PRODUCTIVITY IMPROVEMENT AND COST OPTIMIZATION OF SMALL AND MEDIUM SCALE ENTERPRISES

by

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ABSTRACT

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Productivity improvement and cost optimization have been a topic of discussion for at least a century. The publication of Fredrick Taylor's book 'The Principles of Scientific Management' in 1911 can be considered as the beginning of the Efficiency movement. Surprisingly, the awareness about the principles of Industrial Engineering is relatively low in many family-owned Small and Medium Scale Enterprises (SMEs). According to a World Bank report, formal SMEs make up 45% of total employment and contribute 33% of GDP in emerging markets. In the USA, SMEs make up for more than 95% of all firms and employ 50% of private sector employees. Therefore, it is self-evident that improvement in the productivity of this sector will have a sizable impact on the economy.

Productivity increase and cost optimization are critical tasks for SMEs. In a competitive environment, increasing productivity without installing additional capacity enables the SMEs to avoid heavy investment and maximize their profitability. In comparison with large-scale industries, the SMEs have less cash to spend, and skilled professionals who can implement productivity improvement strategies such as Lean, Six Sigma, Total Quality Management, etc. are not readily available most of the time. Thus, productivity improvement can become a costly and difficult exercise. Therefore, there is a need of a fast and cost effective solution to the problem of productivity improvement.

This work offers a time saving productivity improvement and cost optimization solution for an SME through the implementation of lean methodology and the use of modern simulation packages (Simio). The implementation of lean methodologies supports elimination of waste and makes available resources that were incorrectly allocated, resulting in an increment in productivity. The simulation packages serve as a visual aid to understand the interrelation between various components of the enterprise. Additionally, they serve as a tool for the what-if analysis in case of any changes being made in the existing setup. Most importantly, the use of simulation eliminates the necessity of multiple trial and error cycles, which in turn saves time and reduces the overall cost of the improvement effort undertaken by the company. Finally, this research aims to establish this method of implementation of productivity improvement solution as a standard for similar SMEs to achieve quick results with minimum cost incurred.

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Chapter 1

LITERATURE REVIEW

According to Prime Faraday Technology Watch, in the UK, SMEs in the manufacturing sector make up 99% of the firms and provide employment for roughly 50% of the workforce [10]. However, productivity improvement initiatives have not been very popular with the manufacturing sector of the economy. Although it has been around for decades, the lean methodology—and the tools and techniques it offers—are not widely accepted by the SMEs [1]. Pachanga, Shehab, Roy and Nelder (2006) consider this reluctance to be the result of the uncertainty that surrounds the cost of implementation and the potential benefits of the same. Since it is not always possible to foresee the tangible results of lean implementation, it becomes difficult for the leadership to put their faith in lean methodologies over conventional methods. Conclusively, the authors state that a committed leadership is essential for a successful implementation [1].

The paper by Hawkins (2001) highlights the most important tools that SMEs of this day need in order to maintain their competitiveness and in general, their operational well being. They include lean manufacturing and supply chain responsiveness, among other things [10]. To incorporate both attributes, it is imperative to improve the existing processes. There are multiple barriers that can potentially deter SMEs from implementing improvements. The barriers include employees that are resistant to change, unavailability of additional manpower for additional tasks, lack of highly trained specialists, and lack of standardization [10]. To tackle those barriers, the right question to ask is whether the SMEs can afford not to improve productivity [10]. Additionally, the right outlook about productivity improvement is to look at short-term cost (of productivity improvement initiatives) as long-term investments [10].

Many ideas now termed as ‘lean’ stem from the Toyota Production System (TPS). TPS percolated to Toyota’s suppliers and subsequently entered Japanese mainstream industry [10]. Value stream mapping (VSM), an important technique offered by lean methodology, is used for classifying the activities, identifying non-value adding activities, and eliminating the same for a leaner system performance. Heines and Rich offer seven tools of VSM which include two new tools, Quality Filter Mapping and Physical Structure Mapping [11]. Heines and Rich offer a six-step method of VSM deployment which begins with interviewing the internal stakeholders of the organization, and the final step being the decision, about which of the seven tools described before are appropriate for use in a given situation [11]. This novel approach offers a unique way of implementation of VSM that requires participation from all important stakeholders at all levels, thereby increasing chances of successful implementation of improvement initiatives. This method can theoretically be implemented in any industry / facility [11].

Many practitioners have successfully implemented productivity improvement and waste reduction techniques in the similar niche (i.e. small and medium enterprises). Gupta and Brannan (1995) implemented Just – In – Time (JIT) in a small manufacturing company where preliminary analysis identified various problems in the existing setup [16]. They achieved reduced material movement, reduced lead times, reduced inventory levels, and a smooth flow of materials [16]. Gunasekaran and Lyu implemented JIT in a small automotive parts manufacturing facility and observed a continuous annual growth of 5% to 10% for 3 consecutive years [13]. They noted that improvement in productivity helps bring the quality defects to surface, in both product and production, which were invisible prior to the implementation of JIT [13]. Karlsson and Ahlstrom theoretically implemented the lean principles in an SME manufacturing electronic office supplies and found that the successful implementation of lean is contingent upon lean distribution, lean procurement, and involvement of partners [14].

A committed leadership with a strong belief in methodologies such as lean, still needs quantifiable evidence or data to believe in the profitability of the whole exercise of lean implementation [15]. According to Abdulmalek and Rajgopal, providing quantifiable evidence in advance can be a difficult task because of the sheer complexity of the systems [15]. It is nearly impossible to predict the behavior of all the elements in a facility and about all the Key Performance Indicators (KPIs) because of the dynamic nature and the vast number of variables involved in a facility [2]. In order to generate belief within the leadership, the obvious tool to be used is simulation. Simulation offers a capability of predicting system behavior with preset assumptions. As a result, the combination of lean and simulation provides a tangible and quantifiable effect analysis of the changes and improvements proposed at the beginning of the process [2].

In the early phases of process improvement, a variety of opportunities can be recognized. The prioritization of what opportunities to focus on primarily depends on the policy set forth by the leadership. Based on the amount of resources available, such as manpower, funds, and time, the management may choose to tackle a small group of problems first. In such a case, the combination of lean and simulation tools can be effective for the impact assessment of the prioritized solutions. Basan, Coccola, and Mendez (2014) employed a similar strategy while tackling design optimization problems for a beer packaging line. Various avenues of improvement were identified and subsequently modeled, and it was up to the leadership to choose which improvements out of the proposed set of improvements were to be implemented [7].

Simulation can be considered as a proven and reliable tool to check the requirement, or the lack thereof, of a specific part of the facility. Brown and Sturrock

(2009), for a major HVAC manufacturer, deployed the simulation tool (SIMIO) to check the necessity to structure the assembly line as a belt conveyor, which implies that all the material movement happens at the same time and at the same pace. They found, through the simulation results, that there is no absolute necessity for the material movement to occur as if it was occurring on a belt conveyor and as a result the client facility plans to remove the belt conveyor and install roller conveyors. This result supports the utility of simulation tools in driving ‘lean thinking’ as it provides a tangible result that is essentially what the leadership needs to make a decision [8].

Out of the plethora of simulation tools available in the market, it is necessary to find the one that best suits the requirements. In broad terms, the objective of this project was to establish the combination of lean, simulation, and process improvement techniques as a time-saving, cost-saving way to identify and analyze the changes necessary for productivity improvement. Accordingly, the simulation tool must possess the qualities like flexibility, ease of use, ability to perform experiments, etc. C.D. Pegden, outlines the advantages of SIMIO and observes that it is a graphical, object-oriented tool which requires comparatively less programming [9]. The software is domain neutral, i.e. it is designed so that the objects can be configured to act as elements in virtually all facilities. It also allows creation of new objects if the predefined objects are unable to meet the requirements of simulation [9]. SIMIO can be used in different paradigms and to support event, object, process and agent view, and the occurrence of probabilistic events such as breakdowns, failures, variable lead times, etc. [9]. As it requires less programming and coding, it does not necessarily require a specifically trained professional [9]. As it is domain neutral, it can be deployed at any SME without one having to worry about its applicability [9]. These advantages certainly make SIMIO the tool of interest for this project [9].

Chapter 2

COMPANY AND PRODUCT INFORMATION

2.1 Company Information

To protect the anonymity of the company, this facility is called ‘Autoparts Inc.’ for the purpose of this project. Autoparts Inc. is a leader in manufacturing sheet metal press components in Maharashtra, India. Established in 1967 with small and limited facilities, the company now possesses diverse production facilities to meet varying customer needs and schedules.

Autoparts Inc. has nurtured development, production, and marketing functions to ensure desired quality, reliability, reasonable price, and timely delivery to create values for customer businesses. The group supplies sheet metal press components to Indian and overseas OEMs with consistent growth in intricacy, range, and values. Their business philosophy is to create customer end values for continuous, sustained, and mutual growth.

2.2 Product Information

This research focuses on Autoparts Inc., specifically one division of their manufacturing known as unit 3. The products manufactured by Autoparts Inc. industries at Unit 3 are the sheet metal discs required to cover the brake shoes of TATA ace and Piaggio Vehicle Pvt. Ltd. To manufacture the product, multistage forming processes are carried out. The processes consist of shearing, blanking, forming, vertical drilling, inclined drilling, deburring and visual inspection. The processes are carried out on various presses and other machines on the shop floor. The presses are equipped with the required dies for the forming and drilling operations.

Chapter 3

RESEARCH METHODOLOGY

The first step of the project was data collection. For successful implementation of the methodology, a large amount of data is needed to ensure high accuracy of the results. This data was acquired from an automobile spare parts manufacturing facility in India. The data to be collected was primarily the work measurement data, along with geometric layouts, production statistics, operator details, actual demand, demand forecast, etc. A sample dataset was collected at first. Based on the sample dataset, the number of readings required for the required confidence level and accuracy was calculated.

After data collection was complete and the required number of data points were obtained, the next step was to perform a time study. A time study is a method of calculating the standard time of production for an average component, produced in a predefined environment. Time study considers the worker performance rating and the PFD (Personal, Fatigue, Delays) allowances. As a result, a standard time for the product was obtained which is indicative of the ideal time it takes to manufacture one component.

After the time study was complete, we moved forward to the next stage (i.e. application of lean). In this stage, firstly Value Stream Mapping (VSM) was deployed. This tool is useful in identifying value adding, non-value adding, and necessary non-value adding activities. Secondly, the necessity and possibility of application of 5-S was checked. The inventory levels and transporter routing logic was assessed to identify the waste of unnecessary inventory and waste of transportation and excess motion.

After the opportunities of waste reduction were identified, the next step was to understand and learn the simulation package chosen for use during this project. The package chosen was SIMIO as it offers several considerable advantages. This package requires less coding and programming as compared to other packages available off the shelf. It is graphical and can process large amounts of data with relative ease. These characteristics make it lucrative, as the objective of this project is to establish this method of productivity improvement and cost optimization as a standard for manufacturing oriented SMEs. The target audience in the industry may not have an adequate amount of specially trained workforce available thus; the ease of use offered by SIMIO was a key factor in its selection.

After necessary prowess was achieved in the use of SIMIO, the modeling phase commenced. In the first phase of modeling, the factory floor was modeled using the deterministic / average values. This model should ideally produce results closer to the average performance of the factory. A certain level of error is permitted as a deterministic model is bound to be subject to some approximation. The acceptable rate of error is set at 5%. This means that the model with calculated throughput within +/- 5% of the actual value will be accepted. Successful completion of this phase indicates that the data and the modeling assumptions are representative of the real-world situation.

In the next stage, the complexity of the model was increased. The model was now required to possess probability distributions such as those observed in the obtained dataset in stage 2. This model should ideally give different throughput numbers every run, since the probabilistic approach is now incorporated in the model. However, the average throughput over several production runs should be similar to that of the actual production of the facility. The acceptable rate of error at this phase is set at 3%.

The next step was to brainstorm the opportunities for improvement. Possible improvements can be the solutions to the individual problems identified in the fourth stage or some combination of them. These solutions will then be incorporated into the model and the effect of the changes on KPIs such as throughput levels, inventory levels, worker utilization will be observed. The selection of the best solution depends on the priorities set forth by the company leadership.

The next and final stage was to document and record the findings and observations of this project that can serve as a template for future use by manufacturing oriented SMEs. The advantages of following this method of productivity improvement, as described in the project, was emphasized upon so that the other SMEs can implement this method for their benefit.

Chapter 4

DIRECT TIME STUDY

4.1 Data

To complete the direct time study, a large amount of data was needed. The data was collected at the factory.

In this time study analysis, the following method of data collection was followed. Firstly, measurable work elements were defined. Then, the time taken by the workers to complete these work elements was observed. Subsequently, worker's performance rating was assigned. The measurable work elements found were as follows.

- Shearing Operation – Setup Time
- Shearing Operation – Process Time
- Blanking Operation – Setup Time
- Blanking Operation – Process Time
- First Forming Operation – Setup Time
- First Forming Operation – Process Time
- Second Forming Operation – Setup Time
- Second Forming Operation – Process Time
- Stamping Operation – Setup Time
- Stamping Operation – Process Time
- Cutting and Bending Operation – Setup Time
- Cutting and Bending Operation – Process Time
- Hole Pressing Operation – Setup Time
- Hole Pressing Operation – Process Time
- Tube Hole Operation – Setup Time

- Tube Hole Operation – Process Time
- Contouring Operation – Setup Time
- Contouring Operation – Process Time
- Grinding Operation
- Packing Operation

Time taken to accomplish each of these activities was recorded using the standard time study procedures. The method of recording used was the Snapback Method. The rating was generally assumed at 90%.

The operation sequence is shown in the table below.

Table 4.1 Operation Sequence

Workstation No	Machine Present	Process Present	Operational sequence
1	Press	Blanking	2
2	Press		
3	Press	2nd forming/ drawing	4
4	Press	1st forming/ drawing	3
5	Press	Cutting/ Bending	6
6	Drill	Drill Vertical	7
7	Drill	Drill Inclined	8
8	Deburring	Deburring	9
9	Inspection Table	Inspection	10
10	Press		
11	Press		

Table 4.1 – Continued

12	Press		
13	Press		
14	Press	Stamping	5
15	Press		
16	Shearing M/c	Shearing	1
17	Hand Grinders	Grinding	11
18	Packing area	Packing	12

4.2 Analyst's Notes

The number of occurrence for every work element was not the same. One cycle of blanking operation created an equivalent 4 parts for the process. Therefore, the number of occurrence was set at 0.25. One cycle of shearing operation created equivalent of 40 parts. Therefore, the number of occurrence was set at 0.025. One cycle of packing operation processed 25 parts at the same time. Therefore, the number of occurrence was set at 0.04. Since the observations were recorded over a period of several days, the TEBS and TEAF don't have a single value. Alternatively, a cumulative value is provided. The start time and the end time don't have a single value but the total elapsed time was noted carefully. Observations, wherein the time taken was disproportionately large due to some failure in the machinery, were carefully noted and discarded. There are some outliers in the time study. These can be attributed mostly to mishandling of the equipment and the jobs. For example, there were cases when the job would slide out of the operator's grasp and the operator would have to pick it up.

4.3 Calculations

Number of cycles required –

The formula used to calculate the number of cycles (Nc) required is as follows.

$N_c = ((t\alpha/2 * s)/(k*\mu))^2$

Where,

$t_{\alpha/2}$ = t value for (α = 0.05) i.e. confidence interval of 95%

s = Standard deviation of the sample observations

K = Accuracy or proportion of interval (accuracy = +/- 5% of the actual)

μ = sample mean

Per this formula, a sample of 15 readings was taken for each process element. The sample calculations of the number of readings required per the dispersion of values can be found in the table below. The full spreadsheet of work measurement data recorded can be found is Appendix A.

Element No and Description		Shearing machine - Setup Time			Shearing Machine Process Time			Blanking - Setup time			Blanking - Process Time		
			OT			OT			OT			OT	
	1		112			42			14			18	
	2		127			52			12			21	
	3		207			56			10			20	
	4		99			61			12			22	
	5		103			55			12			20	
	6		100			66			11			22	
	7		102			67			12			30	
	8		103			57			13			23	
	9		101			61			11			21	
	10		89			66			12			21	
	11		95			60			9			22	
	12		99			66			11			27	
	13		100			80			10			20	
	14		102			76			11			23	
	15		112			75			9			19	
Mean			110			63			11			22	
Standard Deviation			28.19573			9.863929			1.324075			3.038901	
Degrees of Freedom			14			14			14			14	
Accuracy (K)		0.05											
Tα/2 at 95% confider		2.145											
No of cycles require		120.8706			45.72715			25.56951			35.54533		

Figure 4.1 Pilot Time Study

After calculating the number of observations required for required accuracy and confidence interval, the highest number was found out to be 147 for Contouring – Setup time. Hence the required number of observations was selected as 150. Standard procedure for calculations was used with allowance shown in the table below.

Table 4.2 Allowances for Direct Time Study

Category	Value
Personal	5%
Basic Fatigue	4%
Variable Allowance – Abnormal Position Allowance	2%
Variable Allowance – Use of Force	1%

Table 4.2 – Continued

Variable Allowance – Noise Level	2%
Variable Allowance - Monotony	1%
Total	15%

According to the International Labor Organization rules, the allowances can be explained as follows [17]. A personal allowance of 5% is necessary for all operations along with a basic fatigue allowance of 4%. Additionally, an abnormal position allowance of 2% is awarded since the working positions are slightly awkward requiring long periods of bending. A 1% allowance is awarded for use of force since the job involves lifting up to 10 lbs. Noise level allowance of 2% is awarded because of the presence of intermittent noises and 1% allowance is given for monotony. Cumulatively, a total of 15% allowance is awarded.

The recorded work measurement data can be found in Figure 4.2, shown below.

4.4 Result

After Using the formula,

Standard Time = Normal Time * (1+ Allowances), the standard time, after all due consideration, was found out to be 1.15 minutes.

The input required to calculate error is the total recorded time and the unaccounted time, the values of which were 204.27 and 3.08 minutes respectively. The error after calculations was found out to be 1.48% that is within the acceptable limit (0% to 2%).

Direct Time Study – Recorded Data

Element – Shearing Machine (Setup Time)

Cycle	R	OT (dec)	NT	Cycle	R	OT (dec)	NT	Cycle	R	OT(dec)	NT
1	0.90	1.12	1.01	30	0.90	1.07	0.96	59	0.90	1.09	0.98
2	0.90	1.27	1.14	31	0.90	1.09	0.98	60	0.90	1.11	1.00
3	0.90	2.07	1.86	32	0.90	1.11	1.00	61	0.90	1.11	1.00
4	0.90	0.99	0.89	33	0.90	1.06	0.95	62	0.90	1.08	0.97
5	0.90	1.03	0.93	34	0.90	1.07	0.96	63	0.90	1.12	1.01
6	0.90	1.00	0.90	35	0.90	1.08	0.97	64	0.90	1.09	0.98
7	0.90	1.02	0.92	36	0.90	1.09	0.98	65	0.90	1.09	0.98
8	0.90	1.03	0.92	37	0.90	1.11	1.00	66	0.90	1.10	0.99
9	0.90	1.01	0.91	38	0.90	1.14	1.03	67	0.90	1.13	1.02
10	0.90	0.89	0.80	39	0.90	1.05	0.95	68	0.90	1.12	1.01
11	0.90	0.95	0.85	40	0.90	1.12	1.01	69	0.90	1.05	0.95
12	0.90	0.99	0.89	41	0.90	1.09	0.98	70	0.90	1.09	0.98
13	0.90	1.00	0.90	42	0.90	1.14	1.03	71	0.90	1.11	1.00
14	0.90	1.02	0.92	43	0.90	1.07	0.96	72	0.90	1.15	1.04
15	0.90	1.12	1.01	44	0.90	1.05	0.95	73	0.90	1.09	0.98
16	0.90	1.07	0.96	45	0.90	1.09	0.98	74	0.90	1.10	0.99
17	0.90	1.46	1.32	46	0.90	1.13	1.02	75	0.90	1.05	0.95
18	0.90	1.09	0.98	47	0.90	1.08	0.97	76	0.90	1.10	0.99
19	0.90	1.07	0.97	48	0.90	1.05	0.95	77	0.90	1.06	0.95
20	0.90	0.99	0.89	49	0.90	1.07	0.96	78	0.90	1.08	0.97
21	0.90	1.00	0.90	50	0.90	1.09	0.98	79	0.90	1.06	0.95
22	0.90	1.12	1.01	51	0.90	1.15	1.04	80	0.90	1.08	0.97
23	0.90	0.90	0.81	52	0.90	1.13	1.02	81	0.90	1.10	0.99
24	0.90	1.03	0.92	53	0.90	1.05	0.95	82	0.90	1.10	0.99
25	0.90	1.08	0.98	54	0.90	1.11	1.00	83	0.90	1.14	1.03
26	0.90	1.12	1.01	55	0.90	1.06	0.95	84	0.90	1.09	0.98
27	0.90	1.07	0.96	56	0.90	1.14	1.03	85	0.90	1.13	1.02
28	0.90	1.10	0.99	57	0.90	1.10	0.99	86	0.90	1.05	0.95
29	0.90	1.08	0.97	58	0.90	1.14	1.03	87	0.90	1.11	1.00

Figure 4.2 Direct Time Study – Recorded Data

The time check can be shown as follows.

Table 4.3 Time Check

Time Check	
Finishing Time (minutes)	
Starting Time (minutes)	
Elapsed Time (minutes)	714.5
TEBS (minutes)	0.48
TEAF (minutes)	0.13
Total Check time (minutes)	0.61
Effective Time (minutes)	703.35
Ineffective Time (minutes)	0
Total Recorded Time (minutes)	703.956
Unaccounted Time (minutes)	10.54405
Recording Error	1.48%

Chapter 5

Value Stream Mapping

5.1 Introduction

Value Stream Mapping (VSM) is the conventional method of charting the process under observation into distinguishable parts. These processes can be categorized into three distinct types: Value - adding processes, Non - value adding processes, Necessary non - value adding processes. An explanation of what these categories entail, along with some examples can be found below.

- Value - adding processes – These processes involve operations where work is being done on the component / product through direct or indirect manual labor, with or without the use of machines [11]. The typical examples of value – adding processes include cutting, drilling, assembly, forging, etc.
- Non - value adding processes – These processes involve operations or actions that are entirely unnecessary and should be eliminated to the highest extent possible. These processes are the most likely causes of waste in the system [11]. The typical examples include waiting time, stacking, work in process (WIP) inventory, etc.
- Necessary non – value adding processes, as the name suggests, these processes do not typically add value to the product but are necessary under current manufacturing / operating environment [11]. To eliminate the waste introduced in the system due to these processes, a redesign of the manufacturing / operating environment is necessary. The examples include material movement, packing and unpacking tools, worker movements, etc.

5.2 Components of VSM

While preparing the current state value stream map for Autoparts Inc., the following components of the manufacturing environment were taken into consideration.

- Supplier - This entity supplies the main raw material to the facility. The main raw material is sheet metal that is supplied on a fixed daily basis. The transport is facilitated through trucks.
- Customer - Finished parts are shipped to this entity after packaging. The transport is facilitated through trucks.
- Process control - This entity is the representation of the management of the facility. This entity provides inputs in form of orders to the supplier and receives inputs in form of orders from the customers. This entity also provides inputs to the first station in the process regarding the quantity and the commencement of processing. It receives input from the final station regarding the completion of process.
- Workstation - This entity represents any active workstation in the process where an operation takes place on the component. A workstation may have a specific number of operators assigned to it.
- Operator – This entity represents the operators working on the shop floor. Some operators are assigned to specific workstations whereas others are shared between multiple workstations or processes.
- Inventory – This entity represents the inventory between two workstations. On the shop floor, material movement is carried out in stacks of 40, thereby accumulating an inventory of 80 parts in between workstations.

- Timeline – Timeline is used to denote the time it takes to complete a specific activity. The crest part of the timeline denotes a Non-Value adding activity whereas a trough part denotes a Value- adding activity.
- Activity ratio – The activity ratio is calculated by dividing the value-added time by the production lead time. The value-added time is the sum of times during which value is added, whereas the production lead time is the sum of non-value added time.
- Information flow – Different types of arrows are used to show the direction and the mode of the flow of information. A straight arrow means manual / handwritten flow of information whereas the lightening arrow means electronic flow of information.

The resulting VSM diagram can be found in below.

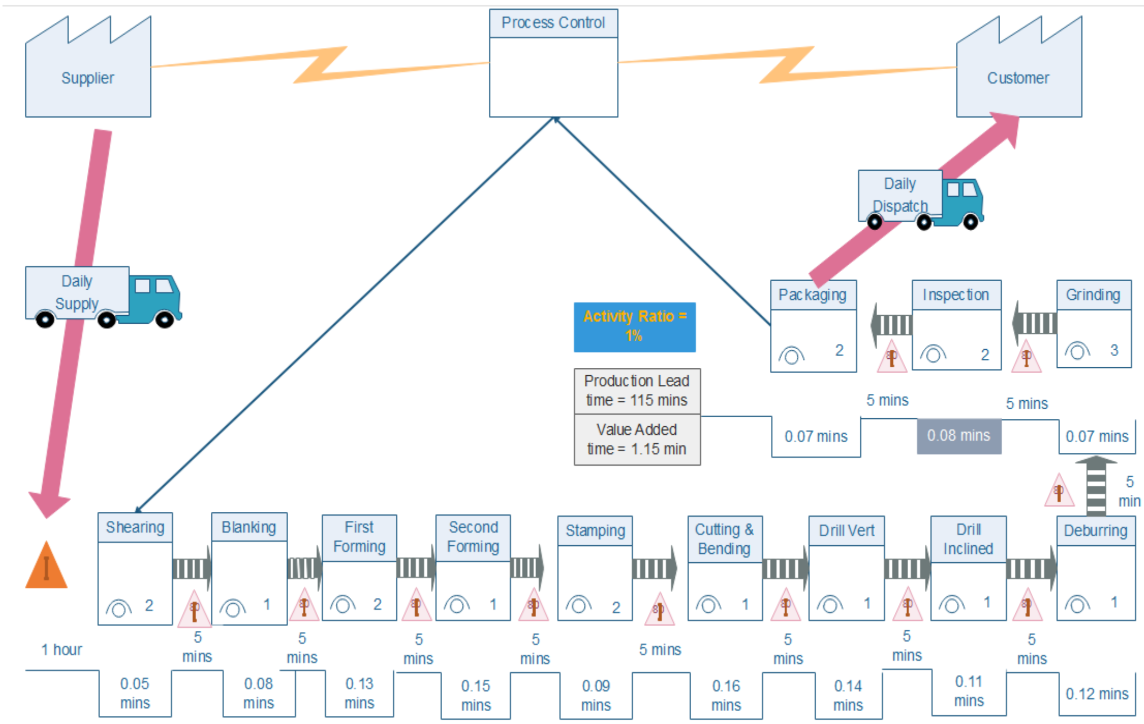


Figure 5.1 Present State Value Stream Map

5.3 Observations

Following observations can be made based on the value stream map.

- There is a high inventory level in between workstations.
- The activity ratio is very poor, i.e. 1%.
- The Non-value adding activities can be reduced to a great extent.

Chapter 6

Simulation

After completion of value stream mapping, the next step in this project is simulation. For a structured effort and standardization, simulation projects are conducted in these sequential steps. They are as follows.

6.1 Problem Definition –

Setting a problem definition involves defining the areas or the aspects of the plant that the project seeks to improve. It also intends to answer the 'why' of the project. Having a clear problem definition will help to have a clear set of objectives and a minimal obscurity in the project goals. In this study, we shall try to tackle an industrial situation where, a managerial team must take decisions about expansion of their sheet metal pressing plant. We have collected the data for current manufacturing conditions at this plant. We have studied their charts to know the manufacturing process and its constraints. Their current production ranges somewhere between 1800 - 1850 components per shift. They have an increase in demand that requires them to increase their production almost immediately. It is predicted that this increase in demand is not a momentary flair, but will continue to rise. It will require a significant capacity increase. It is also mandatory that the suggested changes should not require a substantial capital investment and that the changes should not increase the rigidity of the process. The management thinks that the plant needs to have flexibility in the products manufactured. Currently, the manufacturing line at Autoparts Inc. is an imbalanced system in terms of operator utilization and machine utilization. Also, the overall output is far below the system potential according to the management. Therefore, our goal is to balance the system and to increase the system output at minimum possible expense. We want to provide a turn-key solution for the productivity improvement problem which can be used and reused by moderately skilled professionals in a similar environment, any time in the future.

Problems faced by the company –

Currently, the plant is struggling to match the demand. Problems that the company is facing now are,

- Production output is currently below market demand.
- The machines and operators are underutilized.
- The plant is not efficient in terms of resource utilization.

The constraints under which the analysts are required to operate are as follows.

- Avoid large investments in presses.
- Maximize the utilization of the available resources.
- Avoid layoffs as much as possible.
- Provide a long-term solution for flexibility.

6.2 Project Planning

This step involves planning and managing the resources necessary for the duration of the project.

- Time – The management of the time required for each step can be found in the Gantt Chart shown in Figure 6.1 and Figure 6.2. Postscript 'I' in the Gantt Chart refers to the first of a month and postscript 'II' refers to the second half.
- Manpower – This task will be performed by the analyst with the help and guidance of the Supervising Professor.

- Equipment – The equipment required for this project is a stopwatch and a personal computer to operate the DES tool Simio.
- Software – We have chosen Simio as the discrete event simulation tool. The reasons for choosing simio are as follows.
  - Less programming required as compared to other simulation tools.
  - Excellent Graphical User Interface (GUI).
  - Domain Neutral nature.

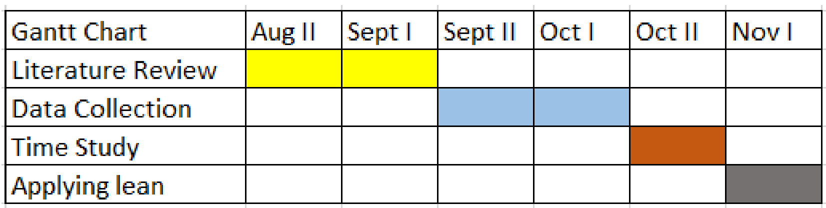


Figure 6.1 Gantt Chart (a)

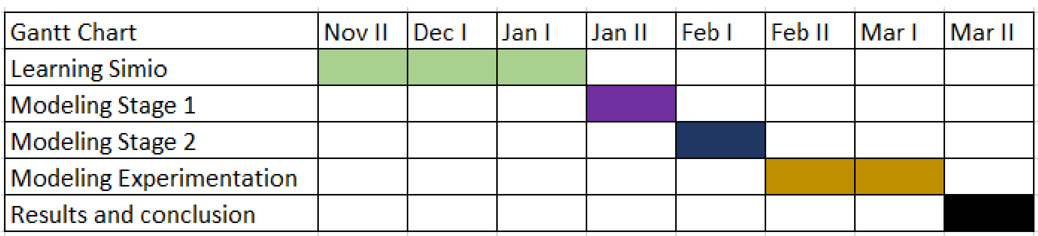


Figure 6.2 Gantt Chart (b)

6.3 System Definition

To achieve the objectives of the project, it is highly important to define the system that we intend to work on. The system definition phase required us to understand the system that we wish to simulate during the project. The system can be described as follows.

- The main raw material that is purchased from the vendors is steel sheets, which arrives in stacks of 80 sheets per day. The sheets are first cut in 10 parts of rectangular shape using the shearing machine, which needs two operators.
- These rectangular cut parts are stacked in the output buffer of the shearing machine. A helper transports these parts with the help of a trolley at the rate of 40 cut pieces per trip to the blanking machine, which is the subsequent operation.
- The parts are stacked up in the input buffer of the blanking machine. The blanking machine, which needs one operator, cuts these parts into circular discs. It cuts 4 circular discs from each rectangular cut piece. Thus, each sheet effectively gives 40 discs.
- The circular discs are stacked up in the output buffer of the blanking machine. From this buffer, the parts are transported to the input buffer of Press 3 where 1st forming/drawing is done. This machine requires one operator for processes and one operator for material movement.
- After press 3 performs its functions, the parts are stacked up in the output buffer from where they are transported to the input buffer of Press 2. Press 2 performs 2nd drawing and the parts are again stacked up in its output buffer. This machine requires one operator.

- From the output buffer of Press 2, the parts go to the input buffer of Press 7 where stamping is done. This machine requires one operator to process the components and one operator to simply transport the materials to and from this machine.
- After Press 7, parts are brought to the input buffer of Press 4, for the cutting and bending operation. Press 4 also requires one operator.
- After the cutting and bending operation, the parts are stacked up in the output buffer. From here, they are taken to the input buffer of the Hole Pressing operation, which requires one operator.
- After Hole Pressing is done, the parts, after being stacked up in the output buffer. They are then transported to the input buffer of the Tube Hole Operation, which requires one operator.
- After the Tube Hole operation is carried out, the parts are stored in the output buffer, ready to be transported to the Deburring machine. Deburring machine needs one operator.
- After deburring is done, these parts are stacked up in the output buffer. From here, they will be taken to the grinding section.
- The input buffer of the grinding section serves as a buffer for the grinding operation part input. There are currently 3 operators who perform this operation using hand held grinders.
- The subsequent operation is packaging operation which requires 2 operators. Here, the finished parts are bundled in batches of 25 and packed for shipment.

The worker allocation is shown in table below.

Table 6.1 Worker allocation in the current system

Workstation	No of Operators
Shearing	2
Blanking	1
First forming	1
Second forming	1
Stamping	1
Cutting & Bending	1
Hole pressing	1
Tube Hole	1
Contouring	1
Grinding (3 Workstations)	3
Packaging	2
Helpers	4
Total	19

Additionally, there is a supervisor and a plant engineer present during the shift.

The actual system is shown in figure below.

Figure 6.3 Picture of the facility.

6.4 Conceptual Model

The conceptual model can be termed as a model that reflects all the vital process parameters as they appear on the actual factory floor. In the case of this project, the conceptual model should contain the following elements.

- Machines
- Workers
- Material handling
- Source of materials
- Flow of material

These elements that are present on the factory floor were suitably termed as per the convenience of the software. Below is the list of the conventional terms and their respective software specific translation.

Table 6.2 Conceptual Model

Conventional Terms	**Software Specific Translations**
Presses	Workstations
Operator	Worker
Material handling	Vehicle
Source of materials	Source
Stacks	Queue
Shearing Machine	Separator
Packaging	Combiner

The geometric layout of the factory is shown in the figure below. It contains two parallel rows of machines placed at a distance from each other. In between the two rows is the storage place where earlier setup items are stored. The middle row also contains the shearing setup. The material receipt and dispatch is accomplished through the door at the eastern side of the plant. The entry and exit of the personnel is facilitated through the door at the southern side of the plant. The actual layout was provided by the company, but the remaining details, however trivial, were measured later to achieve maximum accuracy of the geometric layout.

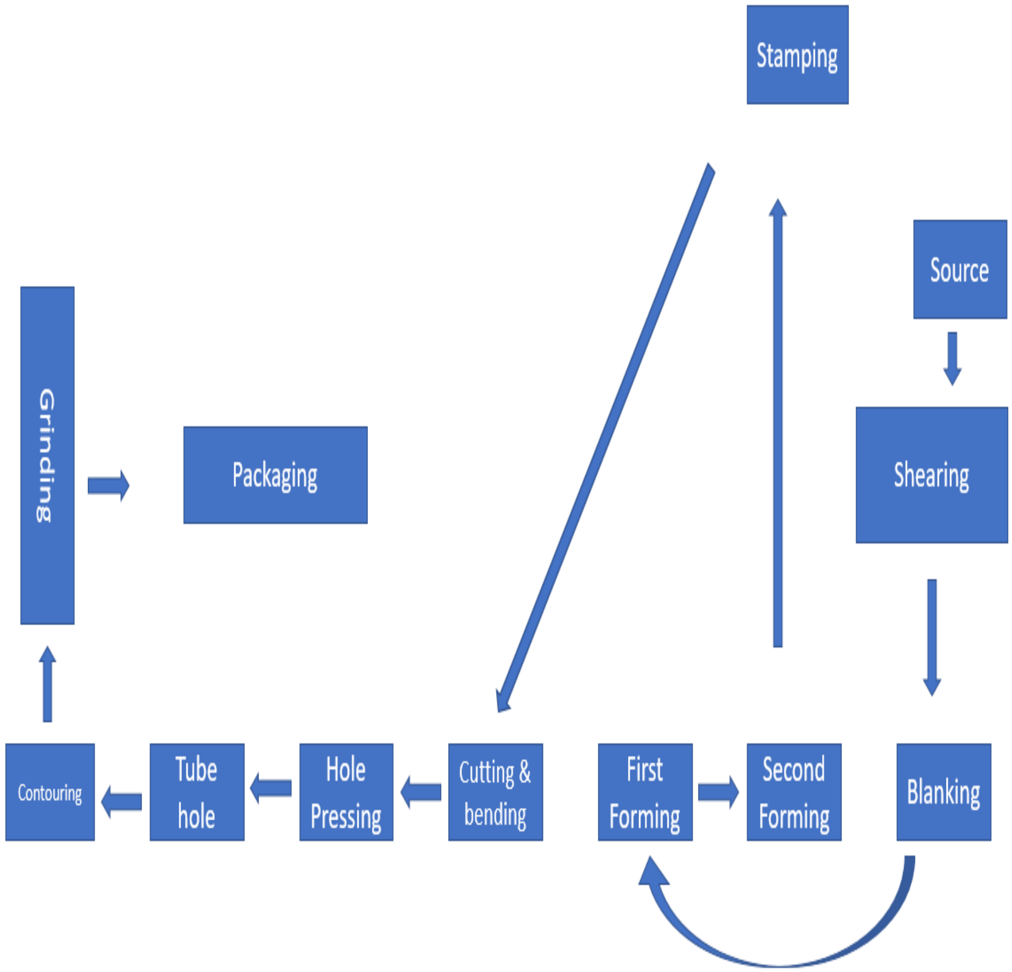


Figure 6.4 Conceptual Model

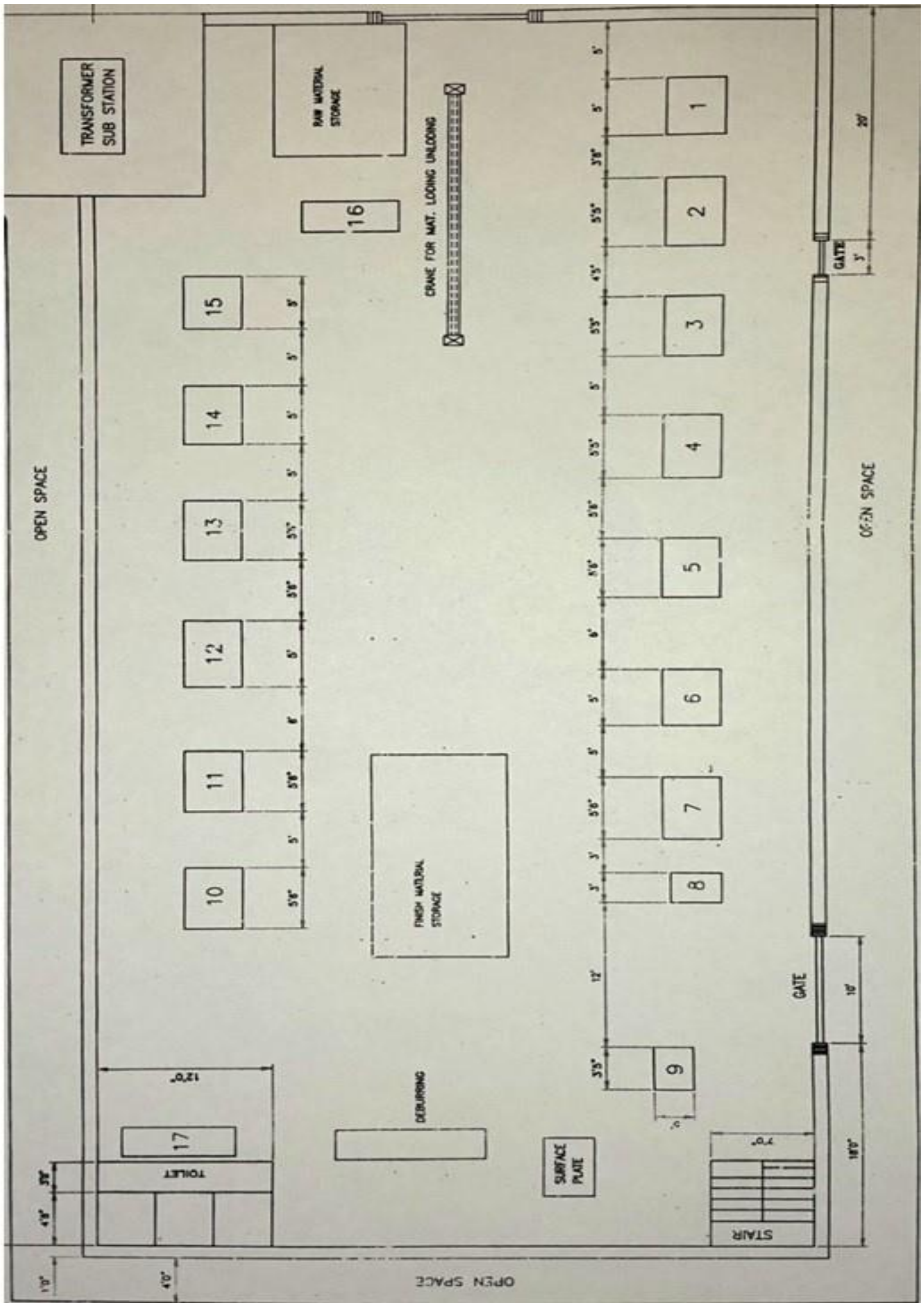


Figure 6.5 Geometric Layout (Courtesy – Autoparts, Inc.)

6.5 Preliminary Design

After the conceptual model is ready, the system performance measures should be selected. The performance measures indicate the factors that are important or decisive in the net performance of the company. Having the detailed plan at this early stage facilitates better understanding of the system and the system variables.

The process variables that we have chosen to vary are as follows.

- System throughput – System throughput is of the prime concern and the project will focus on maximizing the system output.
- Machine utilization – It is imperative that the machines stay in the processing mode for an optimum amount of time. The ideal machine utilization should be between 60% to 80%.
- Operator utilization – The operators should be busy for an optimum amount of time.
- Material movement – Material movement should not be a reason for the sluggishness in the production. We will focus on improvising the existing modes of material movement. We will try to decrease the amount of material movement by adding some new equipment, if necessary.

6.6 Input Data Preparation

For this project, the data recorded during the direct time study was used. Additional data analysis was performed to identify the probability distributions in the data. The work measurement observations can be found in Appendix A and Appendix B.

6.6.1 Data fitting and test for normality.

After recording the work measurement data, it is necessary to identify the probability distributions of the recorded data to understand the patterns. Usually, the most common distribution observed in natural events is the normal distribution, and hence it will be a priority to check for normality in the datasets. If normality can't be confirmed using the statistical analysis tools, we move on to the next possible common data distributions e.g. exponential, lognormal, gamma, beta, etc. If the data does not accurately conform to the requirements of the probability distributions listed, we can assume a triangular distribution, which can be arbitrarily observed in the data. The DES tool chosen for this project (Simio) supports most probability distributions. By incorporating the behaviors of these probability distributions, the simulation model can mimic the real-world situation more accurately.

The stepwise method employed for data fitting of a particular dataset is as follows. This process is performed on each dataset recorded during the direct time study.

- For a dataset, generate a QQ plot using R and a Histogram using MS-Excel. QQ plots and histograms are fairly accurate tools to check for normality in the dataset.
- Conduct the Shapiro -Wilk test using R. Comparing the p-value obtained from the results of the Shapiro-Wilk test with the predetermined level (0.05) we can judge whether there is a confirmed normality in a given dataset.
- If both these steps lead us to a result of normality not being observed in the dataset, we move on to the next step i.e. Chi Square test for goodness of fit. This test is explained below.
- The Chi-Square test is used to test if a sample of data belongs to a population that has a behavior resembling that of a specific probability distribution. This test

can be used for discrete data that is divided in classes. It also requires a significant number of samples for it to be effective and valid. Since, both these conditions are satisfied by the data that we have, the Chi-Square test can be used here. The hypothesis for this test is as follows

H_0: The data follows a specific distribution.

H_1: The data does not follow a specific distribution.

Test condition: Reject H_0 if $\chi^2 > \chi^2_{(1-\alpha,\ k-c)}$

Where,

α = Significance level (0.05)

k = Number of classes/bins (15)

c = Number of estimated parameters for a specific distribution +1

Examples,

- Normal distribution –

  For the normal distribution, two parameters (mean and standard deviation) are required. Hence, c=2+1=3

  Therefore,

  The hypotheses are

H_0: The data follows a Normal distribution.

H_1: The data does not follow Normal distribution.

Test condition: Reject H_0 if $\chi^2 > \chi^2_{(1-0.05,\ 15-3)}$

Similarly,

- Exponential distribution –

  H_0: The data follows Exponential distribution.

H_1: The data does not follow Exponential distribution.

Test condition: Reject H_0 if $\chi^2 > \chi^2_{(1-0.05,\ 15-3)}$

- Poisson distribution

  H_0: The data follows a Poisson distribution.

  H_1: The data does not follow Poisson distribution.

  Test condition: Reject H_0 if $\chi^2 > \chi^2_{(1-0.05,\ 15-3)}$

- Gamma distribution

  H_0: The data follows a Gamma distribution.

  H_1: The data does not follow Gamma distribution.

  Test condition: Reject H_0 if $\chi^2 > \chi^2_{(1-0.05,\ 15-3)}$

- Lognormal

  H_0: The data follows a Lognormal distribution.

  H_1: The data does not follow Lognormal distribution.

  Test condition: Reject H_0 if $\chi^2 > \chi^2_{(1-0.05,\ 15-3)}$

According to the Chi-Square distribution table, for the same level of significance, a smaller Chi-Square value is associated with lesser degrees of freedom. Hence, in order to avoid unnecessary calculation, we will test the hypothesis at c=4. If in any case, we fail to reject the hypothesis, we can go into the additional analysis necessary to identify which distribution the data conforms with.

The sample results of data analysis can be found in Appendix C.

6.7 Model Translation

The actual operations being carried out on the floor need to be converted into equivalent and suitable objects so that they can be used in the software i.e. Simio. Thus, we need to translate the model into a suitable format.

The translation of the model can be explained as below.

- Shearing machine - Shearing machine, as the name suggests, cuts a sheet into 10 equal rectangular pieces of the designed dimensions. As the machine separates one part into several parts, it is equivalent to a separator according to the Simio logic.
- Blanking machine - The blanking machine chiefly serves the purpose of punching the cut sheets, to produce 4 circular discs from each of the pieces. As it separates one component into several components, it can be termed as a separator.
- Presses – The presses used in the plant are required to carry out the various functions. They can be termed as workstations. The workstations under this category are
  - First Forming
  - Second Forming
  - Stamping
  - Cutting and bending
  - Hole Pressing
  - Tube Hole
  - Contouring

- Grinding Machines – The grinding machines in this facility are simple hand held grinders. There is no setup time associated with this operation and hence for the ease of programming, we use server objects to imitate the 3 grinding machines.
- Packaging – At the Packaging station, finished parts are packed in stacks of 25. To resemble this operation, combiners are used.
- Queues – Queues primarily achieve the objective of storing the materials. A queue is required to imitate input buffers, output buffers, and processing buffers.
- Operators – Operators employed at their respective stations perform their respective tasks. Additionally, there are helpers which help in various tasks and assist in material movement. The worker is a versatile resource. It can be used as a secondary resource or a vehicle class object in Simio.

6.8 Verification

To Verify the validity of the translated model, we build a deterministic model which considers only the average/ standard time of every process. Here, no variation is considered whatsoever.

After running the model, we find that the throughput of the simulated process for one shift of 8 hours is 1750 finished components ready for dispatch. This is very close to the real-world system. The error in this model is 3%. Therefore, it can be said that the model generated so far is representative of the actual system and ready for further modifications. The layout of the model is shown in Appendix D.

The assumptions are as follows,

- The skill expertise of the operators is same for all operations.
- Machine failures are not considered.
- Buffer capacity is infinite.

- Movement speed of the vehicle and operator is same for all tasks
- The sheets arrive at once, every day.

The KPIs observed in this model are as follows.

6.8.1 Machine Utilization

Table 6.3 Machine Utilization-Deterministic Model

Machine	Utilization (%)
Shearing	8.32
Blanking	25.39
First Forming	62.82
Second Forming	87.85
Stamping	39.40
Cutting and bending	71.73
Hole Pressing	73.06
Tube Hole	58.15
Contouring	47.14
Grinder 1	9.78
Grinder 2	10.88

Table 6.3 – Continued

Grinder 3	13.81
Packaging	22.63

6.8.2 Operator Utilization

Table 6.4 Operator Utilization-Deterministic Model

Operator	Utilization (%)
OP_SH_1	22
OP_SH_2	22
OP_BL_1	25.39
OP_FF_1	62.82
OP_FF_2	14.31
OP_SF_1	87.85
OP_ST_1	39.4
OP_ST_TRANSPORT	18.52
OP_CB_1	71.73
OP_HP_1	73.06
OP_TH_1	58.15
OP_CT_1	47.14

Table 6.4 – Continued

OP_GR_1	9.78
OP_GR_2	10.88
OP_GR_3	13.81
OP_PK_1	22.6
OP_PK_2	22.6
VEHICLE1	90
VEHICLE2	2

6.9 Model with Variation

To impart variability into the model, which is always present in the real-world system, we use the probability distributions that we identified in the input data preparation step. The addition of probability distribution means that the time required for each operation will now be randomly selected from the assigned probability distribution tables. Resulting system output will vary each time, like that of the real-world production system. After 20 simulated runs of the model, the throughput was as follows

Table 6.5 Stochastic Model Throughput Summary

Run	Throughput	Run	Throughput	Run	Throughput	Run	Throughput
1	1850	6	1857	11	1800	16	1846

Table 6.5 – Continued

2	1828	7	1820	12	1840	17	1848
3	1825	8	1827	13	1844	18	1835
4	1833	9	1852	14	1831	19	1846
5	1830	10	1838	15	1835	20	1839

The average throughput of the 20 runs was found out to be 1840

This throughput is close to the actual throughput with an error of less than 1%. Some of the key observations are listed here.

1. The flow of material is very complex
2. The amount of time for which the machines and operators are utilized is shown in the tables below.

6.9.1 Machine Utilization

Table 6.6 Machine Utilization – Stochastic Model

Machine	Utilization (%)
Shearing	8.79
Blanking	27.5
First Forming	65
Second Forming	75
Stamping	45

Table 6.6 – Continued

Cutting and bending	80
Hole Pressing	70
Tube Hole	55
Contouring	55.21
Grinder 1	10.5
Grinder 2	10.5
Grinder 3	8.75
Packaging	27.5

6.9.2 Operator Utilization

Table 6.7 Operator Utilization – Stochastic Model

Operator	Utilization (%)
OP_SH_1	23
OP_SH_2	23
OP_BL_1	27.5
OP_FF_1	65
OP_FF_2	14.31
OP_SF_1	75

Table 6.7 – Continued

OP_ST_1	45
OP_ST_TRANSPORT	18
OP_CB_1	80
OP_HP_1	70
OP_TH_1	55
OP_CT_1	55.21
OP_GR_1	10.5
OP_GR_2	10.5
OP_GR_3	8.75
OP_PK_1	27.5
OP_PK_2	27.5
VEHICLE1	90.42
VEHICLE2	2

It can be seen that the packaging machine's operators are idle for most of the time. They could be used further down the line. Shearing and blanking machines are also starved for parts.

6.10 Experimentation

Now that we have accurately modeled the existing setup of Autoparts Inc., we can try to implement various changes to the simulated model to understand their impact on the system behavior. We use the waste identification and reduction techniques outlined in the lean methodology. According to the lean methodology, there are seven types of waste that can exist in a system. They are:

- Transport – Waste of transport
- Inventory – Waste of components in the inventory that are not being processed
- Motion – Waste of unnecessary motion that the objects or the operators make
- Waiting – Waste of objects waiting for the subsequent operation
- Overproduction – Waste of excess production
- Overprocessing – Waste of excess processing resulting from poor setup
- Defects – waste of identifying or reworking on defects.

We shall try to find the presence of these defects and try to minimize them as much as possible.

6.10.1 Experiment 1

In this experiment, we shall strive to minimize and simplify the material movement on the shop floor. The material from blanking goes to press 3, then comes back to Press 2, then across the shop floor to Press 7 and then back to Press 4. This is adding a massive bottleneck due to the material movement necessary. We propose that, the dies and punches should be rearranged to regulate the material flow in a straight line. This way, the operators will spend more time in processing and less time in travelling to and from a workstation. The modified layout can be shown as below. Additionally, the quantity of the batch of materials, which is currently set at 40, should be reduced to 30. This way there will be less WIP inventory in the system.

After making the necessary changes and running the model for 20 simulated runs, the average throughput is 2000 components in one shift. The improvement in throughput is 9%.

The KPIs are found to be as follows

6.10.1.1 Machine Utilization

Table 6.8 Machine Utilization-Experiment 1

Machine	Utilization (%)
Shearing	8.35
Blanking	25.44
First Forming	54.56
Second Forming	77.03
Stamping	34.56
Cutting and bending	62.55
Hole Pressing	64.15
Tube Hole	55.32
Contouring	47.96
Grinder 1	16.95

Table 6.8 – Continued

Grinder 2	12
Grinder 3	9
Packaging	28

6.10.1.2 Operator Utilization

Table 6.9 Operator Utilization-Experiment 1

Operator	Utilization (%)
OP_SH_1	24
OP_SH_2	24
OP_BL_1	25.44
OP_FF_1	54.56
OP_FF_2	15.58
OP_SF_1	77.3
OP_ST_1	34.56
OP_ST_TRANSPORT	20.04
OP_CB_1	62.55
OP_HP_1	64.15
OP_TH_1	55.32

Table 6.9 – Continued

OP_CT_1	47.96
OP_GR_1	17
OP_GR_2	13
OP_GR_3	9
OP_PK_1	28
OP_PK_2	28
VEHICLE1	93
VEHICLE2	3

The Key Observations here is that the transporter object is busy for 93% of the time.

6.10.2 Experiment 2

The transporter being busy for 93% of the time is a serious cause of concern. To alleviate this bottleneck, we introduce a conveyor system for the material movement between the two sets of workstations that have the highest distances between them. They are:

- From Shearing Machine to Blanking Machine – 6m.
- From Contouring Machine to the Grinders – 7m.

After making the necessary change, the layout is as follows.

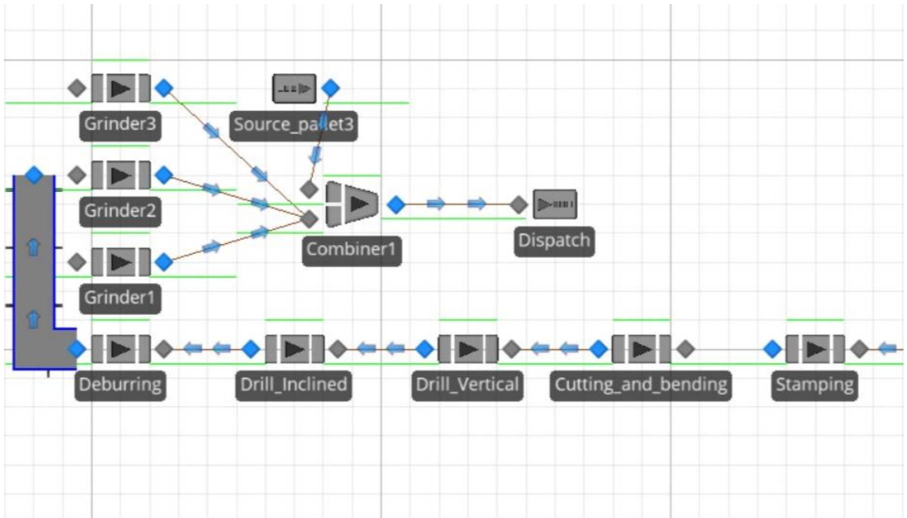


Figure 6.6 Model layout- Experiment 2 (Part A)

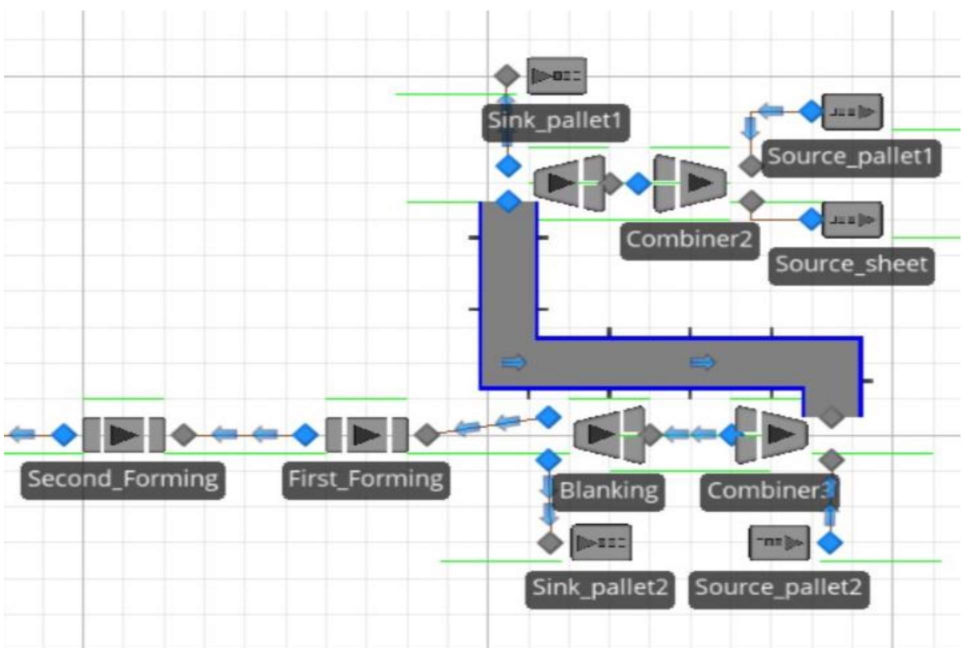


Figure 6.7 Model layout – Experiment 2 (Part B)

After making the changes and running the model, we find that the average throughput of the model is 2250. This goes to prove that the material movement was a bottleneck in the system. The KPIs are as follows.

6.10.2.1 Machine Utilization

Table 6.10 Machine Utilization-Experiment 2

Machine	Utilization (%)
Shearing	8.65
Blanking	26.35
First Forming	62.43
Second Forming	86.91
Stamping	39.67
Cutting and bending	71.38
Hole Pressing	73.03
Tube Hole	63.32
Contouring	53.48
Grinder 1	13.43
Grinder 2	15.36
Grinder 3	13.65
Packaging	29.21

6.10.2.2 Operator Utilization

Table 6.11 Operator Utilization-Experiment 2

Operator	Utilization (%)
OP_SH_1	25
OP_SH_2	25
OP_BL_1	26.35
OP_FF_1	62.43
OP_FF_2	17.92
OP_SF_1	86.91
OP_ST_1	39.67
OP_ST_TRANSPORT	22.91
OP_CB_1	71.38
OP_HP_1	73.03
OP_TH_1	63.32
OP_CT_1	53.48
OP_GR_1	13.43
OP_GR_2	15.36
OP_GR_3	13.65

Table 6.11 – Continued

OP_PK_1	29.21
OP_PK_2	29.21
VEHICLE1	85
VEHICLE2	3

6.10.3 Experiment 3

We can observe from the results of experiment 2 that the grinding machines are busy only for 12% to 13% of the times. Additionally, due to the simplified material movement, the stamping machine transport operator is busy only for 22% of the time. Also, the number of entities exiting the grinding stations was 2353 but only 2250 of them were packaged subsequently. Based on these observations, we propose the following changes.

1. Remove Grinder 3 – The operator will be available for other assignments.
2. Allocate the stamping machine transportation to another shared transporter – The stamping machine transport operator will be available for other assignments.

We allocate these operators to an additional packaging station. In this facility, the task of packaging is done simply by making stacks of 25 finished components and securing them together. Making these changes to the model and running it, we get an average throughput of 2375 finished components per shift. The increment in productivity is 5.5%. The KPIs are as follows.

6.10.3.1 Machine Utilization

Table 6.12 Machine Utilization-Experiment 3

Machine	Utilization (%)
Shearing	8.47
Blanking	26.44
First Forming	62.66
Second Forming	88.56
Stamping	39.46
Cutting and bending	71.35
Hole Pressing	72.82
Tube Hole	63.70
Contouring	54.85
Grinder 1	21.56
Grinder 2	21.86
Packaging 1	15.25
Packaging 2	15.65

6.10.3.2 Operator Utilization

Table 6.13 Operator Utilization-Experiment 3

Operator	Utilization (%)
OP_SH_1	25
OP_SH_2	25
OP_BL_1	26.44
OP_FF_1	62.66
OP_FF_2	17.82
OP_SF_1	88.56
OP_ST_1	39.46
OP_ST_TRANSPORT	22.92
OP_CB_1	71.35
OP_HP_1	72.87
OP_TH_1	63.7
OP_CT_1	54.85
OP_GR_1	21.56
OP_GR_2	21.86
OP_GR_3 (at packaging 2)	15.65

Table 6.13 – Continued

OP_PK_1	15.25
OP_PK_2	29.21
VEHICLE1	91
VEHICLE2	3

6.11 Analysis and Interpretation

The simulation initiative has been successful in identifying the opportunities of improvement and studying the impact various changes on the overall system behavior. The summary of results of the various stages of simulation can be shown in a bar chart as follows.

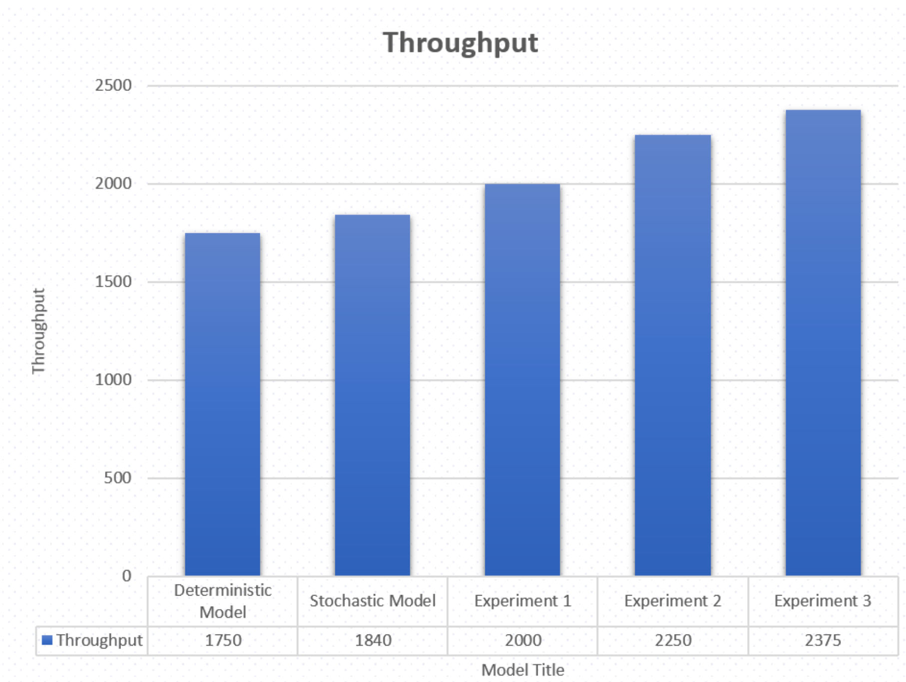


Figure 6.8 Summary of Throughput

As per the goals set at the initial stage, we have taken the system through the entire simulation process to increase the productivity of the system at minimum expenditure. The total improvement in productivity earned over these experimentations can be given by,

$$\text{Total Increase in Productivity} = \frac{Final\ Throughput - Original\ Throghgput}{Original\ Throughput}$$

= (2375 - 1800) / (1800)

= 31%

The expenses that will be incurred are shown below. This report will be submitted to the industry for perusal. It will be their decision whether to opt for these modifications.

Table 6.14 Expenses Involved

Experiment	Additional Investment Required
Experiment 1	No investment required
Experiment 2	Conveyor 36' @ INR10000/running foot = INR360000 ($5200)
Experiment 3	No investment required

As we can see, the proposed changes require minimal capital investments. The expenses involved in rearranging the dies and installation of conveyors will be assessed and taken care of by the management, if they choose to implement the changes.

Chapter 7

Conclusion

It is motivating to understand that this method has positive results. We set out with some constraints that we were supposed to operate under. These constraints were set forth by the management of the facility. Comparison of the final result with the original constraints and problem statement will help us assess the effectiveness of the proposed changes.

The first constraint dictated that investments in presses were to be avoided. This was partly because of the fact that there were additional presses present with the facility and they can be repurposed to carry out any pressing operation with changes in dies and fixtures. This constraint is strictly followed throughout the course of the project. None of the experiments require the purchase of a press. Experiment 1 however requires the press 2 to be returned to working conditions from its current nonfunctioning state. This will require minimal investment and no purchases whatsoever.

The second constraint required us to maximize the utilization of the resources already present. The resources such as the machines and the operators have had an increase in average utilization. If the results of the deterministic model and the results of experiment 3 are compared, it can be observed that the machines and the operator utilization numbers have increased by 10% on average. This is indicative of an optimized cost structure. The ideal utilization levels for machines and operators may be considered as 60% - 80%. Excessive utilization of the machine resources may cause excessive wear and tear and thus higher rate of rejection. Similarly, excessive utilization of the operator resource may cause fatigue and may introduce defects.

The third constraint was avoiding layoff as much as possible. This constraint can be attributed to the management's reluctance to lay off the operators as most of the operators have been working there for a number of years. This constraint was strictly adhered to. This can be witnessed in the third experiment. In this experiment, the operators that were busy for a small amount of time were allocated to other tasks. Care was taken that the workstations where the underutilized operators were originally allocated do not suffer losses in productivity. Additionally, the new assignments were designed as to increase the overall productivity of the operation.

This method of productivity improvement is a viable solution for flexibility. Hypothetically, if the facility needs to make any changes to the facility, either because of increased demand or because of changes in the product, the facility can implement this same approach to find the optimized system performance.

Conclusively, we can say that we have fared well with the problem statement that we were presented with and with the constraints we were supposed to follow. The results produced through this project, if implemented, can increase the productivity of the facility by more than 30%. The increase in productivity has little cost associated to it. The cost burden shared per component is negligible considering the lifespan of the purchased items, such as conveyors, and the volume of production during that span.

Chapter 8

Future Scope

8.1 Scope for Improvement

In this project, the inventory between two stations was reduced from 80 parts to 60 parts. This reduction in inventory levels boosted the production. In future, we will try to reduce the inventory levels even further. However, there is a possibility that with increased throughput levels, the material movement system will be overburdened. This brings us to the second improvement possible. If the material movement system is overburdened because of the increased throughput, an end-to-end conveyor system could be installed. This will eliminate the need for manual material movement entirely.

Additionally, we can try to implement a Constant Work In Progress (CONWIP) system. To successfully implement a CONWIP system, it is necessary that the process is fairly balanced, with the processing times of each cells being similar. We can observe from the time study that the process times for the processes vary greatly. Hence, to successfully facilitate the CONWIP system, we will have to perform extensive line balancing. One way to achieve this level of line balancing is to introduce automation for the repetitive processes. Operations from first forming to contouring are repetitive, which require no special skills from the operator. If these operations are automated, the process and setup times can be greatly regulated.

The improvements such as end-to-end conveyors and automation require extensive capital investments. This is not in line with the constraints set forth by the management for this study. If the constraints were to be relieved, the options such as conveyors and automation can be explored for an added increase in the productivity.

8.2 Scope for Implementation

This project is a turn-key solution for productivity improvement and system simulation. The resources necessary to commit to and to complete this project are easily accessible. The data is supposed to be available with the professional working in the facility. It would require a DES tool that can be purchased online. The technical knowledge required does not necessarily require years of training. With the understanding of some of the key concepts of industrial engineering, tasks like the time study can be successfully performed. The DES tool may need some getting used to but for an experienced professional, it will not take more than a week. As a result, this project can be used as a template in any industry similar in size, scope, and operating in similar market situations.

Appendix A

Direct Time Study – Pilot Study

Element No. and Description	Shearing Machine - Setup Time	Shearing Machine - Process Time	Blanking - Setup Time	Blanking – Process Time
	OT	OT	OT	OT
1	112	42	14	18
2	127	52	12	21
3	207	56	10	20
4	99	61	12	22
5	103	55	12	20
6	100	66	11	22
7	102	67	12	30
8	103	57	13	23
9	101	61	11	21
10	89	66	12	21
11	95	60	9	22
12	99	66	11	27
13	100	80	10	20
14	102	76	11	23
15	112	75	9	19
Mean	110	63	11	22
Standard Deviation	28.19573	9.863929	1.324075	3.038901
Degrees of Freedom	14	14	14	14
Accuracy(K)	0.05	0.05	0.05	0.05
$T_{\alpha/2}$ at 95%Confidence	2.145	2.145	2.145	2.145
No. of cycles required	121	46	26	36

Element No. and Description	First Forming - Setup Time	First forming - Process Time	Second Forming - Setup Time	Second Forming – Process Time
	OT	OT	OT	OT
1	7	6	11	4
2	7	5	10	4
3	8	4	9	3
4	6	5	11	3
5	6	4	11	3
6	7	6	9	3
7	5	5	10	3
8	5	6	10	3
9	7	7	9	3
10	10	6	10	4
11	7	4	8	4
12	7	5	9	4
13	8	5	9	4
14	7	5	10	4
15	7	3	11	4
Mean	7	5	10	3
Standard Deviation	1.125195	0.919011	0.870292	0.46661
Degrees of Freedom	14	14	14	14
Accuracy(K)	0.05	0.05	0.05	0.05
$T_{\alpha/2}$ at 95%Confidence	2.145	2.145	2.145	2.145
No. of cycles required	49	63	15	37

Element No. and Description	Stamping - Setup Time	Stamping - Process Time	Cutting & Bending - Setup Time	Cutting & Bending – Process Time
	OT	OT	OT	OT
1	4	5	9	10
2	3	4	11	5
3	3	5	6	5
4	4	4	15	9
5	3	4	11	6
6	3	5	11	6
7	3	5	11	5
8	4	5	9	6
9	3	5	11	6
10	3	4	8	5
11	3	4	11	4
12	3	5	9	5
13	2	4	9	6
14	3	4	7	5
15	3	5	7	5
Mean	3	5	10	6
Standard Deviation	0.571339	0.394932	2.232995	1.576117
Degrees of Freedom	14	14	14	14
Accuracy(K)	0.05	0.05	0.05	0.05
$T_{\alpha/2}$ at 95%Confidence	2.145	2.145	2.145	2.145
No. of cycles required	63	14	101	137

Element No. and Description	Hole Pressing - Setup Time	Hole Pressing - Process Time	Tube Hole - Setup Time	Tube Hole – Process Time
	OT	OT	OT	OT
1	8	5	5	6
2	9	10	8	4
3	11	8	8	7
4	9	4	5	5
5	7	6	6	6
6	3	7	5	9
7	8	8	12	6
8	9	6	8	6
9	8	5	7	5
10	5	7	8	5
11	5	8	7	4
12	5	8	6	4
13	5	7	8	5
14	8	6	8	5
15	5	10	7	4
Mean	7	7	7	5
Standard Deviation	1.9784	1.817313	1.85699	1.345185
Degrees of Freedom	14	14	14	14
Accuracy(K)	0.05	0.05	0.05	0.05
$T_{\alpha/2}$ at 95%Confidence	2.145	2.145	2.145	2.145
No. of cycles required	144	144	124	117

Element No. and Description	Contouring - Setup Time	Contouring - Process Time	Grinding	Packing – Stacks of 25
	OT	OT	OT	OT
1	5	6	4	169
2	10	6	7	159
3	7	7	7	177
4	8	6	10	158
5	5	3	13	181
6	8	5	5	167
7	6	6	5	170
8	9	6	8	164
9	8	4	8	178
10	6	6	7	171
11	7	5	8	178
12	8	6	7	163
13	4	5	6	172
14	5	3	9	180
15	3	3	8	162
Mean	7	5	7	170
Standard Deviation	1.857211	1.230421	2.115421	7.731393
Degrees of Freedom	14	14	14	14
Accuracy(K)	0.05	0.05	0.05	0.05
$T_{\alpha/2}$ at 95%Confidence	2.145	2.145	2.145	2.145
No. of cycles required	148	112	147	4

Appendix B

Direct Time Study - Sample Observations

Direct Time Study – Recorded Data

Element – Shearing Machine (Setup Time)

Cycle	R	OT (dec)	NT	Cycle	R	OT (dec)	NT	Cycle	R	OT(dec)	NT
1	0.90	1.12	1.01	30	0.90	1.07	0.96	59	0.90	1.09	0.98
2	0.90	1.27	1.14	31	0.90	1.09	0.98	60	0.90	1.11	1.00
3	0.90	2.07	1.86	32	0.90	1.11	1.00	61	0.90	1.11	1.00
4	0.90	0.99	0.89	33	0.90	1.06	0.95	62	0.90	1.08	0.97
5	0.90	1.03	0.93	34	0.90	1.07	0.96	63	0.90	1.12	1.01
6	0.90	1.00	0.90	35	0.90	1.08	0.97	64	0.90	1.09	0.98
7	0.90	1.02	0.92	36	0.90	1.09	0.98	65	0.90	1.09	0.98
8	0.90	1.03	0.92	37	0.90	1.11	1.00	66	0.90	1.10	0.99
9	0.90	1.01	0.91	38	0.90	1.14	1.03	67	0.90	1.13	1.02
10	0.90	0.89	0.80	39	0.90	1.05	0.95	68	0.90	1.12	1.01
11	0.90	0.95	0.85	40	0.90	1.12	1.01	69	0.90	1.05	0.95
12	0.90	0.99	0.89	41	0.90	1.09	0.98	70	0.90	1.09	0.98
13	0.90	1.00	0.90	42	0.90	1.14	1.03	71	0.90	1.11	1.00
14	0.90	1.02	0.92	43	0.90	1.07	0.96	72	0.90	1.15	1.04
15	0.90	1.12	1.01	44	0.90	1.05	0.95	73	0.90	1.09	0.98
16	0.90	1.07	0.96	45	0.90	1.09	0.98	74	0.90	1.10	0.99
17	0.90	1.46	1.32	46	0.90	1.13	1.02	75	0.90	1.05	0.95
18	0.90	1.09	0.98	47	0.90	1.08	0.97	76	0.90	1.10	0.99
19	0.90	1.07	0.97	48	0.90	1.05	0.95	77	0.90	1.06	0.95
20	0.90	0.99	0.89	49	0.90	1.07	0.96	78	0.90	1.08	0.97
21	0.90	1.00	0.90	50	0.90	1.09	0.98	79	0.90	1.06	0.95
22	0.90	1.12	1.01	51	0.90	1.15	1.04	80	0.90	1.08	0.97
23	0.90	0.90	0.81	52	0.90	1.13	1.02	81	0.90	1.10	0.99
24	0.90	1.03	0.92	53	0.90	1.05	0.95	82	0.90	1.10	0.99
25	0.90	1.08	0.98	54	0.90	1.11	1.00	83	0.90	1.14	1.03
26	0.90	1.12	1.01	55	0.90	1.06	0.95	84	0.90	1.09	0.98
27	0.90	1.07	0.96	56	0.90	1.14	1.03	85	0.90	1.13	1.02
28	0.90	1.10	0.99	57	0.90	1.10	0.99	86	0.90	1.05	0.95
29	0.90	1.08	0.97	58	0.90	1.14	1.03	87	0.90	1.11	1.00

88	0.90	1.07	0.96	109	0.90	1.15	1.04	130	0.90	1.08	0.97
89	0.90	1.06	0.95	110	0.90	1.13	1.02	131	0.90	1.14	1.03
90	0.90	1.13	1.02	111	0.90	1.09	0.98	132	0.90	1.10	0.99
91	0.90	1.09	0.98	112	0.90	1.06	0.95	133	0.90	1.10	0.99
92	0.90	1.11	1.00	113	0.90	1.05	0.95	134	0.90	1.08	0.97
93	0.90	1.09	0.98	114	0.90	1.05	0.95	135	0.90	1.12	1.01
94	0.90	1.08	0.97	115	0.90	1.10	0.99	136	0.90	1.09	0.98
95	0.90	1.15	1.04	116	0.90	1.09	0.98	137	0.90	1.11	1.00
96	0.90	1.12	1.01	117	0.90	1.10	0.99	138	0.90	1.05	0.95
97	0.90	1.12	1.01	118	0.90	1.08	0.97	139	0.90	1.12	1.01
98	0.90	1.09	0.98	119	0.90	1.13	1.02	140	0.90	1.15	1.04
99	0.90	1.09	0.98	120	0.90	1.07	0.96	141	0.90	1.07	0.96
100	0.90	1.12	1.01	121	0.90	1.15	1.04	142	0.90	1.10	0.99
101	0.90	1.13	1.02	122	0.90	1.13	1.02	143	0.90	1.07	0.96
102	0.90	1.07	0.96	123	0.90	1.06	0.95	144	0.90	1.05	0.95
103	0.90	1.09	0.98	124	0.90	1.14	1.03	145	0.90	1.08	0.97
104	0.90	1.11	1.00	125	0.90	1.08	0.97	146	0.90	1.10	0.99
105	0.90	1.08	0.97	126	0.90	1.06	0.95	147	0.90	1.11	1.00
106	0.90	1.12	1.01	127	0.90	1.09	0.98	148	0.90	1.12	1.01
107	0.90	1.05	0.95	128	0.90	1.09	0.98	149	0.90	1.11	1.00
108	0.90	1.08	0.97	129	0.90	1.08	0.97	150	0.90	1.11	1.00

Total OT	164.30
Rating	90%
Total NT	147.87
No. of Observations	150
Average NT	0.99
% Allowance	15%
Elemental	1.13
No. of occurrences	0.025
Elemental Standard Time	0.03

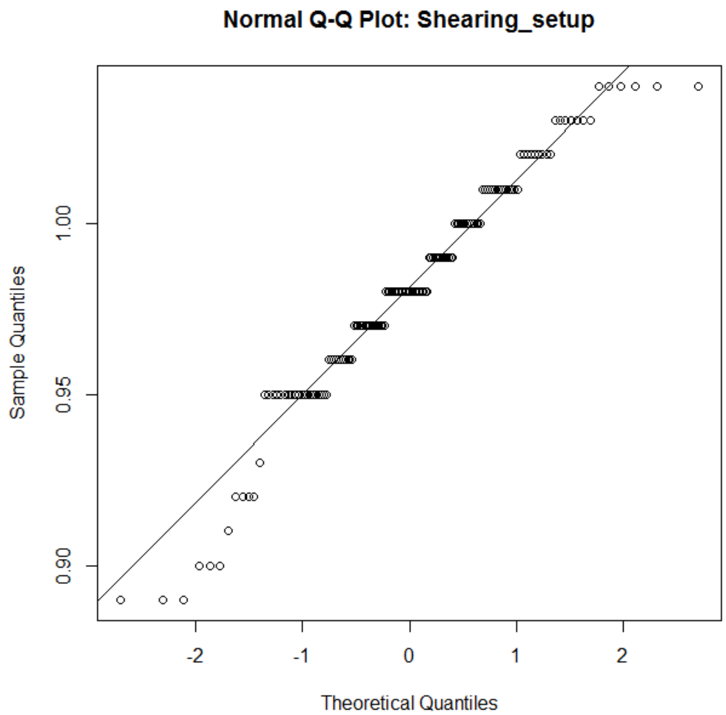
Appendix C

Data Fitting - Sample Calculation

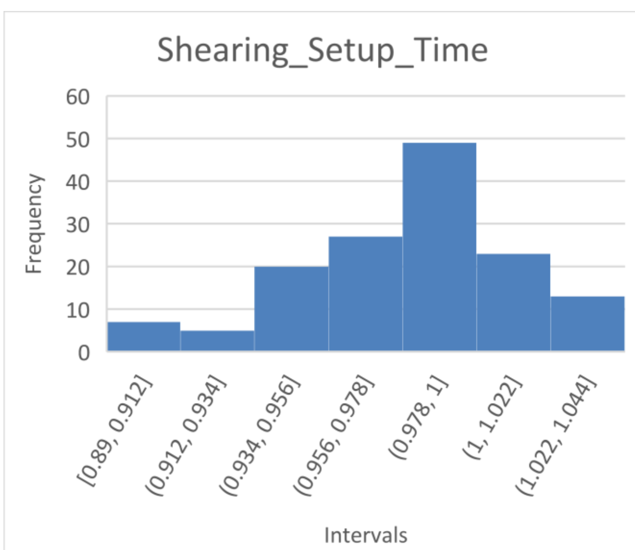
Data fitting and test for normality

1) Shearing setup time

Shapiro-Wilk normality test -



data: x1$Shearing_setup
W = 0.96219, p-value = 0.0005338
Pearson chi-square normality test -
data: x1$Shearing_setup
P = 90.792, p-value = 3.469e-14
Critical Chi Sq. Value = 19.67514
Normal Distribution Parameters -
Mean = 0.9802
Standard Deviation = 0.0336
Result = Normality not confirmed.



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Shapiro Wilk Test - Reference
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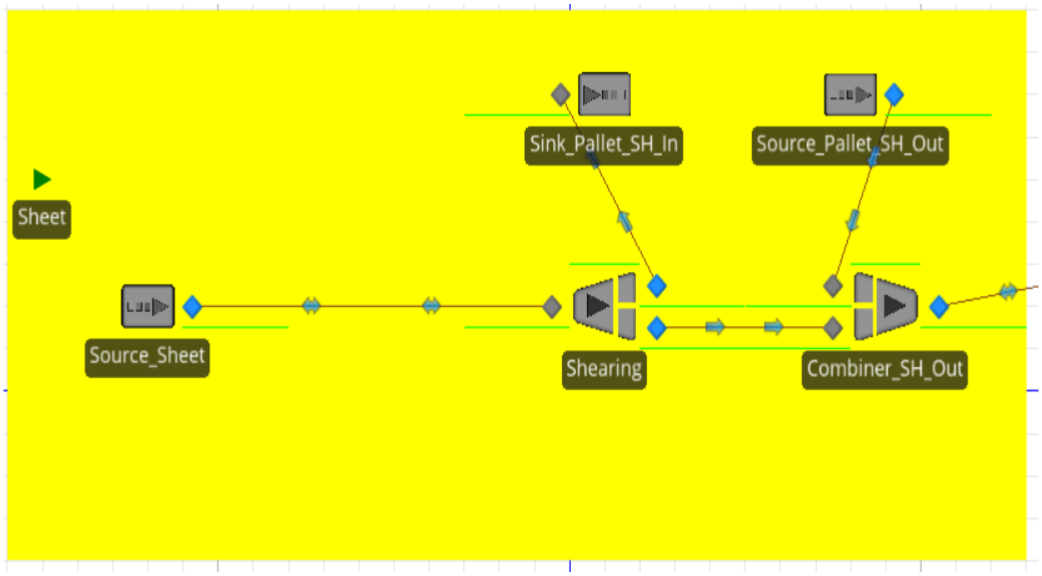
https://CRAN.R-project.org/package=mvnormtest

```
#Normality testing of shearing(Setup_time)
x1 <- read.csv(file.choose(),header=T)
qqnorm(x1$Shearing_setup,main = "Normal Q-Q Plot: Shearing_setup")
qqline(x1$Shearing_setup)
shapiro.test(x1$Shearing_setup)
z1=pearson.test(x1$Shearing_setup)
z1
qchisq(0.05,z1$n.classes-4,lower.tail=FALSE)
```

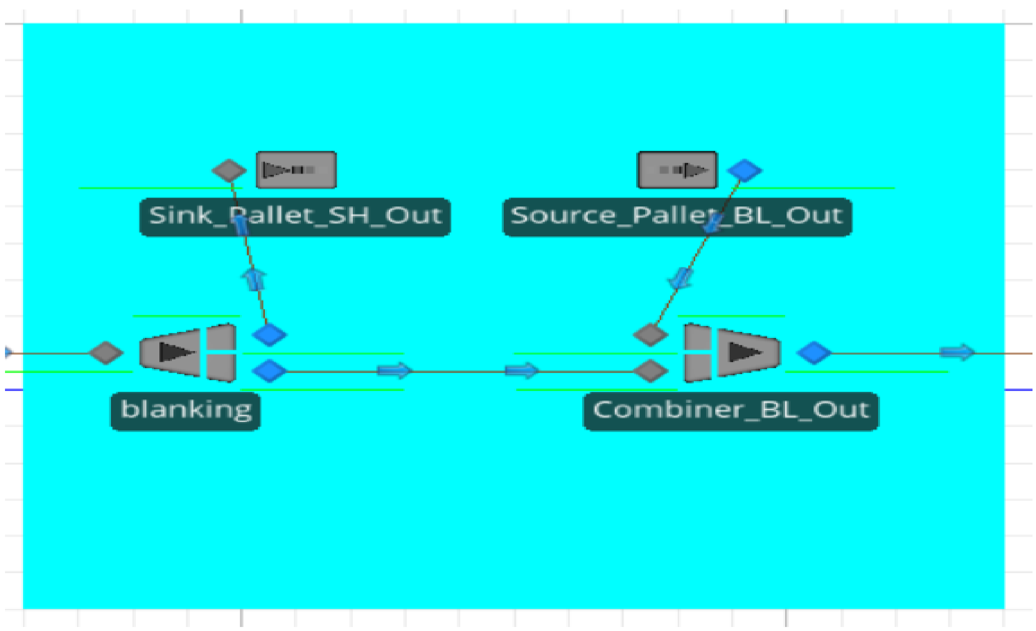
Appendix D

Simio Model Layout

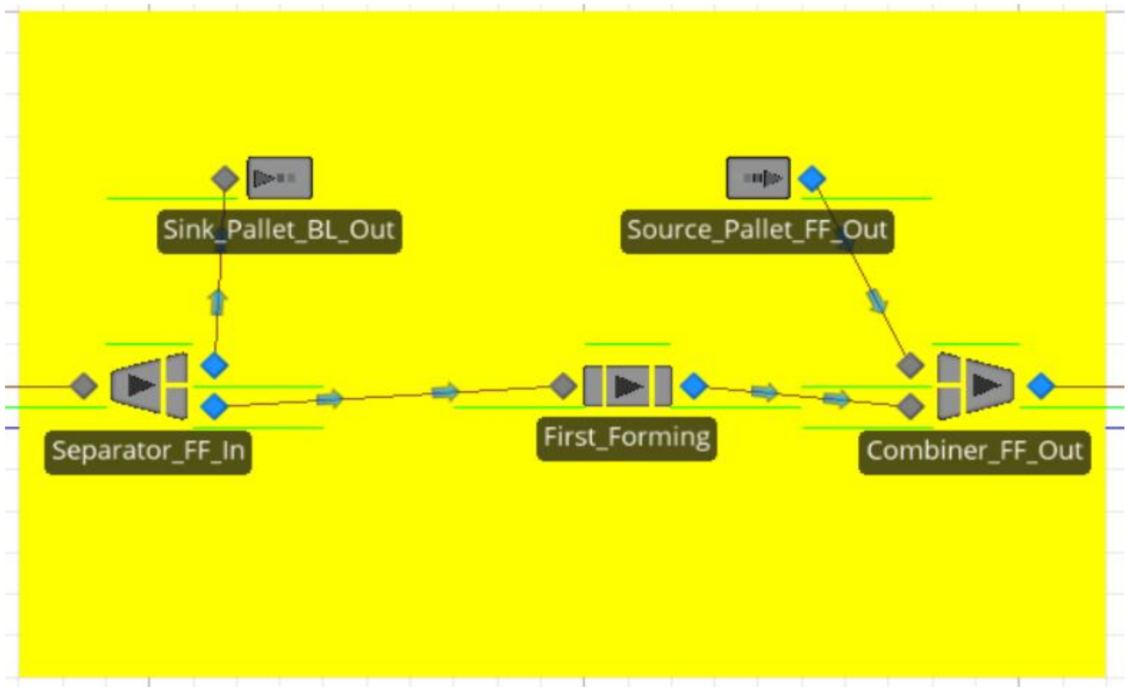
1. Shearing Machine



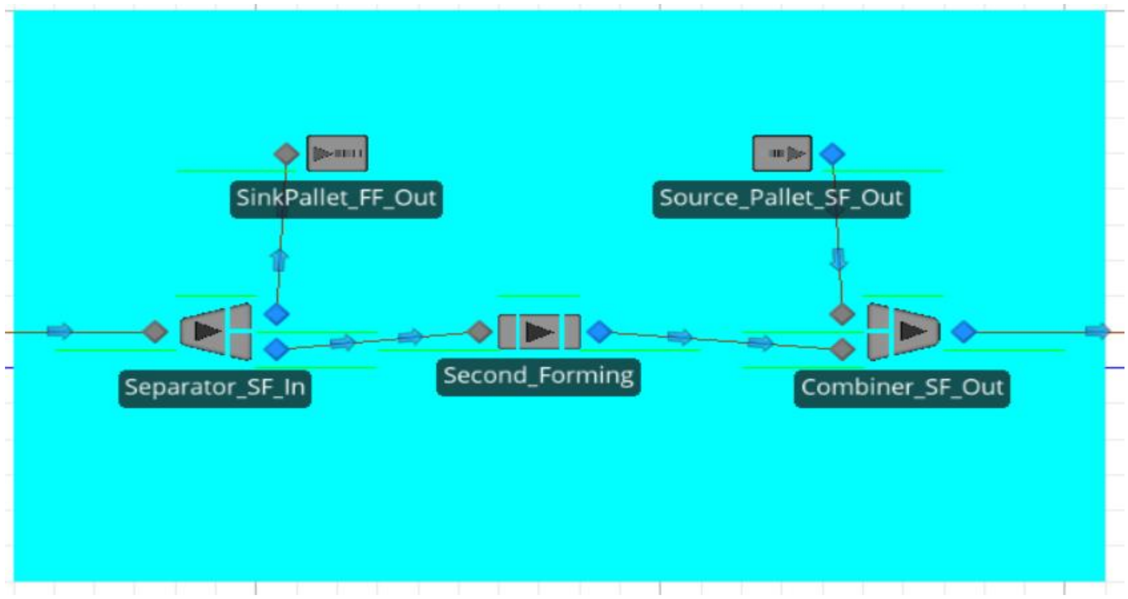
2. Blanking



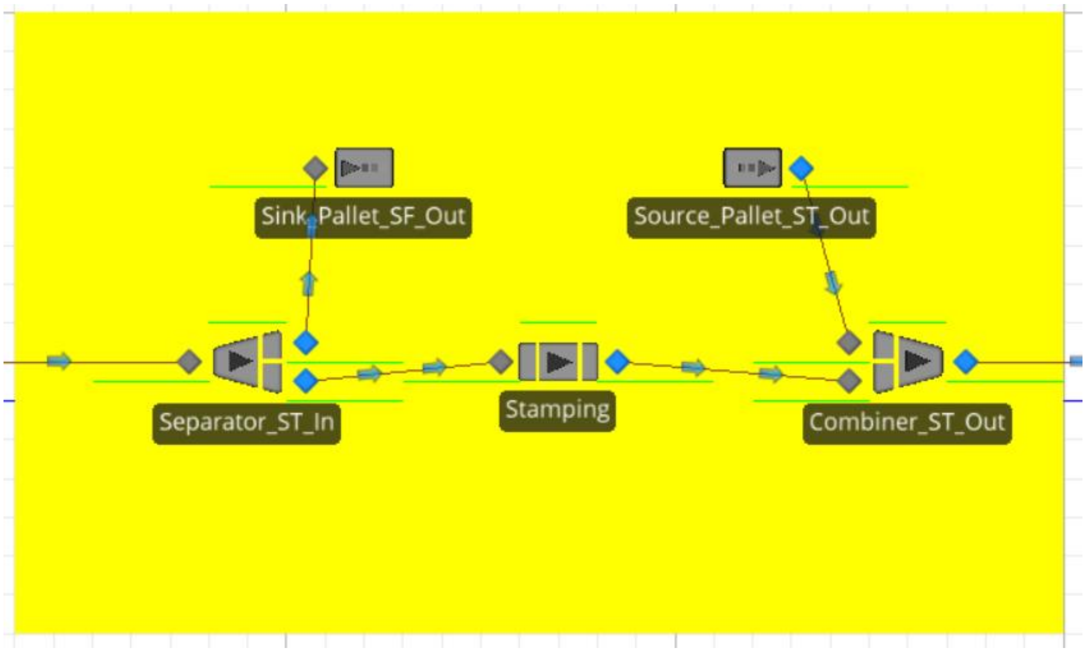
3. First Forming



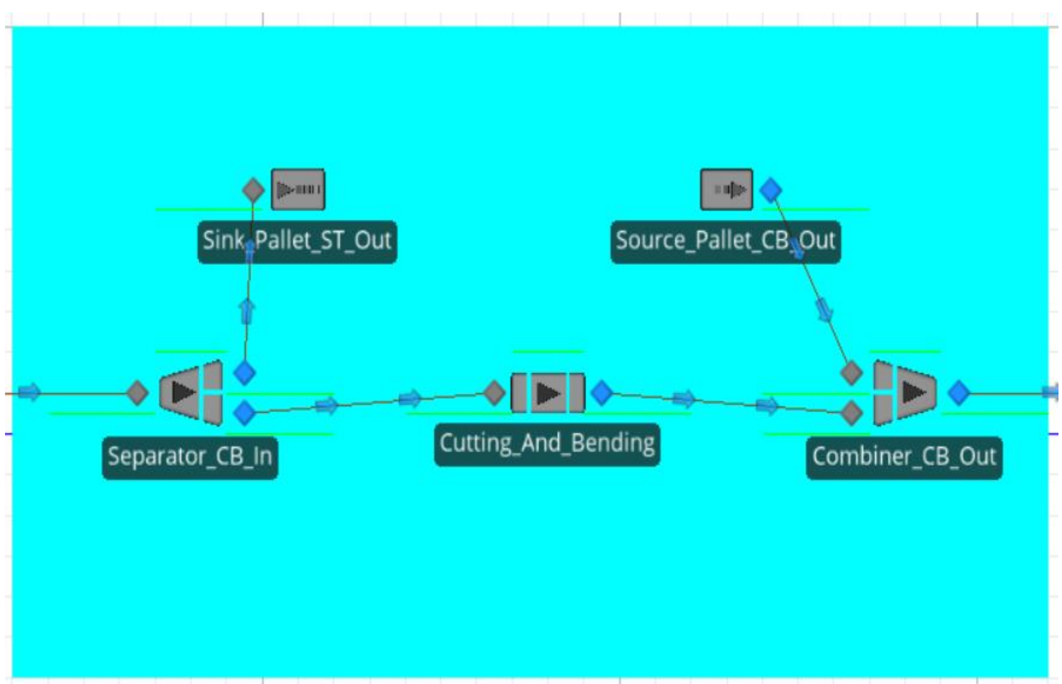
4. Second Forming



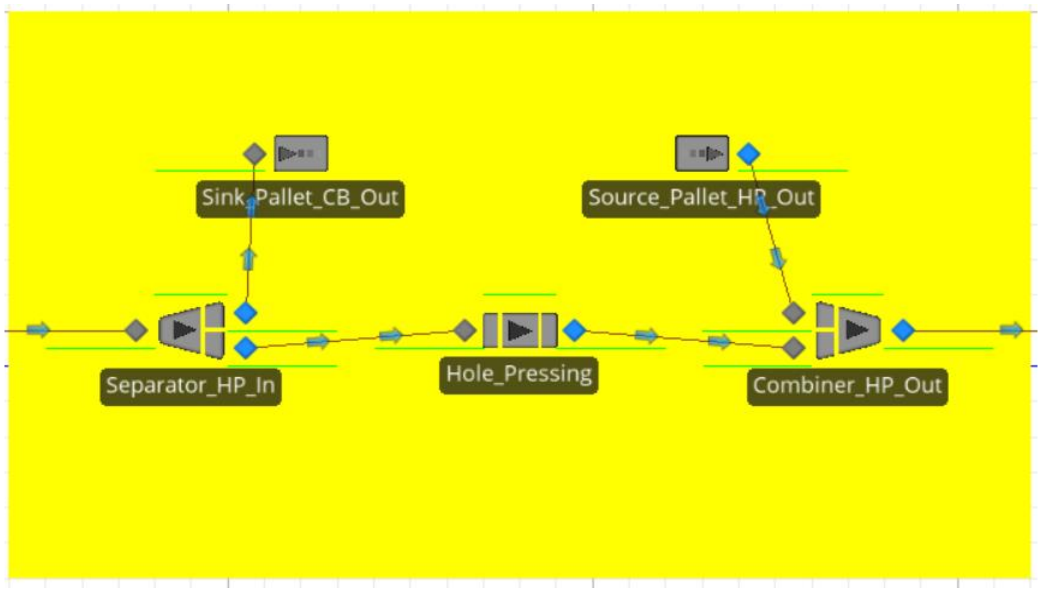
5. Stamping



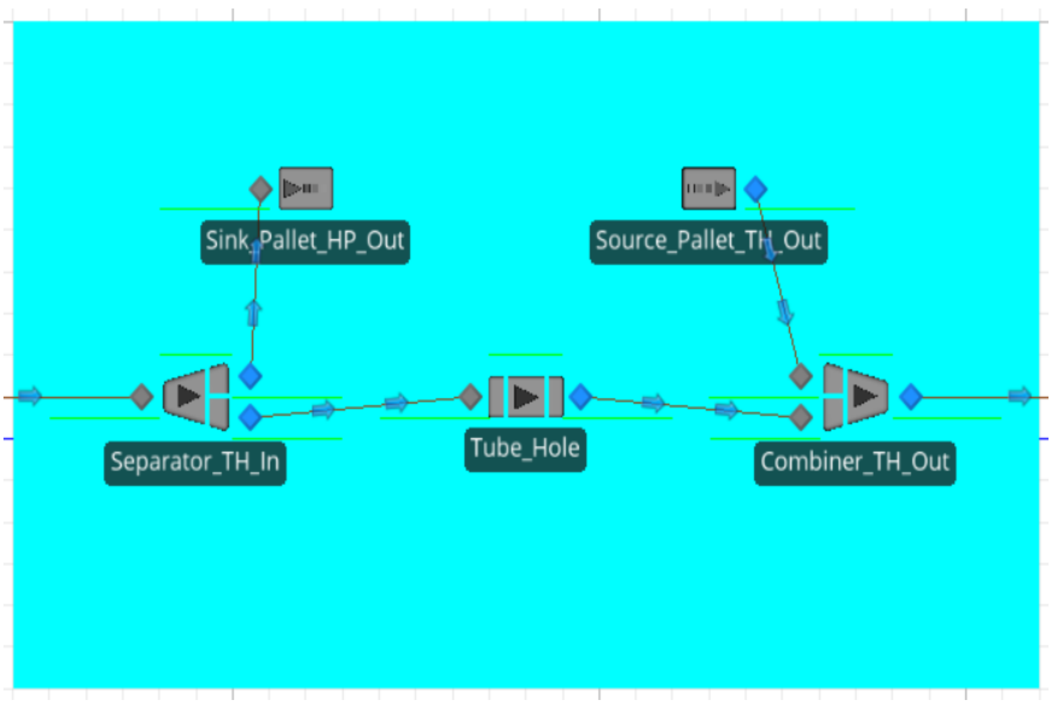
6. Cutting and Bending



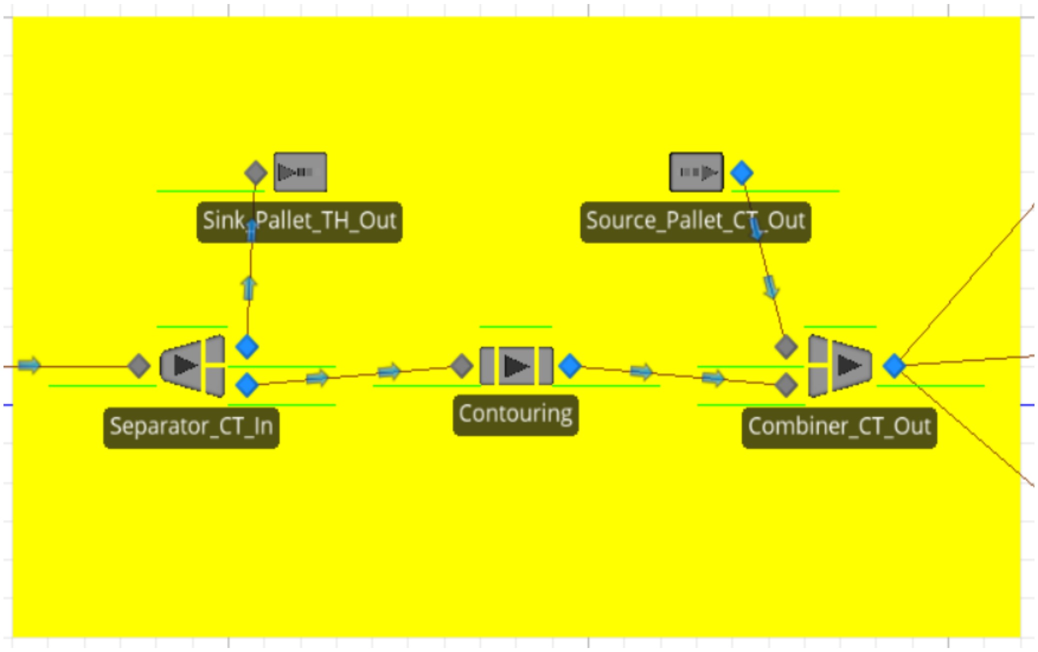
7. Hole Pressing



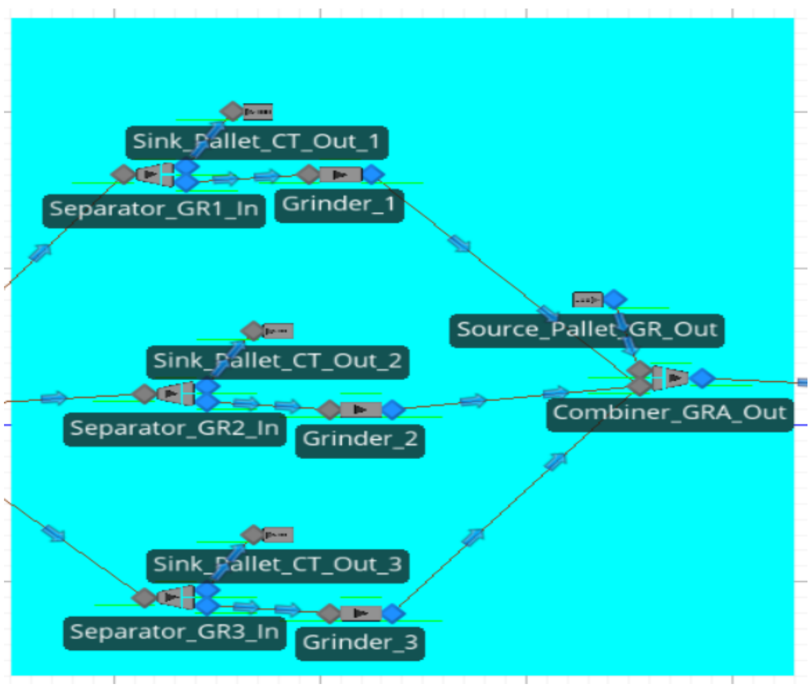
8. Tube hole



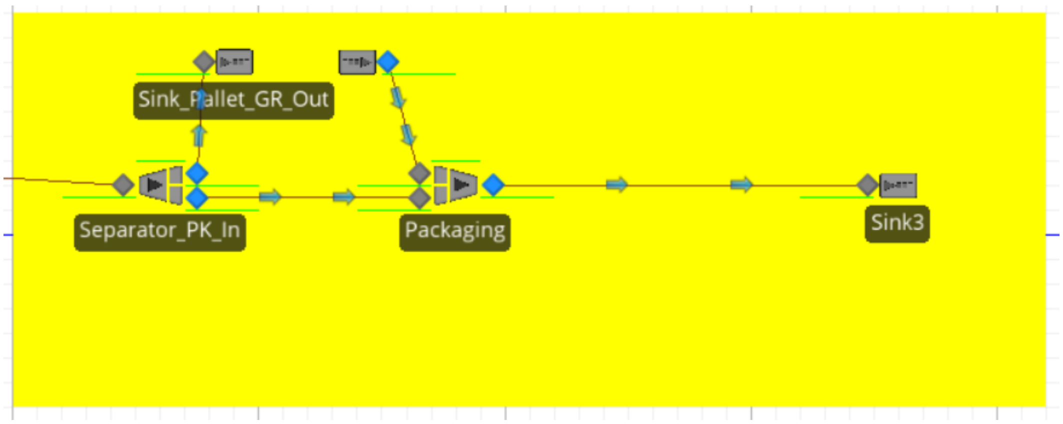
9. Contouring



10. Grinding



11. Packing



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Value Stream Map

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