstation S13, the task 1 (Attach collar foam) is combined with the task 2 (Invert collar lining) to meet total processing time of 27 seconds.

The maximum processing time for 1 worker is 30 seconds (takt-time). The actual number of worker at this workstation (S13) is 2 and it takes only 27 seconds (< 30s) for them to complete their work. OK. Make sure that target reach takt time

Therefore, the suggestion of this situation is applied to 1 worker for both tasks at workstation S13 instead of 2 in real system. (Reduce 1 operator in stitching area)

Decision : reduce 1 worker. This can be affect to qualification. Merge some job needed, redesign layout or position of worker.

5.1.2 Workstation S14 (stitching area)

Similarly, workstation S14 also includes 2 tasks: Spray hot melt and attach collar lining. The below table shows the processing time of each task and total processing time of workstation S14 is recorded (10 replications) by stopwatch:

Table 5-3: Workstation S14 – Spray hot melts and attaches collar lining

Workstation S14		Description	Processing Time (second)	Total	Actual worker
Task 1:	Spray hot melt	Open and spray full cement on foam	10	11	1
		Transfer to next process	1		
Task 2:	Attach collar lining	Attach collar lining	12	16	1
		Press by hand around the collar top	3		
		Transfer to next process	1		

At this workstation S14, the task 1 (Spray hot melt) is combined with the task 2 (attach collar lining) to meet total processing time of 27 seconds.

The maximum processing time for 1 worker is 30 seconds (takt-time). The actual number of worker at this workstation (S14) is 2 and it takes only 27 seconds (< 30s) for them to complete their work.

Therefore, the suggestion of this situation is applied to 1 worker for both tasks at workstation S14 instead of 2 in real system. (Reduce 1 operator in stitching area)

5.1.3 Workstation P12 and P14 (stitching area)

These tables below show total processing time of workstation P12 and P14 are recorded (10 replications) by stopwatch:

Table 5-4: Workstation P12 – Stitch binding tongue

Workstation P12	Description	Processing Time (second)	Total	Actual worker
Stitch binding tongue	Check components before stitch	2	13	1
	Stitch binding tongue	11		

Table 5-5: Workstation P14 – Stitch tongue label to tongue

Workstation P14	Description	Processing Time (second)	Total	Actual worker
Stitch tongue label to tongue	Check components	1	13	1
	Stitch tongue label to tongue	9		
	Excess thread	2		
	Transfer to next process	1		

The suggestion of this situation is to combine the task of workstation P12 (Stitch binding tongue) with the task of workstation P14 (Stitch tongue label to tongue). Only 1 worker is used for both workstations instead of 2 in real system. (Reduce 1 operator in stitching area)

If we combined 2 workstations (P12 and P14) together, we could save one worker. Because the total processing time of both stations is only 26 seconds less than takt time (30 seconds) so it also satisfied manpower constrain.

To sum up, we can reduce or save 3 workers in stitching area by eliminating, combining, simplifying the assembly process.

5.1.4 Workstation A22 (Assembly area)

This case is the same as station S13 and S14, it also included 2 tasks: Cleaning the upper and cement SW-07 on upper. The below table shows the processing time of each task and total processing time of workstation is recorded (10 replications) by stopwatch:

Table 5-6: Workstation A22 – Cleaning the upper and cement SW-07 on upper

Workstation A22		Description	Processing Time (second)	Total	Actual worker
Task 1:	Cleaning the upper	Check components	2	11	1
		Cleaning	9		
Task 2:	Cement SW-07 on upper	Cement SW-07 on upper	15	17	1
		Transfer to next process	2		

At this station A22, the task 1 (Cleaning the upper) is combined with the task 2 (Cement SW-07 on upper) to meet total processing time of 28 seconds.

The maximum processing time for 1 worker is 30 seconds (takt-time). The actual number of worker at this workstation (A22) is 2 and it takes only 28 seconds (< 30s) for them to complete their work. The suggestion of this situation is using 1 worker for both tasks at workstation A22 instead of 2 workers in real system. (Reduce 1 operator in assembly area)

5.1.5 Station A28 and A29 ((Assembly area)

These below tables show the processing time of each workstation and total processing time of workstation A28 and A29 recorded (10 replications) by stopwatch:

Table 5-7: Workstation A28 – Unlace

Workstation A28	Description	Processing Time (second)	Total	Actual worker
Unlace	Check shoes	3	15	1
	Unlace	12		

Table 5-8: Workstation A29 – De-last and arrange last

Workstation A29	Description	Processing Time (second)	Total	Actual worker
De-last + Arrange last	De-last	9	13	1
	Check shoes	3		
	Transfer to next process	1		

The suggestion of this situation is combined the task of workstation A28 (Unlace) and the task of workstation A29 (De-last and arrange last) using only 1 worker for both workstations instead of 2 workers in real system. (Saving 1 operator in assembly area)

If we combined 2 stations (A28 and A29) together, we could save one worker. Because the total processing time of both stations is only 28 seconds less than Takt time (30 seconds)

5.1.6 Workstation A30 and A32 ((Assembly area)

These tables below show the processing time of each workstation and total processing time of workstation A30 and A32 recorded (10 replications) by stopwatch:

Table 5-9: Station A30 – Rolling hot melts sock liner and insert sock liner on shoes

Workstation A30	Description	Processing Time (second)	Total	Actual worker
Rolling hot melt Sock liner + Insert Sock liner on shoes	Rolling hot melt Sock liner	11	12	1
	Insert Sock liner on shoes	2		

Table 5-10: Station A32 – Crum tissue upper and insert tissue paper on shoes

Workstation A32	Description	Processing Time (second)	Total	Actual worker
Crumple tissue paper + Insert tissue paper on shoes	Crumple tissue paper	9	13	1
	Insert tissue paper on shoes	3		
	Transfer to next process	1		

Similarly, the task of workstation A30 (Rolling hot melt Sock liner + Insert Sock liner on shoes) is combined with the task of workstation A32 (Crumple tissue paper + Insert tissue paper on shoes) to meet total processing time of 25 seconds. Only 1 worker is used for both workstations instead of 2 workers in real system. If we combined 2 workstations (A30 and A32) together, we could save one worker.

Finally, after analyzing and calculating, totally we can eliminate or save 6 workers at workstation S13, S14, P12, P14 (Stitching area) and A22, A28, A 29, A30, A32 (Assembly area).

Table 5-11: Saving manpower

No.	Operation	Actual manpower	Requested manpower
S13	Attach Collar foam + Invert Collar lining	**2**	**1**
S14	Spray hot melt + Attach Collar lining	**2**	**1**
P12	Stitch binding tongue	**1**	**1**
P14	Stitch Tongue label to Tongue	**1**	
A22	Cement SW -07 on upper	**2**	**1**
A28	Unlace	**1**	**1**
A29	De-last + Arrange last	**1**	
A30	Rolling hot melt Sock liner + Insert Sock liner on shoes	**1**	**1**
A32	Crumple tissue paper + Insert tissue paper on shoes	**1**	
Total		**12**	**6**

These bottlenecks defined above are due to lacking of 6 workers at workstation S3, S5, S6 and A19, A18, A25. Besides that all these tasks can't be divided into sub-tasks or combined with other tasks. Therefore, the solution of this case is just only increasing capacity at these stations to improve the bottleneck.

We can use 6 workers that eliminated from workstation S13, S14, P12, P14 (Stitching area) and A22, A28, A 29, A30, A32 (Assembly area) and assign them to workstation S3, S5, S6 and A19, A18, A25. Simulation is run to confirm the improvement.

5.1.7 Solution feasibility

Check the feasible of solution he proposed

5.1.7.1 Reducing workers in stitching area:

As the analysis above, we reduce or save 3 workers from workstation S13, S14, P12, P14 in stitching area by eliminating, combining, simplifying the assembly process.

Regarding the workstation S13, we only use one worker for both tasks that are the attach collar foam and the invert collar lining in workstation S13. From standard cycle time and takt-time, we easily determine the manpower requirement:

$$\boldsymbol{Manpower\ requirement} = \frac{Standard\ cycle\ time\ of\ S13}{takt\ time}$$

The manpower requirement of station S13 is $\frac{27}{30}$ = 0.9 (1 worker). For one worker, it will take only about 27 seconds to complete both tasks (below takt-time).

Workstation S14	$$\boldsymbol{Manpower\ requirement} = \frac{Standard\ cycle\ time\ of\ S14}{takt\ time}$$ The manpower requirement of workstation S14 is $\frac{27}{30}$ = 0.9 (1 worker)
Workstation P12 and P14	$$\boldsymbol{Manpower\ requirement} = \frac{SCT\ of\ P12 + SCT\ of\ P14}{takt\ time}$$ The manpower requirement of tis case is $\frac{26}{30}$ = 0.87 (1 worker). Only 1 worker is used for 2 workstations.

5.1.7.2 Reducing workers in assembly area:

As the analysis above, we reduce or save 3 workers from workstation A22, A28, A 29, A30, A32 in assembly area. It is the similar with stitching area. The manpower requirement of each situation is:

Workstation A22	$$\boldsymbol{Manpower\ requirement} = \frac{Standard\ cycle\ time\ of\ A22}{takt\ time}$$ The manpower requirement of workstation A22 is $\frac{28}{30}$ = 0.93 (1 worker)
Workstation A28 and A29	$$\boldsymbol{Manpower\ requirement} = \frac{28}{30} = 0.93$$ The manpower requirement is just only 1 worker for 2 workstations A28 and A29.
Workstation A30 and A32	$$\boldsymbol{Manpower\ requirement} = \frac{25}{30} = 0.83$$ The manpower requirement is just only 1 worker for 2 workstations A30 and A32 in the real system.

As a result, we can use 6 workers instead of 12 workers as the real system. Specifically, we eliminate 6 workers from workstation S13, S14, P12, P14 (Stitching area) and A22, A28, A

29, A30, A32 (Assembly area). Instead of placing two workers, one worker is more efficient because the workers in the production line had been trained to do all tasks. Therefore, the total processing time probably is satisfied the time constrain (takt-time).

5.1.8 Comparison between actual and improvement output

Table 5-12: Comparison between actual and improvement output for initial improvement

COMPARISON	ACTUAL OUTPUT	OUTPUT IMPROVEMENT	DIFFERENCE	PERCENTAGE
REPLICATION 1	518	933	415	44%
REPLICATION 2	526	988	462	47%
REPLICATION 3	520	934	414	44%
REPLICATION 4	533	985	452	46%
REPLICATION 5	536	933	397	43%
REPLICATION 6	550	985	435	44%
REPLICATION 7	520	933	413	44%
REPLICATION 8	529	988	459	46%
REPLICATION 9	532	932	400	43%
REPLICATION 10	533	990	457	46%
REPLICATION 11	528	934	406	43%
REPLICATION 12	529	985	456	46%
REPLICATION 13	530	933	403	43%
REPLICATION 14	550	988	438	44%
REPLICATION 15	545	932	387	42%
REPLICATION 16	550	989	439	44%
REPLICATION 17	533	934	401	43%
REPLICATION 18	543	987	444	45%
REPLICATION 19	529	931	402	43%
REPLICATION 20	533	986	453	46%
TOTAL	**10667**	**19200**	**8533**	**44%**

The simulation model is revised with new number of workers at workstation S3, S5, S6 and A19, A18, A25. The result is 40% improvement compare to actual output.

It valid in some aspects but external factor can make this target not achieved.

5.1.9 PPH achievement

Assume that working time is 8 hours/day, we have totally 20 replications that the working time is: $(8\ x\ 20) = 160\ hours$

Total of manpower is 108 workers

The PPH efficiency will be achieved: PPH = $\frac{Total\ output}{(total\ working\ time)\ x\ (total\ manpower)}$

$$= \frac{19200}{(160\ x\ 108)} = 1.11$$

Table 5-13: PPH achievement of initial improvement

TOP MODEL	PPH	Baseline	Target PPH	Achieved	Gap to Target
ACTUAL SYSTEM	0.67	0.73	1.09	-19%	69%
IMPROVEMENT SYSTEM	1.11	0.73	1.09	51%	0%

Based on the results in the table above, we conclude that PPH efficiency with improved bottleneck increases by approximating 70% compared with actual system. That is the improvement system achieved 51% PPH while the actual system is under baseline of PPH -19%.

5.1.10 Line balance loss percentage of initial improvement

Table 5-14: Line balance loss (%) of initial improvement

LINE BALANCE LOSS PERCENTAGE (% LBL)		
AREAS	ACTUAL SYSTEM	IMPROVEMENT SYSTEM
STITCHING	48.6%	18%
ASSEMBLY	55.6%	11.3%

The line balance loss percentage at stitching area is only 18%, that is 48.6% less than the actual system. It means the improved system is more balanced than actual one by over 30%.

On the other hand, %LBL of improvement system of assembly area is 11.3% smaller than actual system (55.6%).

5.2 Further improvement

Using optimal theory, this phase modifies the initial improvement by minimize number of workstation. Lingo software is used for that purpose.

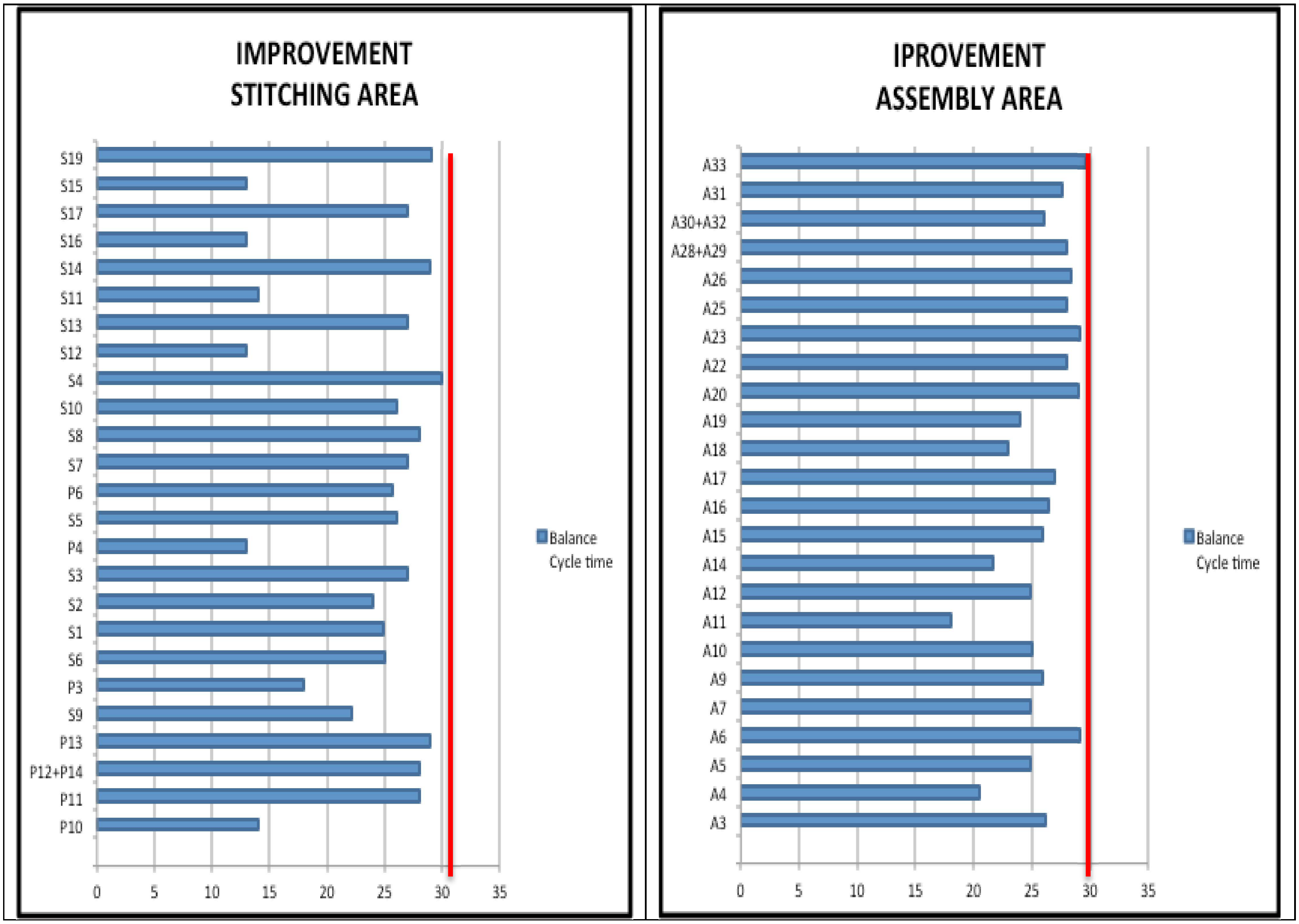


Figure 5-1: Balance cycle time for initial improvement OK.

Looking at the figure 5-1 the improved balance cycle time diagram of the phase 1. We can easily recognize that whether some workstations in stitching area balance or not?

In this state, total number of workstation at stitching area is 25, and assembly area is 24 workstations. The time and precedence will be showed in tables below:

Table 5-15: Work element assigned to the station at stitching area OK, need for ARENA and Lingo

ELEMENT	DESCRIPTION		TIME (SECOND)	PREDECESSOR
1	P10	Stitch computer Tongue lace loop to Tongue	14	
2	P11	Stitch Tongue to Tongue lining	28	1
3	P12+P14	Stitch binding tongue and Tongue label to Tongue	28	2
4	P13	Stitch tongue bottom	29	3
5	S9	Stitch collar lining edges	22	
6	P3	Attach + Press Toe box to Toe cap	18	
7	S6	Zigzag Stitch back tab to heel upper	25	
8	S1	Stitch Imation decor heel upper	25	7
9	S2	Stitch side stripe (l/m) to vamp	24	8
10	S3	Stitch side check (med) to vamp	27	9
11	P4	Attach eyestay rienf to eyestays	13	
12	S5	Stitch Eyestay to vamp	26	10,11
13	P6	Attach heel tab rienf to heel tab	26	
14	S7	Stitch heel cap to upper 1st	27	12,13
15	S8	Stitch heel cap to upper 2st	28	14
16	S10	Stitch collar lining to upper	26	5,15
17	S4	Stitch Toe cap to vamp	30	6,16
18	S12	Spray hot melt + Attach internal counter to upper	28	17
19	S13	Attach Collar foam + Invert Collar lining	27	18
20	S11	Spray hot melt Attach to toecap	28	19
21	S14	Spray hot melt + Attach Collar lining	29	20
22	S16	Punched holes eyestay	13	21
23	S17	Stitch tongue to upper	27	4,22
24	S15	Stitch Upper bottom	13	23
25	S19	Shoe lacing + Putting upper on the trolley	29	24

Table 5-16: Work element assigned to the station at assembly area

ELEMENT	DESCRIPTION		TIME (SECOND)	PREDECESSOR
1	A3	Chilling & Heating	26	
2	A4	Prepare last	21	
3	A5	Point hot melt + Attach Texon to last	25	2
4	A6	Apply latex C 310 to Upper	29	1
5	A7	Apply latex C 310 to Texon	25	3
6	A9	Toe lasting	26	4,5
7	A10	Side lasting	25	6
8	A11	Tighting shoes lacing	18	7
9	A12	Heel lasting	25	8
10	A14	Prepare sole	22	
11	A15	Pointing marking	26	9
12	A16	Gauge marking Q'ter	26	11
13	A17	Grinding bottom marking upper	27	12
14	A18	Air blowing + Transfer	23	10
15	A19	Primer PR 505 on sole	24	14
16	A20	Primer W-104 L on upper	29	13
17	A22	Cement SW -07 on upper	28	16
18	A23	Cement SW -07 on sole	29	15
19	A25	Attach sole to upper	28	17,18
20	A26	Universal pressing + Transfer line	28	19
21	A28+A29	Unlace and Delast + Arrange last	28	20
22	A30+A32	Rolling hot melt Sockliner + Insert Sockliner on shoes and Crumple tissue paper + Insert tissue paper on shoes	26	23
23	A31	Cleanning	28	21
24	A33	Tighting shoes lacing	30	22

5.2.1 Grouping workstations by using optimization method

5.2.1.1 Purpose:

We consider reducing number of workers by minimizing workstation to increase PPH efficiency performance.

5.2.2 Lingo model

5.2.2.1 Objective: Minimize the required number workstations

5.2.2.2 Constrains

1. For each task, there must be one assigned station.
2. Precedence constraints: For each precedence pair, the predecessor task i cannot be assigned to a later station than its successor task j. Definitely, technological sequencing requirements, the order in which the work elements can be accomplished is limited.
3. For each station, the total time for the assigned tasks must be less than the maximum cycle time.

5.3.1 Grouping result

Table 5-17: Grouping result at stitching area

GROUPING STITCHING AREA		
X(1, 1)	1.000000	0.000000
X(2, 14)	1.000000	0.000000
X(3, 17)	1.000000	0.000000
X(4, 19)	1.000000	0.000000
X(5, 10)	1.000000	0.000000
X(6, 12)	1.000000	0.000000
X(7, 2)	1.000000	0.000000
X(8, 3)	1.000000	0.000000
X(9, 4)	1.000000	0.000000
X(10, 5)	1.000000	0.000000
X(11, 1)	1.000000	0.000000
X(12, 6)	1.000000	0.000000
X(13, 7)	1.000000	0.000000
X(14, 8)	1.000000	0.000000
X(15, 9)	1.000000	0.000000
X(16, 11)	1.000000	0.000000
X(17, 13)	1.000000	0.000000
X(18, 15)	1.000000	0.000000
X(19, 16)	1.000000	0.000000
X(20, 18)	1.000000	0.000000
X(21, 20)	1.000000	0.000000
X(22, 21)	1.000000	0.000000
X(23, 22)	1.000000	0.000000
X(24, 23)	1.000000	0.000000
X(25, 24)	1.000000	0.000000

Table 5-18: Grouping result at assembly area

GROUPING ASSEMBLY AREA		
X(1, 1)	1.000000	0.000000
X(2, 2)	1.000000	0.000000
X(3, 3)	1.000000	0.000000
X(4, 4)	1.000000	0.000000
X(5, 5)	1.000000	0.000000
X(6, 6)	1.000000	0.000000
X(7, 7)	1.000000	0.000000
X(8, 8)	1.000000	0.000000
X(9, 11)	1.000000	0.000000
X(10, 9)	1.000000	0.000000
X(11, 13)	1.000000	0.000000
X(12, 14)	1.000000	0.000000
X(13, 15)	1.000000	0.000000
X(14, 10)	1.000000	0.000000
X(15, 12)	1.000000	0.000000
X(16, 16)	1.000000	0.000000
X(17, 17)	1.000000	0.000000
X(18, 18)	1.000000	0.000000
X(19, 19)	1.000000	0.000000
X(20, 20)	1.000000	0.000000
X(21, 21)	1.000000	0.000000
X(22, 23)	1.000000	0.000000
X(23, 22)	1.000000	0.000000
X(24, 24)	1.000000	0.000000

At stitching area, the current number of workstation is 25. However, the result (figure 5-2) shows that the objective solution is 24 workstations. It means combining two workstations P10 and P4; sharing one workstation only, reduces one workstation.

Assembly area still keeps 24 workstations at minimum; there is no worker reduction.

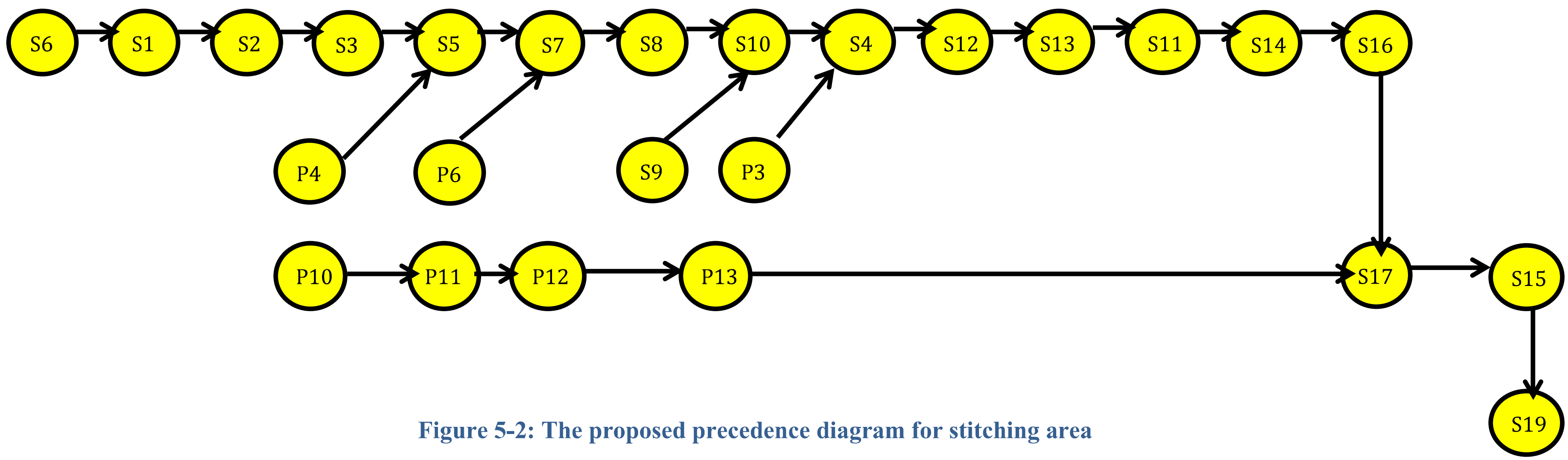


Figure 5-2: The proposed precedence diagram for stitching area

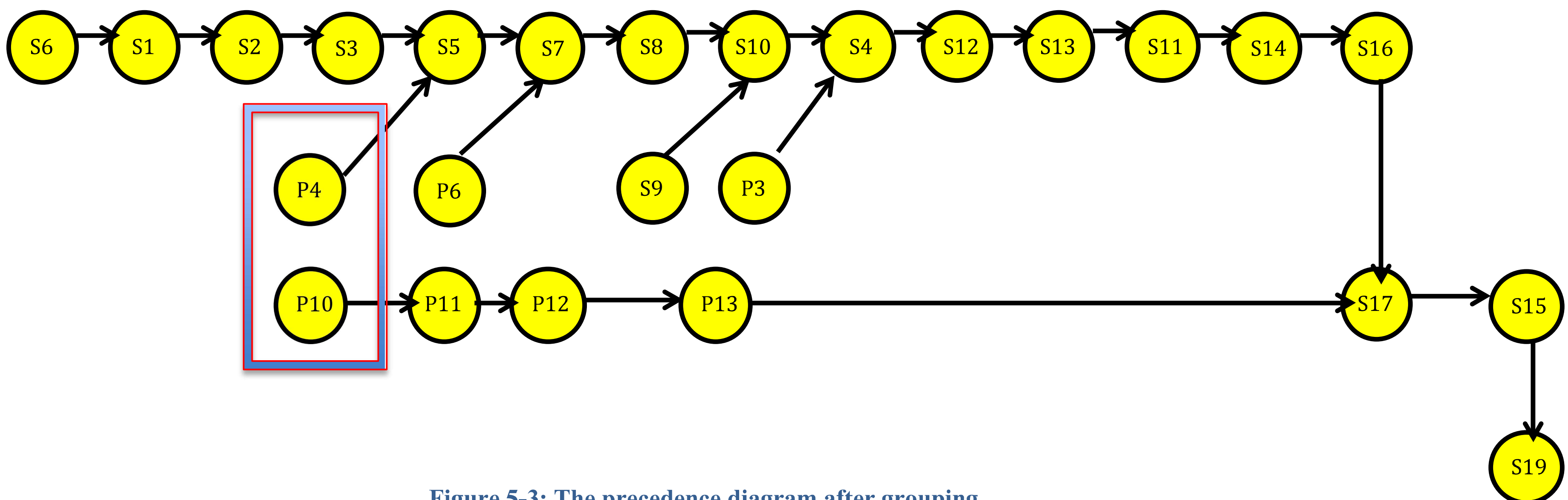


Figure 5-3: The precedence diagram after grouping

Table 5-19: Comparison between actual and improvement output for further improvement

COMPARISON	ACTUAL OUTPUT	OUTPUT IMPROVEMENT	DIFFERENCE	PERCENTAGE
REPLICATION 1	518	933	415	44%
REPLICATION 2	526	988	462	47%
REPLICATION 3	520	934	414	44%
REPLICATION 4	533	985	452	46%
REPLICATION 5	536	933	397	43%
REPLICATION 6	550	985	435	44%
REPLICATION 7	520	933	413	44%
REPLICATION 8	529	988	459	46%
REPLICATION 9	532	932	400	43%
REPLICATION 10	533	990	457	46%
REPLICATION 11	528	934	406	43%
REPLICATION 12	529	985	456	46%
REPLICATION 13	530	933	403	43%
REPLICATION 14	550	988	438	44%
REPLICATION 15	545	932	387	42%
REPLICATION 16	550	989	439	44%
REPLICATION 17	533	934	401	43%
REPLICATION 18	543	987	444	45%
REPLICATION 19	529	931	402	43%
REPLICATION 20	533	986	453	46%
TOTAL	**10667**	**19200**	**8533**	**44%**

After using arena to run the data for further improvement, we still obtained that result of output is more than 40% comparing with actual output. Therefore, PPH efficiency increases approximates 70% comparing with actual system, which is similar to initial improvement. However, the line balance loss percentage is less than initial improvement, from 18% to 15% for further improvement.

To sum up, depending on the current state of production line, the alternatives apply the concept of eliminating, combining, simplifying the assembly process without any additional machine and manpower by using direct observation method.

Two phases for improvement are proposed:

Initial improvement: The first phase is that solving bottleneck by improving cycle time below takt time and utilization manpower. Using arena to run the data with takt time is 30 second, we obtained that output from simulation is 40% higher than actual output. We have improved the line balance loss percentages from 48.6% to 18% at stitching area and decreasing by over 40% at assembly area. Therefore, the PPH efficiency will be 50% of achievement and reach the target of company.

Further improvement: Continuing with result of initial improvement, we have modified and developed one more step to group workstations by optimization method. It means minimizing number of workstation to balance cycle time between processes. We concluded that although PPH efficiency still increase by approximates 70% comparing with actual system, the line balance loss percentages improve from 18% to 15% at stitching area.

CHAPTER 6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Adidas Company using the PPH as a KPI (key performance indicator) to evaluate the line performances in production line of factories. The aim of this thesis is improving the efficiency KPI by considering the working time, number of worker existing on production line and productivity (output).

Over six months of thesis research, basically the student has achieved a number of results in the research process, including:

- Learned about the systems, processes and problems existing in production line
- Analyzed of the current state by direct observation and use simulation tools to visualize the overall process and operation of workstation in production line, thereby define the remaining issues of Rebook model:
    1. Lack of manpower requirement leads to the actual manpower is insufficient to meet standard manpower.
    2. The cause of cycle time of workstation 3, 5, 6 (stitching area) and 18, 19, 25 (assembly area) are higher than takt-time.
- Validated the simulated model similar to the real system.
- Tow phases for improvement to be developed:
    1. Solving bottleneck by improving cycle time below takt time and utilization manpower. We obtained that result of output more than 40% compare with actual output by simulation. It is also conducted that PPH efficiency with improved bottleneck increases approximately 70% comparing with actual system. Therefore, decreasing the line balance loss percentages from 48.6% to 18% at stitching area and by over 40% at assembly area.
    2. Using lingo model program, minimize number of workstation to satisfy takt time (30s) can be a way for improvement. We conducted that although PPH efficiency still increase approximately 70% comparing with actual system, the line balance loss percentages have more improve from 18% to 15% at stitching area due to

one saved workstation.

- Improved the PPH efficiency, helps reach the target to meet management required.
- Utilized the current manpower needs no adding more workers.

6.2 Recommendation

Depending on the analyzing and proposing above solutions, the company should pay more attention to manage number of worker or assign suitable work to employee to achieve the target. We suggest that companies should reduce the amount of worker at stations S13, S14, P12+P14 (stitching area) and A22, A28+A29, A30+A32 (assembly line) by transferring these workers to workstations S3, S5, S6 (stitching area), A18, A19 and A25 (assembly area). Lack of workers is the cause of low PPH efficiency and not achieved the target. Therefore, the optimum number of workstation is found by linear programming. As the result, P4 and P10 workstations should be combined to save area and place for smooth running production line. In fact, the line balance loss percentages %LBL is decrease from 48.6% to only 15%. Moreover, companies should quickly grasp the application of technology world like Simulation software and Lingo software to help improve the efficiency of production and better serve customer needs.

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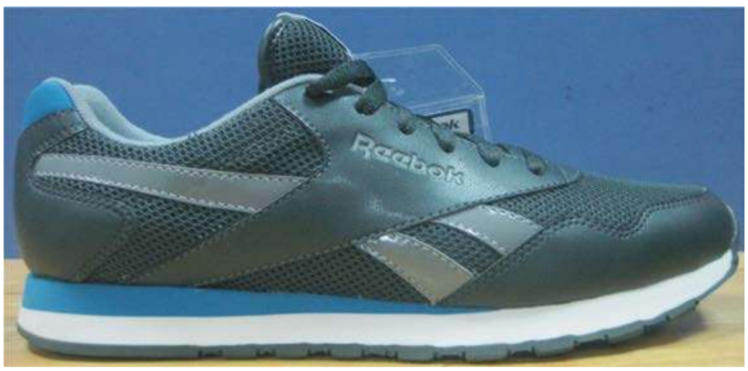
APPENDIX

THE PRODUCTS



Reebok Complete Royal CL

Princess Wide

DATA COLLECTION

RECORDED	1	2	3	4	5	6	7	8	9	10
Worker 1 (task 1)	12	13	13	12	12	12	14	12	13	12
Worker 2 (task 2)	15	15	14	15	15	14	13	15	13	14
Total (processing time S13)	27	28	27	27	27	26	27	27	26	26

RECORDED	1	2	3	4	5	6	7	8	9	10
Worker 1 (task 1)	11	12	12	12	10	11	12	12	11	12
Worker 2 (task 2)	16	16	17	15	16	15	16	16	16	15
Total (processing time S14)	27	28	29	27	26	26	28	28	27	27

RECORDED	1	2	3	4	5	6	7	8	9	10
Total (processing time P14)	13	13	12	11	12	12	12	11	12	12

RECORDED	1	2	3	4	5	6	7	8	9	10
Worker 1 (task 1)	12	11	11	10	12	10	11	11	11	12
Worker 2 (task 2)	16	16	17	15	16	15	16	16	16	15
Total (processing time A22)	28	27	28	25	28	25	27	27	27	27

RECORDED	1	2	3	4	5	6	7	8	9	10
Total (processing time A28)	13	13	12	11	12	12	12	11	12	12

RECORDED	1	2	3	4	5	6	7	8	9	10
Total (processing time A29)	13	13	12	11	12	12	12	11	12	12

RECORDED	1	2	3	4	5	6	7	8	9	10
Total (processing time A30)	10	12	12	11	12	14	12	11	12	12

RECORDED	1	2	3	4	5	6	7	8	9	10
Total (processing time A32)	13	14	13	11	13	15	13	12	13	13

SOURCE LINGO

STITCHING AREA:

```
MODEL:
  ! Assign tasks to stations in stitching area so
   1) Precedence constraints among tasks are satisfied, and
   2) Each station is assigned no more than a specified amount of work,
   3) Objective is to minimize the number stations required;
 ! Keywords: Line balancing, Assembly line balancing;
 SETS:
  ! There is a set of tasks, each with a duration T;
  TASK: T;
  ! Predecessor, successor pairings must be
    Observed (e.g. a must be done before B, B
    Before C, etc.);
  PRED( TASK, TASK);
  ! There are a specified number of workstations;
  STATION: USE;
```

```
  TXS( TASK, STATION): X;

  !  X(i,k) = 1 if task i is assigned to station k, else 0;

 ENDSETS


 DATA:

  ! There is an estimated time required for each task..;

TASK= @ole('data_lingo.xls','Tasksts');

T = @ole ('data_lingo.xls','Ctsts');

PRED= 1,2 2,3 3,4 4,23 5,16 6,17 7,8 8,9 9,10 10,12 11,12 12,14 13,14 14,15 15,16 16,17 17,18
18,19 19,20 20,21 21,22 22,23 23,24 24,25;

 STATION= 1..25;

! Cycle time or upper limit on work in each station;

CYCTIME = 30;

 ENDDATA

  ! Variables:

    USE (k) = 1 if station k is used, else 0,

    X (i,k) = 1 if task i assigned to station k, else 0;

  ! Minimize the number of stations;

  MIN = @SUM(STATION(k): USE(k));

  ! For each task, there must be one assigned station;

  @FOR( TASK( i):

   [DOTASK] @SUM( STATION( k): X( i, k)) = 1);

  ! Precedence constraints;

  ! For each precedence pair, the predecessor task i cannot be assigned to a later station than its
successor task j;

  @FOR( PRED( i, j):
```

```
  [PRD] @SUM( STATION( k): k * X( j, k) - k * X( i, k)) >= 0);

 ! For each station, the total time for the assigned tasks must be less than the maximum cycle
time, CYCTIME;

 @FOR( STATION( k): [KNAP] @SUM( TXS( i, k): T( i) * X( i, k)) <= CYCTIME*USE(k);

  @BIN(USE(k));

         );

 ! If station k is used, then station k-1 must also be;

  @FOR( STATION(k) | k #GT# 1:

   [NOGAP] USE(k) <= USE(k-1);

        );

 ! The X (i,j) assignment variables are binary integers;

 @FOR( TXS: @BIN( X));

!  If task i assigned to station k, then k is used;

 @FOR( TXS(i,k):

   [CUT] X(i,k) <= USE(k));

END
```

ASSEMBLY AREA:

```
MODEL:

  ! Assign tasks to stations in an assembly line so
```

```
   1) Precedence constraints among tasks are satisfied, and

   2) Each station is assigned no more than a specified amount of work,

   3) Objective is to minimize the number stations required;

 ! Keywords: Line balancing, Assembly line balancing;

 SETS:

  ! There is a set of tasks, each with a duration T;

  TASK: T;

  ! Predecessor, successor pairings must be

    Observed (e.g. A must be done before B, B before C, etc.);

  PRED( TASK, TASK);

  ! There are a specified number of workstations;

  STATION: USE;

  TXS( TASK, STATION): X;

  !  X(i,k) = 1 if task i is assigned to station k, else 0;

 ENDSETS


 DATA:

! There is an estimated time required for each task..;

TASK= @ole('data_lingo.xls','Task');

T = @ole ('data_lingo.xls','Cycle_Time');

PRED= 1,4 2,3 3,5 4,6 5,6 6,7 7,8 8,9 9,11 10,14 11,12 12,13 13,16 14,15 15,18 16,17 17,19
18,19 19,20 20,21 21,23 22,24 23,22;

 STATION= 1..24;

CYCTIME = 30;

 ENDDATA

  ! Variables:
```

```
    USE(k) = 1 if station k is used, else 0,

    X(i,k) = 1 if task i assigned to station k, else 0;

! Minimize the number of stations;

 MIN = @SUM(STATION(k): USE(k));

 ! For each task, there must be one assigned station;

 @FOR( TASK( i):

   [DOTASK] @SUM( STATION( k): X( i, k)) = 1);

 ! Precedence constraints;

 ! For each precedence pair, the predecessor task

   i cannot be assigned to a later station than its

   successor task j;

 @FOR( PRED( i, j):

  [PRD] @SUM( STATION( k): k * X( j, k) - k * X( i, k)) >= 0

     );

 ! For each station, the total time for the assigned tasks must be less than the maximum cycle
time, CYCTIME;

 @FOR( STATION( k):

  [KNAP] @SUM( TXS( i, k): T( i) * X( i, k)) <= CYCTIME*USE(k);

  @BIN(USE(k)); ! USE(k) is a binary variable;

     );

 ! If station k is used, then station k-1 must also be;

  @FOR( STATION(k) | k #GT# 1:

   [NOGAP] USE(k) <= USE(k-1);

     );

 ! The X (i,j) assignment variables are binary integers;

 @FOR( TXS: @BIN( X));
```

```
@FOR( TXS(i,k):
   [CUT] X(i,k) <= USE(k));
END
```