Mixed Model Assembly Line Design in a Lean implemented Manufacturing Industry

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Abstract: In this study, mixed model assembly line is developed for two different models of gloves, formerly assembled on separate lines, in a gloves manufacturing firm where lean principles are implemented, with the aim of minimizing lead time and production cost. As process constraints and precedence relations differ from one model to another, the precedence diagram of mixed model assembly line is designed, combining common processes. The skill level of the workers in terms of i) ability to perform a specific task, and ii) time taken to perform a specific task by a specific category worker is also considered while developing a mixed model from individual models. Largest candidate rule has been employed to verify line balancing. The proposed mixed model assembly line was then validated using ARENA simulation software. The performance of proposed mixed model was analysed by comparing it with previously existing set-up in terms of production rate, savings and total cost as well. The comparison analyses were further extended to determine unit and monthly production costs. The results show that the implementation of the model proposed provides substantial improvements in: production rate, production cost, set-up time, waste reduction. Furthermore, this model facilitates successful implementation of lean manufacturing and sustainability through improvements in terms of waste reduction.

Keywords: Mixed-model assembly line, Lean implementation, Set-up time, Simulation, Gloves manufacturing, Skill-based classification, Largest-candidate rule, Waste-reduction

1. Introduction

The concept of manufacturing assembly line has been introduced by Henry Ford in 1900s. Primary purpose of assembly line was to provide an efficient, organized and highly productive system. An assembly line usually comprised of a set of workstations to perform a sequence of processes, organized in a fashion. A station is an entity in assembly line upon which a specific task is executed on part/product. Each workstation may differ from others in number of machines or workers, depending upon the job to be performed on that station. The process starts by feeding raw material at a specific and known rate into workstations lying at start of the assembly line. Time taken by a station to complete a task is known as process time (Fonseca et al., 2005). Assembly lines are categorized into single, multi or mixed models. In today's competitive market, manufacturers strive to reduce lead time, without compromising quality. The employment of single assembly line in customized production requires a lot of investment. To front this problem, mixed model assembly lines have been developed and practiced. Mixed-model assembly lines are used to produce different products, without carrying large inventories (Miltenburg, 1989). In a mixed model assembly line, variation exists in the models which are being assembled on a single line. These models may have different sequence and precedence constraints. The precedence relation of the mixed model assmbly line is the resultant of individual precedence relations of all the models. Similar tasks of all the models are assigned to same station, which reduces setup time.

Recently, various researches studied the development and balancing of the stitching line in garment industries. (Gungor and Agag, 2014) studied shirt stitching mixed model assembly line balancing using COMSOAL (Computer Method for Sequencing Operations for Assembly Lines) to tabulate assembly lines and concluded that it will result in balancing losses and increased number of employees and stations. (Karabay, 2014) solved a real world industrial problem using new practical techniques 1 (PT1) and 2 (PT2). These newly developed techniques are compared with Rank Positional Weight (RPW) separately, and then in combination of PT1-RPW and PT2-RPW. The highest efficiency of 97.4% is offered by the two combinations of PT1-RPW and PT2-RPW with 22 workstations in each setup. (Abeya and Mulugeta, 2014) used ARENA simulation software for performance measurement of footwear manufacturing system. Simulation revealed the current manufacturing problems including low balancing efficiencies, high WIP, and imbalanced flow between the two lines. After soving these problems, efficiencies are improved from 58.7% and 67.6% to 93.5% and 86.3% for stitching and lasting lines, respectively. (Xu and Li, 2013) minimized total unfinished work and idle times by developing a model and solving it with modified genetic algorithm and Lingo 9. (Kurkin and Simon, 2011) used Tecnomatix Plant Simulation 9 software for simulation of a production line in order to create space for a new project. (Hailu et al., 2015) employed ARENA simulation software to solve a transportation time and cost problem in manufacturing industry and saved 6.5 hours per 30 days of production. (Kitaw et al., 2010) used ARENA simulation model to identify bottlenecks and suggested alternatives to select the best option based on throughput, work content distribution and total number of workers.

Numerous techniques and algorithms employed to solve assembly line problems in extant literature. (Mamun et al., 2012) proposed a set of procedures for mixed-model assembly line problems (MALBP) and minimized total number of workstations in plastic bag manufacturing plant. (Özcan and Toklu, 2009) presented simulated annealing technique for mixed model two-sided assembly line balancing problem and achieved same level of production with less number of stations. (Bae et al., 2015) used ARENA simulation model to improve productivity and throughput. (Biele and Mönch, 2015) employed VNS algorithm using C++ in an aerospace industry problem of mixed model assembly line to minimize total inventory and labor cost, considering sequence of operations. (Yang et al., 2017) used PSO to improve efficiency of sequencing. The results show that improved PSO outperformed other techniques in multi-objective mixed-model problems.

Removing non-value added activities and continuous improvement enhances operational performances of the system. With the development of advanced manufacturing tools, chances of improvement are there in assembly line balancing. This can be done by employing lean manufacturing tools including value stream mapping (Álvarez et al., 2009, Rohani and Zahraee, 2015). Performance of these tools is further enhanced when these advanced mechanisms are integrated with simulation analyses before real implementation (Yang et al., 2015). It is important to mention that while adopting any kind of mechanism, there are multiple objectives which need to be addressed in optimizing a mixed model assembly line system. These objectives usually include minimizing the probability of starvation events, WIP, and number of stations (Merengo et al., 1999). Another important aspect is equal utilization of the resources.

Various researchers have worked on different aspects of the mixed model assembly lines using different optimization techniques, including algorithms and other mathematical/analytical tools. However, the implementation, balancing and optimization of mixed model assemly line in garment stitching, especially, in gloves manufacturing has not been explored in extant literature. The assembly line of gloves manufacturing is different in a way that the changes in size or design are frequent which requires repositioning of machines due to new process sequence while launching a new model of gloves in a multi model assembly line. Thess frequent changeovers, a considerable amount of time is wasted in non-value added activities which result in delay and low performances. To avoid this delay and wastge of resources, a mixed model assembly line is proposed as it will help in minimizing non-value added activities. The proposed mechanism is designed considering precedence constraints, skill level of the operators, number of workstations, and similarity between operations. Similar operations of the two models were merged to make one work station. Few other operations which are different but having cycle times considerably less than the required cycle time, i.e. 1 minute were also combined to make one workstation. The precedence constraints were given due imporatnce and it has been assured that there is no violation of the precedence while assigning different activities to one work station. The proposed mixed model assembly line is then compared with the multi-model single assembly lines in terms of production rate, labour cost and economy. The results show that the proposed mixed model achieves substantial performace improvement in gloves manufacturing assembly line.

2. Methodology

2.1 Existing Multi-model Assembly Lines

There are several multi model assembly lines for making goal keeper gloves in existing set-up of Comet Sports Factory. The operations of the assembly line comprise various types of stitching, each performed on a specific sewing machine. The manufacturing of different models of gloves differ in terms of: final joining of palm and backhand, backhand fashion design, safety spines, style of the thumbs, fastening mechanism and aesthetics. Considering manufacturing, few models are entirely different from others and cannot be assembled on same line. However, there exists models that can be assembled simultaneously because of minor differences in assembling operations. Figure 1 and 2 show the precedence diagrams of two slightly different models, namely Model A and Model B. The details of the operations of these models(A and B) are given in Table 1 and Table 2, respectively.

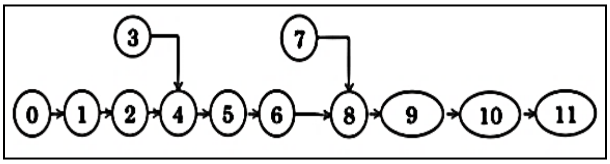

Figure 1. Precedence diagram of Model A

Table 1 Operations and cycle times in Model A

Operation Number	Description	Time (sec) /Pc
0	Pasting Design on Mesh	53
1	Design Stitching	52
2	Gusset Stitching	55
3	V-Notch Joining	28
4	Palm & Elastic Joining	30
5	Backhand & Elastic	30
6	Thumbs Stitching	32
7	Strap Making	30
8	Strap Joining	28
9	Final Stitching	58
10	Piping	60
11	Trimming/Cleaning	55

The performance of the line can be determined by the operation having longest cycle time. Usually, it is preferred that the longest cycle time should not exceed 1 minute and the operations having cycle time greater than 1 minute are adjusted by increasing the number of workers/machines. As a pair (right and left hand) of gloves have to be manufactured, the operations having cycle time considerably lower than 1 minute are automatically adjusted by assigning same worker/machine to perform same operation for pair (both hands). Similarly, a separate worker/machine is assigned for each left and right hand glove for the operations having cycle time nearly/exactly equal to 1 minute. Figures 1, 2 and 4 show actual workstations in which number of workers/machines can vary for the purpose of line balancing.

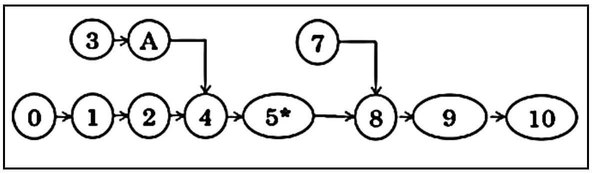

Figure 1 Precedence Diagram of Model B

Table 2 Operations and cycle times in Model B

Operation Number	Description	Time (Sec)/Pc
0	Pasting Design on Mesh	52
1	Design Stitching	90
2	Gusset Stitching	55
3	V-Notch Stitching	26
A	V-Notch & Mesh joining	26
4	Sides Joining	27
5	Cuff Making	26
7	Strap Making	30
8	Strap Joining	27
9	Final Stitching	58
10	Piping	28
11	Spine insertion	59
12	Closing	25
13	Trimming/Cleaning	55

Another important aspect is required skill level of the worker to perform a specific operation. Some of the operations given in tables 1 and 2 are simple and an average skilled worker can perform quite easily. However, other operations are so complex that only a highly skilled worker can perform. As wage rate of the workers depend on skill level, the workers are classified into three levels: skilled (a), semi-skilled (b) and low-skilled (c). Figure 3 demonstrates the requirement of skilled workers for each operation of Model A and Model B. It will not be economical to engage a skilled worker for an operation which can be performed by a low-skilled worker. Furthermore, there is a process constraint that a semi-skilled or a low-skilled worker cannot perform all operations. This classification of workers helps in per unit cost analysis and in making process sequences for new models. There is a decrease in salary of the worker in terms of skill level from "a" to "c".

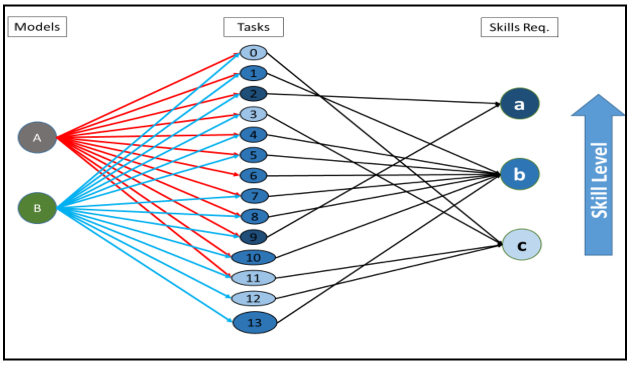

Figure 2 Assignment of different skilled operators

2.2 Initial Statistics

This work is based on the data collected from Comet Sports Factory, a gloves manufacturing industry, situated in Sialkot, Pakistan. This data includes standard operating procedures (SOPs), precedence diagrams and time study. Some auxiliary notes about constraints were also taken.

Under multi-model settings, the required production rate and line efficiency of model A and B are determined. The production rate target is determined by time study and required demand in given time. In stitching line, the targets are hourly basis. In presented study, the actual production rate was observed hourly for one-day, and average production rate was 45 products per hour. The ratio of observed/actual over required production rate gives us line efficiency (L.E). The formla to calculate required production rate is given in equation (1).

$$R_{p(required)} = \text{RequiredDemand/AvailableTime} \quad (1)$$

$$R_{p(required)} = 450/7.5{=}60 \ \text{(pcs/hr)}$$

$$R_{p(observed)} = 45 \ \text{(pcs/hr)}$$

Line efficiency can be calculated using formula given in equation (2).

$$L.E. = R_{p(observed)} / R_{p(required)} \quad (2)$$

From equation (2), the line efficiency for any multi Model A or B is 73 %. The cycle time (T_c) can be calculated from efficiency using equation (3).

$$T_c = 60E / R_p \quad (3)$$

From equation (3), the cycle time is 58.4 sec.

Number of workers can also be determined using formula given in equation (4).

$$W_A^* = MinInteger \geq T_{WC} / T_c \quad (4)$$

The optimum number of workers that should be present in this line for Models A and B are 18 and 21, respectively. T_c is same for both models because of same production rate for model A and model B.

2.3 Non Operational Times

Non-operational or non-value added time is the time consumed in daily setup and model changeover in each line. For every new model to be launched, there is some non-operational time known as model changeover time. This changeover time includes the time taken in;

i. Machine change
ii. Briefing to operators
iii. Thread change
iv. Waiting

Whenever, there is a change in model, the machines are arranged according to required layout. Operators and machines are added or removed depending upon required processes for a given model. Operators are arranged in sequence of operations and skills of workers. Raw material is distributed among operators. Quality manager gives briefing and provide technical support. After sample approval, the production process starts, i.e., the operators will start stitching with the help of quality in-charge, who help in performing the assigned task and also ensures quality. Few among B and C type skilled workers take more time at start of new tasks. It was observed that this whole start-up process takes 65 minutes on average.

From above statistics, the waiting time for each pair can be determined. As observed R_p is 45 pairs per hour which means that it takes 82 seconds to complete one pair. Whereas, ideally it should have taken 60 seconds with no waiting time. There are 15 minutes of waiting time for each 44 pairs, or 20 seconds for each pair. Hence, $T_{waiting}$ = 20 seconds. This Model changeover time affects production. Which is discussed in upcoming section.

2.4 Proposed Mixed model

The porposed model to avoid wastage of time and resouces is a mixed model assembly line. In this model, the changeover time is saved which ultimately mitigate wastage in terms of workers' cost. The of all, balancing of the proposed mixed model assembly line is verified using largest candidate rule method (Jaganathan, 2014, Groover, 2016). It has been found that the line is well balanced. Furthermore, optimum number of workers have been determined and allocated at each station, discussed in followings paragraphs. The precedence diagram of the mixed model assembly line, developed by combining the precedence diagrams of Model A and B, is presented in Figure 4. Table 3 demonstrates the description of the operation and cycle time per piece and per pair of gloves. Ideally if these two designs are run on a multi model line, there should be zero non-operational time, i.e. no wastage of time. As $T_{waiting}$ is 15 minutes per hour, a significant increase in production rate can be achieved by reducing waiting time. Validation of this ideal hypothesis is employed using ARENA simulation tool (Kayar and Akalin, 2016, Chen et al., 2014, Arriaga-Martinez and Gamba-Lavin, 2014).

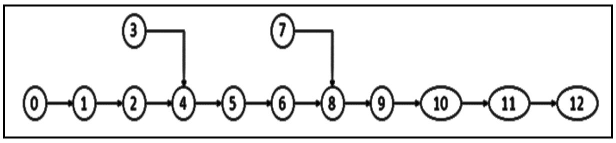

Figure 3 Precedence diagram of proposed Mixed Model

Table 3 Description and cycle time of the operations of proposed mixed model assembly line

Serial #	Operation Description	Operation Time (sec)		Required Skill Level
		Per piece	**Per pair**	
0	Pasting Design on mesh	53	106	C
1	Design Stitching	71	142	B
2	Gusset Stitching	55	110	A
3	V-Notch stitching & Joining	27	54	B
4	Palm & Elastic/Mesh Joining	28	56	B
5	Backhand & Elastic/Mesh Joining	29	58	B
6	Thumbs Stitching/Cuff Making	29	58	B
7	Strap Making	30	60	C
8	Strap Joining	27	54	C
9	Final Stitching	58	116	A
10	Piping	28	56	B
11	Spine Insertion	59	118	C
12	Closing Trimming/Cleaning	65	130	C

The significance of the proposed mixed model line is presented as follows. The cycle time for mixed model line can be calculated and is given in equation (5).

$$T_c = \frac{\text{ProductiveTime/hour}}{\text{Target/hour}} = 56 \text{ Sec} \quad (5)$$

It is evident that the cycle time is also reduced from 58.4 seconds (multi model) to 56 seconds (mixed model). This is because of assigning right job to the right person (worker). The number of workers for the proposed mixed model line can be determined using equation (4).

$$W^* = 1118/56 = 20$$

The number of workers required in proposed mixed model assembly line are 20. Calculated number of workers successfully carried out the processes of mixed model line. The assignment of tasks to respective skilled worker is done with the help of task-skills graph, presented in Figure 3.

Predicted Line Efficiency at different levels of production rate can be determined and is given below.

i. When $R_{p(observed)}$ = 55 pairs/hr, Line Efficiency (L.E) = 55/60 = 91.7

ii. When $R_{p(observed)}$ = 50 pairs/hr, Line Efficiency (L.E) = 50/60 = 83 &

iii. When $R_{p(observed)}$ = 45 pairs/hr, Line Efficiency (L.E) = 45/60 = 75%

3. Results and Discussion

The proposed mixed model assembly line is analyzed with the help of simulation using Arena input analyzer. From simulation results, the production rate of mixed model line is 60 pairs/hr, with 83 % line efficiency. The comparison of the production rate per day for model A, model B and mixed model is presented in table 4.

Table 4: Comparison of production rate per hour

	Model A	Model B	Mixed model
Production rate (pairs/hr)	45	45	50

It is evident that the proposed mixed model performs better than existing models. This increase in production is due changeover savings which occurred during existing multi model assembly line. For detailed analysis, comparison is made between real time observations of multi model lines and simulated production of mixed model. The result of the daily production are presented in Figure 5.

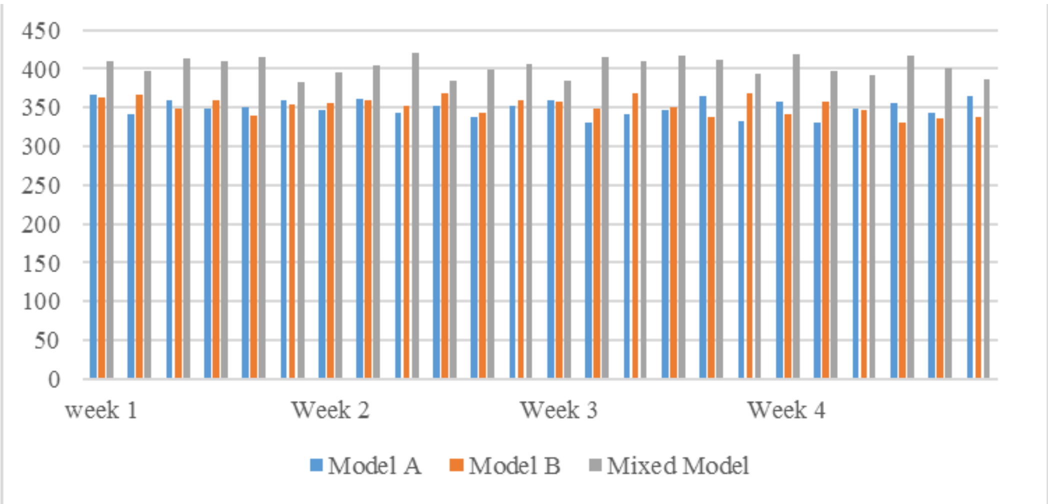

Figure 4 Comparison of existing and proposed models (daily production)

3.1 Cost Analysis

Though the impact of proposed model is significant for other types of costs as well, however, only labor cost is included in this study which changes with skill level of the workers. Labor cost is indeed the most critical in assembly lines, especially, in garments/gloves stitching lines as idle time of the workers for waiting product to arrive increases the cost. The cost of the labor considering skill of the workers in proposed and existing models can be calculated using equation (6).

$$Cost = \sum_{i=1}^{3} q_i d_i \quad (6)$$

Where "i" represents type of skill level of the worker (a, b or c), "q_i" is the labor cost of i[th] type worker and "d_i" is the number of i[th] type workers required.

The cost of the workers in models A and B is presented in Table 5.

Table 5: Start-up cost per order change

Models	Number of workers			Total cost for 65 minutes
	"a" level workers	"b" level workers	"c" level workers	
Model A	2	7	3	$ 10.60
Model B	2	7	4	$ 11.33

Table 5 calculates the cost of the workers during startup when there is a change in model. As changeover time is 65 minutes, the cost is determined for startup time period to show the amount that organization was bearing due to idleness of workers in startup process due to order/model change in multi model lines. The conversion of these multi model lines into mixed model assembly line enabled the organization to remove the change of model once started.

Table 6: Comparison of multi and mixed model lines

Models	Monthly production	Monthly cost	Economy rate
Model A	8397	188768.9	22.48051
Model B	8455	201691.9	23.85475
Mixed model	9677	198461.3	20.50855

Cost per day for each multi model line and a mixed line is given in table 6. Monthly production and monthly costs are also presented. Production rate of mixed model line is higher but cost is in-between model A and B. So a better comparison can be made using the economy rate, which is actually a ratio between monthly cost and monthly production. This ratio shows that for a period of four weeks, mixed model line shows less cost over production ratio. Mixed model lines do not require any significant change in setup but a slight change in design can be incorporated. So in this mixed model line, setup time and above mentioned $T_{waiting}$ times are not considered. In multi model lines this setup time was incorporated every time when a new model was launched. This problem is demolished in mixed model line. And only one-time setup time is required. So by employing mixed model 65 minutes of setup time is saved for each model change.

4. Conclusions

In this study, a mixed model assembly line is proposed as a replacement to existing multi model lines. The main objective of the proposed approach was to improve performance of the gloves stitching assembly line. The (two) existing models were slightly different from each other, i.e., perfectly made to put in a mixed model line. In proposed mixed model line, workers were allocated by coordination and discussion with quality and production department. The results of the proposed mixed model assembly line were then compared with the multi model lines. From analysis, it is evident that there was a wastage of 65 minutes (average) in existing multi model lines, whenever there is a change in order/model. This delay has been mitigated in proposed setup. The comparison of production rate, production cost and economy rate for existing multi model lines and proposed mixed model line show that the proposed mixed model line make substantial performance improvements in assembly line. Furthermore, the proposed model also help in minimizing the waste which is a core part of firm's efforts towards Lean manufacturing.

Instead of single or multi model lines, mixed model setups can be developed in stitching industries where order quantity is low or medium. This technique significantly reduces the cost in terms of workforce, time, resources and energy consumption. Furthermore, it increases the production rate, line efficiency, skill level and monthly production.

While developing a mixed model line system in stitching industries, rework and sudden breakdown causes damage to the planning department. In future studies consideration of rework or unplanned breakdowns can be incorporated.

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