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Discrete event simulation for improving production layout: A Case of shoe manufacturing facility

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Abstract: Facility layout design has an obvious effect on the productivity and efficiency of the manufacturing systems. Generally, layouts have been optimized by reorientation of machines and workers to improve system's performance. The objective of this research is to analyse the current layoutwithout disturbing the production runs using discrete event simulation and propose an optimum facility layout for productivity improvement.In the presented work, different layout configurations for shoe making shop floor were tested using Technomatix plant simulation. The results of the current production layoutwere compared with two proposed layouts. The comparison showed that the proposed hybrid layout could help company to minimize non-value adding time and work in process inventory, which will lead to production increase. In other words, proposed hybrid layout will help company to increase their productivity.

Key words: Shoe manufacturing, Facility layout, Case study, Hybrid layout, Productivity improvement

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1. Introduction

Shoe manufacturing is one of the earliest and major sectors of Pakistan, which is flourished on local resources and consumption. This sector mostly exports leather footwear to more than 60 countries in five continents of the world(The Pakistan Business Council [PBC], 2019).In the previous decade, the global share of Pakistan in the export of footwear was only 0.001% ($110 million). Whereas, the competitors like India, Bangladesh and Sri Lanka have the export figures in billions. Recently, according to the latest survey by the Pakistan Bureau of Statistics (PBS), the export figures have raised to $98.232 million in 2020 as compared to exports worth $90.627 million in the preceding year(Shahbandeh, 2020).Local availability of good quality leather, low wage rate, skilled labour and limited technology are few favourable factors for this sector, but still, it is performing below its potential(Rafiq, 2016). Pakistan Footwear Manufacturing Association (PFMA) is an important platform supporting the producers; but for small and medium industries facing dynamic demands and competitive market, need of the hour is to make use of scientific approaches to develop optimize solutionwith limited resources. Despite of technological advancements, there is significant scope of improvement in this sector by the application of productivity enhancement tools.

New trends have forced developers and planers towards the use of cost effective, convenient and efficient simulation-based techniques. The use of heuristics methods like Tabu Search (TS), Genetic Algorithm (GA), Simulated Annealing (SA) and Hybrid approaches are now limited; because they are time consuming, complex and focus more on material handling, cost and distance with limited consideration of actual machine dimensions and equipment setting(Naranje, Reddy & Sharma , 2019).Whereas, the simulation model can capture several attributes and requirements of the real-life problem, helping to efficiently re-evaluate and change the layout design.Various simulation software such as Promodel, Arena, CATIA, Quest, I grip and Technomatrix are available commercially to build and simulate complete manufacturing system.

Nadiah (2007)proposed an efficient production layout for a shoemaking factory using CATIA software and analysedthe proposed layout using systematic layout planning method.Lee, Shin and Ryu (2010)developed a simulation model with reduced lead time, by targeting the bottleneck process in a shipyard.Optimization of material flow through improvement in logistics was performed byKliment, Radko and Janek (2014)using simulation tool.The bottlenecks in the production process were identified and later verified using Product LifecycleManagement (PLM) module in the manufacturing process.Blaga, Stanăşel, Hule and Pop (2017)performed line balancing and eliminated thebottleneck workstation through modelling and simulation. To increase productivity and reduce production cost Zhang, Wang, Wang, Cui, and Cheng (2019)used systematic layout planning theory. They analysed the number of equipment and material transportation in shoe production area using technomatrix plant simulation software. The newly developed layout reduced the distance that material covers from storage unit to packing unit.Hassan, Kalamraju, Dangeti, Pudipeddi, and Williams (2019)in theirstudy presented a simulation-based approach in shoe manufacturing system. They improved the system's throughput, machine utilization and ergonomics concerns; with reduction in defect rate and worker head count. Naranje et al. (2019)employed the simulation technique to address inventory management and factory layout problems. He developed an optimized layout using systematic layout planning (SLP) tools to identify the problems in the current system and used Technomatrix software for performing the validation of model.As seen from the literatures surveyed, simulation has produced promising results in many application areas without disturbing the original systems. Present effort belongs to the same research stream and is focused to improve the productivity limited by design problems.

The aim of this study is to introduce a simulation-basedapproach that reflects the real-time status of a shoe production line using Technomatrix plant simulation. This, not only allows fora more accurate analysis of the output compared to the traditional methods, but also identifies the bottleneck regions and starving regions through WIP inventory analysis.

The article is arranged as follow:Section 2 discusses the available literature on the issue, Section 3 presents the current EVA production layout,highlighting the work in process inventory situation at each workstation, while Section 4is followed by the simulation of the two improved layouts, Section 5 gives the statistical analysis for the selection of an improved system; finally,Section 6 outlines the concluding remarks.

2. Literature Review

The literature review presented is divided into two broad sections, first one presents the use of Technomatrix simulation software (see Table1) in different researches and other section summarisesthe tools and techniques used by researches for layout optimization (see Table2).

Table 1. Use of Technomatrix plant simulation for bottle neck analysis

References	Application area
Siderska (2016)	Production and logistics processes of a nail manufacturing facility.
Kikolski (2016)	Production line
Fedorko and Vasil (2018)	AGV network, handling the systems of sea containers in a variety of logistics processes.
Sobrino, Ružarovský, Holubek, and Velíšek (2019)	Conveyor system.
Blaga et al. (2017)	Sliding gear manufacturing line.
Feng and Gao (2019)	Plant factory of an Agricultural industrial park.
Russkikh and Kapulin (2020)	Electronic manufacturing line
Petrila, Brabie, and Chirita (2016)	Manufacturing line of hydrostatic assemblies and sub-assemblies for aerospace industry.

Siderska (2016)focuses on the application of Tecnomatix plant simulation to optimize the operation of production line and logistics processes. The research highlighted the bottlenecks of the whole production process. By adding an extra nail sharpening workstation into the system increased the production up to nearly 70% within 24 hours. Kilolski(2016)discussed an example of computer simulation performed so as to analyse the production bottlenecks. His model allowed the identification of bottleneck station, which interferes in the operation of the entire process. Improvement in the system by extension of parallel position resulted in the smooth work of the production line. The efficiency of the new process increased from 541units to 826 units of the manufactured semi-finished product during an eight-hour-long shift.An interesting example of Technomatrix plant simulation was introduced byFedorko et al. (2018). The work presents the outcome of simulation of AGV system in the logistic processes. Computer simulation helped to evaluate the process of planning individual logistics processes in the company. Sankey’s diagram helped to visualize the material flow which indicated the uneven usage of three devices as 75%, 22% and 8%. The inclusion of an add on programming method in the simulation software helped to create the simulation model for logistic process.Recently virtual commissioning is rated as a suitable approach to shorten the physical plant start-up and to ensure the smooth transition into the serial production phase. Bearing in mind the growing importance of novel virtual commissioning tools and methods, Sobrino et al. (2019)provided the interested audience a general introductory insight into the early stages of VC in Tecnomatix Plant Simulation using the S7-PLCSIM Advanced software and its PS interface PLCSIM_ Advanced. Blaga et al. (2017)used Tecnomatix Plant Simulation to put in evidence the bottleneck in the manufacturing flow. Simulation enabled to evaluate the performance of various production tasks. The bottleneck removal significantly increased productivity from 58 parts to 64 parts during aneight hours shift. Feng and Gao(2019)used Tecnomatix software to simulate a plant factory that will be built in Fudong Modern Agricultural

Industrial Park, Handan city. The design and simulation study helped in the analysis of bottleneck process and scheme comparison before putting the system into operation. A mechanical design scheme is provided for logistics equipment based on simulation results and Trizz theory. Efficient use of production capacity is very important in engineering tasks. The simulation model developed in the study helped to visualize the work of the make-to-order production shop, which according toRusskikh and Kapulin (2020)provides decision makers an understanding of the behaviour of the system. Using Tecnomatix, Petrila et al. (2016)performed an analysison manufacturing flows within industrial enterprises producing hydrostatic components. Simulation managed to optimize the execution time of the entire assembly with a difference of approximately two hours for one single assembly. In case of larger manufacturing batches, this difference is much more evident.

Table 2. List of tools and techniques used for layout optimization

References	Tool and techniques
Kovács (2020)	Lean methods and facility layout design (FLD)
Naranje et al. (2019)	Systematic Layout Planning (SLP) tools and Technomatrix
Zhang et al. (2019)	Mathematical algorithms, heuristic methods and simulation.
Izadinia and Eshghi (2016)	Mixed Integer Programming (MIP) model and Ant colony optimization algorithm
Abraham, Krömer , and Snášel (2015)	Mathematical method for workflow calculation and simulation
Jaffery, Mohamed, and Rose (2017)	Witness simulation software
Laosiritaworn, Pinchai, and Jarupuncharadsri (2020)	CORELAP (ComputerizedRelationship Layout Planning), ROC (rank order clustering)Algorithm and ARENA software
Barnwal and Dharmadhikari (2016)	Systematic layout planning pattern theory
Hassan et al. (2019)	Stat::Fit and simulation with Intelligent Objects(Simio) software
Septiani, Divia, and Adisuwiryo (2020)	Pro Model simulation

Suhardi et al. (2019)used Systematic Layout Planning (SLP) and Quick Exposure Check (QEC) method to ergonomically redesign the facility layout. Based on the calculation of total material handling cost and simulation two design alternatives were proposed. One of the proposed alternativesreduced the total material handling cost by 22.92% and material transfer time by 34.01%.Taking into consideration the increasing cost of healthcare in the U.S,Gosavi et al. (2016) used Discrete-event simulation to identify design solutions for cost savings. They studied a total of four models under the Patient Aligned Care Teams program. Model 4 reduced patient travel distance and average queuing waits.Cost minimization and efficiency improvement are key ingredients for increase in market competitiveness and sustainability. The purpose of Kovács (2020) research was to elaborate the efficiency of lean and facility layout design (FLD) method simultaneously. In the selected case study, the application of 13 Lean and the FLD method led to the improvement of 10 quantitative and 5 qualitative indicators:

productivity; cycle-time; number of workstations and operators; WIP (work-in-process) inventories; space used for assembly; material workflow; travel distance of materials; material handling cost; labor cost; component supply; products' quality; transparency; standardization; workplace ergonomics. Naranje et al. (2019)used systematic layout planning (SLP) tools and simulation to analyse the problems in current inventory management systems. The proposed analysis provided the company an optimized inventory plan and factory layout.Facing the new trend of Industry 4.0, virtual factory technology is believed to be helpful for plant layout design and production planning in limited time and at a reasonable cost. An illustrative case demonstrated an integrated mathematical algorithms and heuristic methods approach when applying simulation to balance the operation performance and the planning cost(Zhang et al., 2019).Izadinia and Eshghi(2016)developed a Mixed Integer Programming (MIP) model to generate a robust solution for Uncertain Multi-Floor Discrete Layout Problem UMFDLP. The study presented an application of new version of robust model formulti floor layout problem with uncertainty in predefined departments' locations, demands and material flows between departments. A hybrid ACO (Ant Colony Optimization) algorithm was developed and validated for solving the problem.For manufacturing industries, increased productivity and better efficiency of the production line are the most important goals. In case of small and medium enterprises (SME) with low volume production mostly relies on traditional way of management. In a same scenario Witness simulation software is being used by Jaffery et al. (2017) to simulate the layout and the output is focusing on the improvement of layout in terms of productivity and efficiency. A new layout has been designated by rearranging the layout, simulation showed a reduction of 2.84% and 1.08% on idle time of the filling and stamping machine. In terms of productivity, the original layout produces 216 units per hour while the newly improved layoutcould produce 224 units per hour.In a case study of Siam GN metal sheet, the manufacturer of customized metal sheet products. Laosiritaworn et al. (2020)used CORELAP (Computerized Relationship Layout Planning) and Group technology based on ROC (rank order clustering) algorithm to design the improved layouts. Later ARENA software was used to simulate the new layout from both techniques. Two layouts were designed based on CORELAP and ROC algorithm. CORELAP layout with 17% reduction in both material handling distance and total production time was found to be superior to ROC layout with only 11% reduction.Barnwal and Dharmadhikari(2016)studied and developed engine reconditioning process layout of an automobile industry. Then new layout developed is based on the systematic layout planning pattern theory to reduce engine reconditioning cost and increase productivity. Large comparative distance between several departments caused long travel distance and impedes the smooth material flow and leads to higher cost. The redesigning offered production rate increased by 28%, the production time per unit came down by 3.34% and total distance travelled reduced by 14%.In a shoe making company, the original manufacturing process was beset by problems including low throughput, high headcount, overly high or low machine utilization, unduly large rejection rates, and ergonomic concerns. To overcome the problemsHassan et al. (2019)has described a successful application of simulation and analysis which provided significant improvements, includingdoubling the output while reducing worker headcount to two-thirds of its initial value.In a study conducted at cable manufacturing firm, goods produced are stored in finished goods warehouses with two types of packaging, namely haspel and roll. The units produced are stored randomly in a warehouse where products are lost due to mixing of items. ProModel simulation was used by Septiani et al. (2020)to evaluate the layout of finished goods warehouses for haspel types so that they can be grouped and minimize displacement time. A total displacement time of 140.27 hours was identified in the real system. Two scenarios were analyzed with displacement time of 139.21 and 128.08 hours. The results of scenario two resulted in a decrease in displacement time of 8.69% by grouping the haspel and adding material handling.

As discrete event simulation has provided promising results without disturbing the original systems, therefore this study will introduce a simulation-basedapproach that reflects the real-time status of a shoe production line using Technomatrix plant simulation.

3. Current Production System: Model and Evaluation

The shoe production facility under consideration manufactures leather shoes, Ethylene-Vinyl Acetate (EVA), Polyurethane (PU) and PolycarbonateUrethane (PCU) shoes. The above motioned products are made in different sections based on product-oriented layout. Organization has been following batch manufacturing strategy, where components are produced in high volume according to customer order and are stored inwarehouse. The EVA production hall in the manufacturing facility which used in this research has 3 production lines as shown in figure 1.

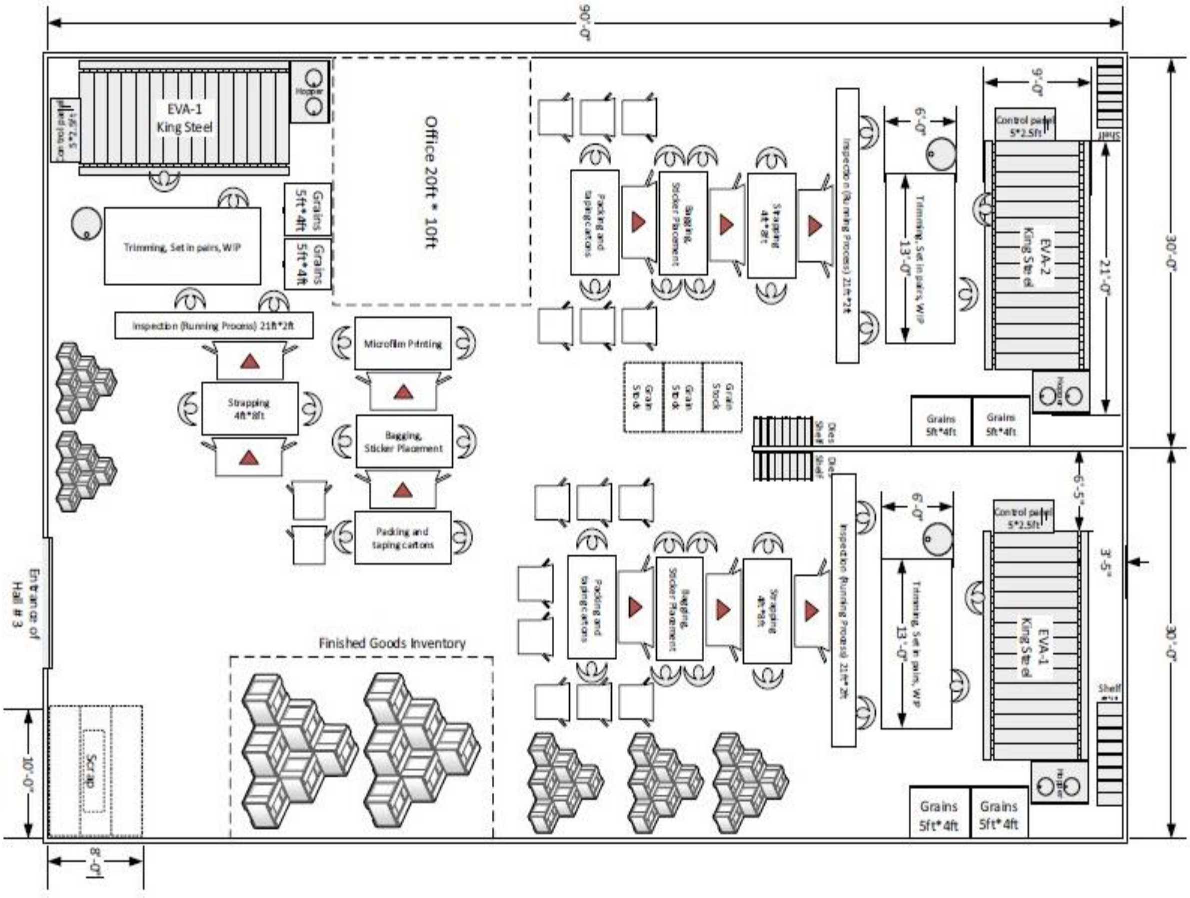


Figure 1: Existing layout of EVA production hall

Each assembly line starts with the automatic production of mid solesby an injection mouldingmachines named EVA king steel 1,2 and 3allthe exceeding processes are performed on this sole. The soles produced are manually removed from the machine; mould is then cleaned and sprayed with a non-stickingagent.Later, the extrusion on the sole is trimmed, and worker pairs the same size soles in a basket.Afterwards, the baskets are inspected manually to check the sole quality as per standards. In the fourth step, plastic straps are inserted in the sole. Later on, the sole is heated and is placed in a punch which prints a film onto the sole. The pairs are then packed in poly bags followed by price tags and bar codes pasting. Before shifting to warehouse, the finished products are placed in cartons according to the model and size. Final inspection is performed by quality inspectors, later the cartons are transferred for shipment. Figure 2 shows the EVA production line operations.

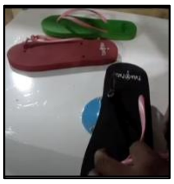
Step 1	Step 2	Step 3	Step 4	Step 5	Step6
EVA Moulding Machine	Unloading & Spraying	Trimming	Strapping	Microfilm printing	Bagging
					
Cycle time 3.25 min	Unloading time 20 sec Spraying time 4min	Cycle time 30 sec per pair	Cycle time 30sec per pair	Cycle time 20 sec	Cycle time 20sec per pair
Automated	1 worker	2 workers	2 workers	2 workers	2 workers

Figure 2: Production processes of EVA shoe manufacturing line.

Except step 1 all operations are performed manually.During Gemba walk it was observed that presence of semi-skilled labour, frequent shifting of workers during assembly, poor line balancing and process-oriented layout produce huge piles of inventory at each station as shown in the figure 3. Due to layout configuration the soles produced from each injection moulding machine has to wait to be processed by their own assembly line. As a result, semi-finished units are accumulated on the floor after each workstation leading to congested working space and limited material and worker flow.

Figure 3: High work in process inventory

To get a better visualization of the processes 2D and 3Dsimulation models of the current layoutwere created using commercial simulation software (Technomatrix plant simulation version 15)as shown in the figure 4. The production floor has a process-oriented layout with EVA sole producing machine followed by a manual assembly line. The soles produced are constricted to be processed by itsown assembly line. The workers are paid according to the conforming units produced in each shift, no scheduled is prepared for the load distribution. Units are made according to the customer demand in large quantity and are stored in the warehouse. Dedicated workforce is not assigned to each workstation, based on the availability and production load labour is shifted to other operations which cause line balancing problems. The assembly lines of EVA 1 and 2 are horizontally aligned, apart by a distance of 12 feet while the third assembly line of EVA 3 is aligned vertically. The whole production floor occupies an area of 90x60 square feet. For the simulation model few assumptions regarding the EVA production lines were made:

- Uniform distribution (min, max) was used for the simulation of EVA king steel machines due to lack of historical data of failure and MTTR.
- The frequency of maintenance required by the machine and the time taken for maintenance was also input using a uniform distribution.

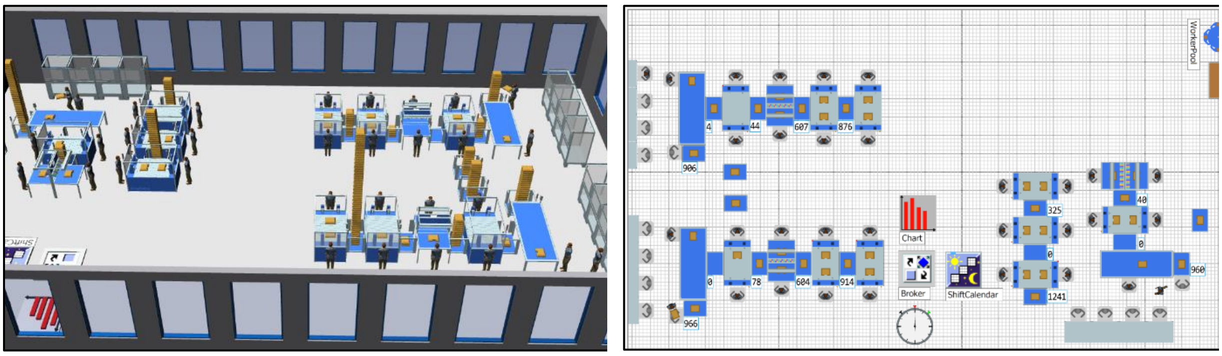


Figure 4: 2D and 3D simulation model of current layout

A24-hours simulation was run using event simulation controller; the values obtained are shown in figure 5.The results showed that the 18539 pairs of shoes exit each day from the manufacturing facility, with 772 pairs per hour. The mean lifetime includes processing, inspection, transportation and waiting time in hours. The value-added time is only 6.50% of the total. As it can be observed that parts spend only 8.81% and 0.91%of the total time in production and transportation while 91% time is spent in storage. The portion column shows the high waiting time in red colour bar.

Simulation time: 1:00:00:00.0000

Cumulated Statistics of the Parts which the Drain Deleted									
Object	Name	Mean Life Time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
Exit	Pair_of_Shoes	19:49.3519	18539	772	8.81%	0.19%	91.00%	6.50%	

Figure 5. Figure showing the simulation results of the current layout

To analyse the inventory situation, statistical report of the buffer stock at each workstation was generated as shown in figure 6.The number of entries and exits showed the units entering and leaving the workstations. While maximum contents represent the work in process inventory. It can be observed from the table that on all three assembly lines, work in process inventory level is low till first inspection station.Inventory level begins to rise after the inspection process.Total inventory at assembly line 1 is 2133 units, with maximum 893 units before packing operation. Assembly line 2 has an inventory count of 2190 units, with maximum number of 916 units before packing operation. Line 3 comparatively has account of 2287 units, but an additional operation of microfilm printing is performed on this line which has the highest inventory count of 1243 units.

Object	Number of Entries	Number of Exits	Minimum Contents	Maximum Contents
InventoryBeforeTrimming1	9599	8693	0	460
InventoryBeforeTrimming2	9598	8632	0	495
InventoryBeforeTrimming3	9521	8561	0	487
InventoryBeforeInspection1	8692	8688	0	27
InventoryBeforeInspection2	8631	8631	0	28
InventoryBeforeInspection3	8560	8560	0	30
InventoryBeforeStrapping1	7819	7775	0	138
InventoryBeforeStrapping2	7767	7689	0	142
InventoryBeforeStrapping3	7702	7662	0	97
InventoryBeforeMicrofilmPrinting3	7660	6419	0	1243
InventoryBeforeBagging1	7773	7166	0	615
InventoryBeforeBagging2	7687	7083	0	609
InventoryBeforeBagging3	6417	6417	0	74
InventoryBeforePacking1	7164	6288	0	893
InventoryBeforePacking2	7081	6167	0	916
InventoryBeforePacking3	6415	6090	0	356

Figure 6. Inventory situation at each workstation

Validation of the obtained results was done by making a comparison with the production data collected from the shop floor. The results obtained had a percentage error above 10% due to quality problems faced in real production scenario which were assumed in simulation; the results are shown in figure 7.

Data Collected from EVA production and Packaging Department		Data Obtained from Simulation		Percent Error
Date	No. of Conforming pairs of shoes produced	Simulation Run	No. of Conforming pairs of shoes produced	
Tuesday, September 1, 2020	18500	1	18969	2.54%
Wednesday, September 2, 2020	18900	2	18536	1.93%
Thursday, September 3, 2020	19050	3	17828	6.41%
Friday, September 4, 2020	17080	4	19316	13.09%
Monday, September 7, 2020	18947	5	19475	2.79%
Tuesday, September 8, 2020	18000	6	18804	4.47%
Wednesday, September 9, 2020	19334	7	18654	3.52%
Thursday, September 10, 2020	19950	8	18983	4.85%
Friday, September 11, 2020	16640	9	19633	17.99%
Monday, September 14, 2020	18300	10	16845	7.95%
Tuesday, September 15, 2020	18060	11	18904	4.67%
Wednesday, September 16, 2020	18700	12	19796	5.86%
Thursday, September 17, 2020	19105	13	18770	1.75%
Friday, September 18, 2020	20010	14	18573	7.18%
Monday, September 21, 2020	18550	15	18632	0.44%
Tuesday, September 22, 2020	18500	16	18911	2.22%
Wednesday, September 23, 2020	17840	17	18976	6.37%
Thursday, September 24, 2020	18700	18	17307	7.45%
Friday, September 25, 2020	18700	19	18437	1.41%
Monday, September 28, 2020	18250	20	18932	3.74%
Tuesday, September 29, 2020	16900	21	18998	12.41%
Wednesday, September 30, 2020	20300	22	18904	6.88%
Average	18560	Average	18736	0.95%

Figure 7. A comparison between real and simulated data

The production department of EVA shoe has three manual assembly lines; current layout and worker configuration produce large units of work in process inventory. Inventory level increases after the inspection process and keeps on increasing, with highest inventory at line 3 before microfilm printing operation. A summary of the current layout design has been given in table 3.

Table 3.Summary of the current layout's problems

Systems throughput	18539 pairs per day
Systems throughput per hour	772 pairs per hour
Time spent on workstation	8.81%
Time spent in storage	91%
Total inventory at line 1	2381 units
Total inventory at line 2	2462 units
Total inventory at line 3	1345 units
Inventory before microfilm printing	1243 units

4. Proposed Facility Layout Designs:

We proposed the following two facility layout designs to improve the productivity of the system.

i. Hybrid layout

ii. Product layout with increased number of workers

4.1. Hybrid Layout:

To overcome the design problem, ahybrid layout with combined benefits of process and product-oriented layout was suggested. The similar activities were grouped at the workstations as per process layout requirement, and the workstations were arranged as per product flow which is product layout characteristics as shown in the figure8. The EVA production machines are arranged in line with a common grain storage area. The work now can enter from one end of the line and exit from the other end. Assembly workstations are grouped together as trimming, inspection, strapping and bagging sections.Based on process layout configuration each section has three workstations. Theworkstations are sequenced as per product flow. The microfilm printing station has been placed separately to avoid blockage of floor area. The machines are 3 feet apart. With two workers per station.

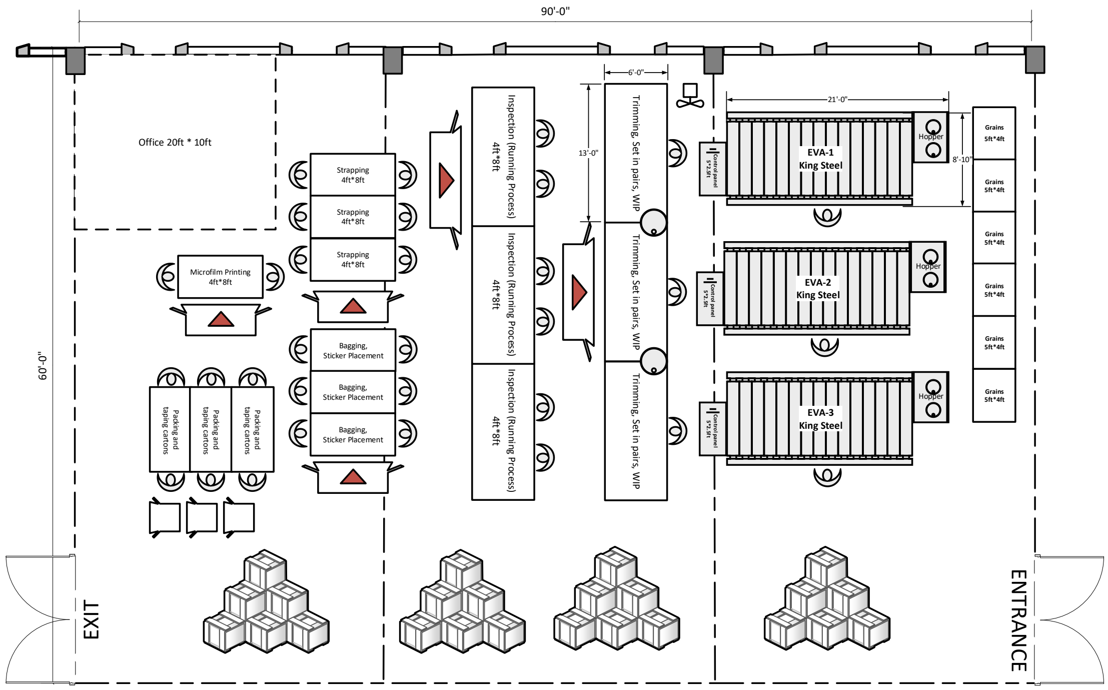


Figure 8. Hybrid Layout

A 2D and 3D simulation model of the hybrid system was made by relocating the workstation is shown in figure 9. Now instead of having three separate assembly lines. The assembly workstations are arranged in front of the injection moulding machines. Soles produced by the machines don't have to wait to be processed by their own assembly line; rather they can be processed on any of the workstation available.

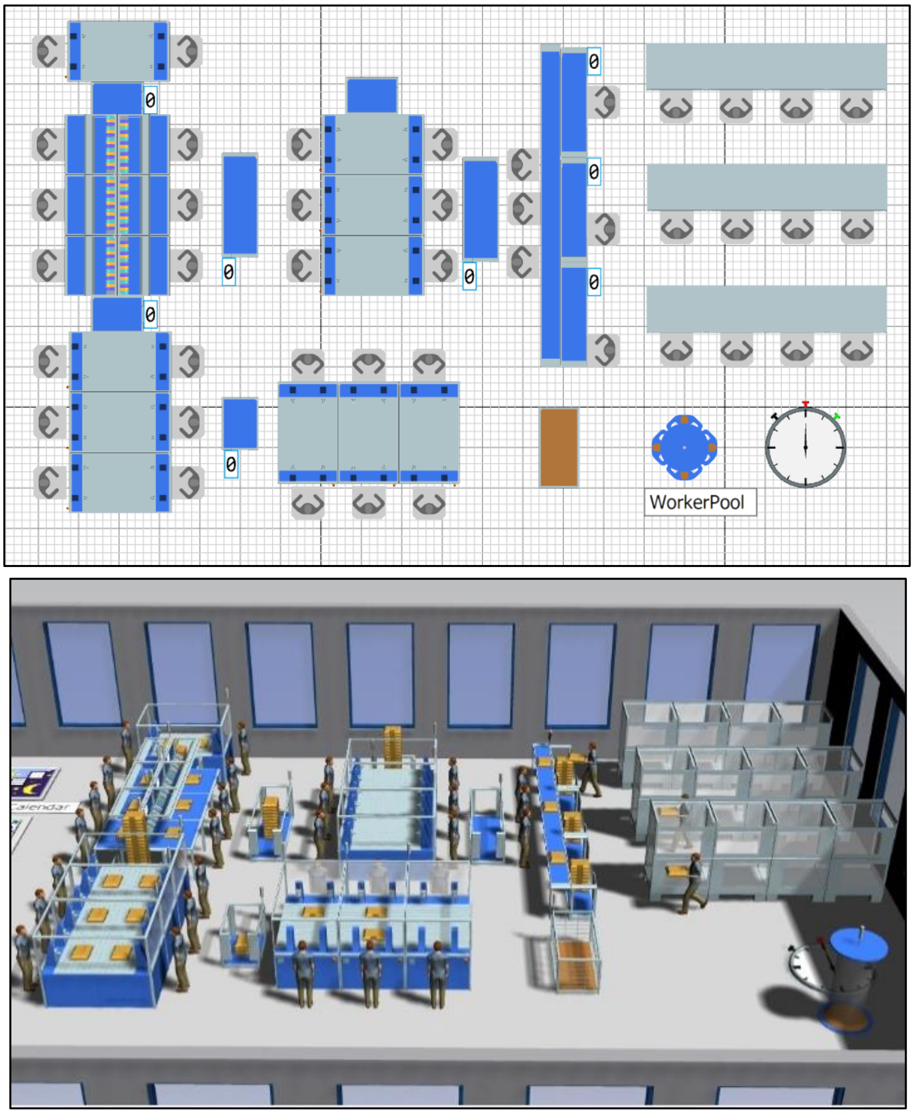


Figure 9. 2D and 3D simulation model of proposed hybrid layout

The simulation was performed on the hybrid layout, and the results obtained are shown in figure 10.The throughput has been improved from 18539 to 20322 pairs per day, with an increase of 75 pairs produced per hour. Previously time spent in production and transportation was 8% and 0.19% which has now been improved to 13% and 0.45%, with a decrease of storage from 91 to 86%. Furthermore, the result shows an increase of 3.19% in value added.

Simulation time: 1:00:00:00.0000

Cumulated Statistics of the Parts which the Drain Deleted									
Object	Name	Mean Life Time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
Exit	Pair_of_Shoes	13:19.5881	20322	847	13.48%	0.45%	86.07%	9.69%	

Figure 10. Simulation results of proposed hybrid layout

To analyse the inventory situation in the proposed hybrid layout, statistical report was generated for all the buffers in the simulation, the results obtained are presented in figure 11. By relocating the workstations, the number of units waiting in the inventory has been reduced, with maximum inventory count before microfilm printing 1092units which is 151 units less than the previous design (See Table 4). This workstation has been placed separately to avoid blockage of the material flow.

Table 4. Summary of the hybrid layout results

Systems throughput	20322 pairs per day
Systems throughput per hour	847
Time spent on workstation	13.48%
Time spent in storage	86.7%
Maximum inventory before microfilm printing	1092 units

Object	Number of Entries	Number of Exits	Minimum Contents	Maximum Contents
InventoryBeforeTrimming1	9455	8515	0	460
InventoryBeforeTrimming2	9496	8527	0	495
InventoryBeforeTrimming3	9477	8500	0	487
InventoryBeforeInspection	25539	25539	0	60
InventoryBeforeStrapping	22981	22917	0	210
InventoryBeforeMicrofilmPrinting	7504	6414	0	1092
InventoryBeforeBagging	21819	21246	0	587
InventoryBeforePacking	21240	20326	0	916

Figure 1. Inventory results of the hybrid model

4.2. Product Layout with increased number of workers:

In the second case, already existing layout was simulated by increasing the number of workersonpacking and taping workstation, which had maximum inventory of 2165 units in the current layout. The layout of the second proposed systems is shown in figure 12. A 2D and 3D simulation model is shown in figure 13. In the current production facility design the total number of workers on packing and taping station are 6, which is now increased to 8 workers in the second proposed layout. After running the simulation for 24 hrs the results obtained by the new system are shown in figure 14 and 15. After this arrangement the throughput of the facility per day is 19320 units, which is 781 more pairs per day than existing but 1002 pairs less than hybrid layout. The number of parts produced per hour is 805, which is 33 more pairs per hour than existing but 42 pairs less than first proposed design. The percentage of time spent in production and transportation is again 4.48 to 0.22% less as compared to hybrid. The value-added time of the second proposed design is also 2.49% low.

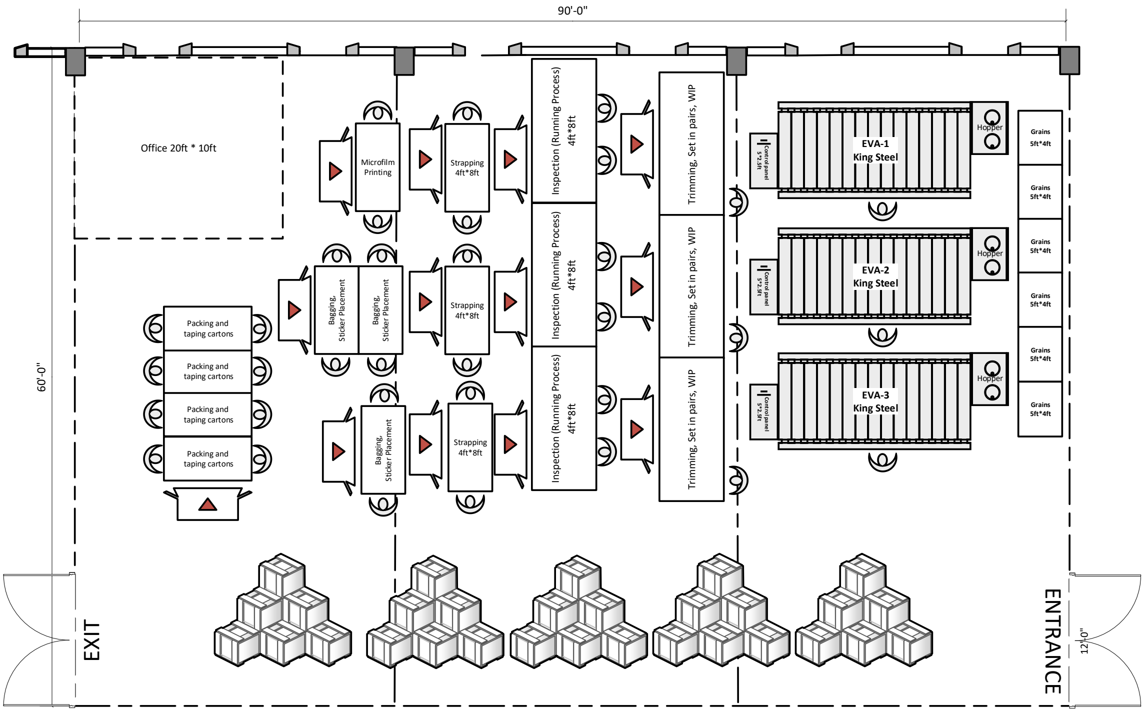
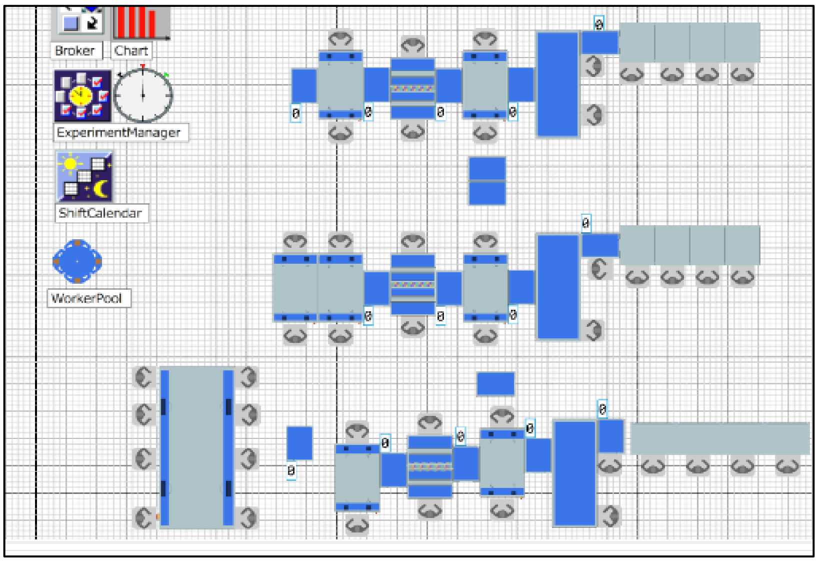


Figure 2. Product-oriented layout with increased workers



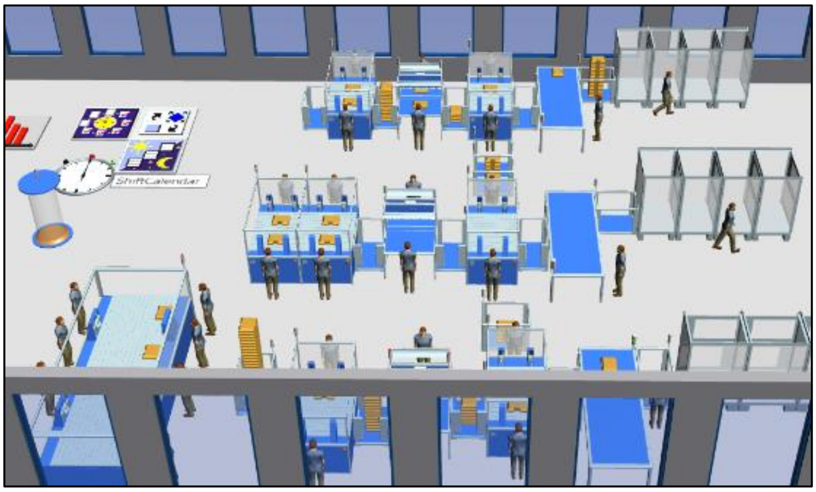


Figure 3. 2D and 3D simulation model of proposed product layout with increased workers

Simulation time: 1:00:00:00.0000

Cumulated Statistics of the Parts which the Drain Deleted									
Object	Name	Mean Life Time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
Exit	Pair_of_Shoes	16:32.8356	19320	805	9.44%	0.23%	90.33%	7.20%	

Figure 4. Simulation results of proposed product layout with increased workers

Object	Number of Entries	Number of Exits	Minimum Contents	Maximum Contents
InventoryBeforeTrimming1	9599	8693	0	460
InventoryBeforeTrimming2	9598	8632	0	495
InventoryBeforeTrimming3	9521	8561	0	487
InventoryBeforeInspection1	8692	8688	0	27
InventoryBeforeInspection2	8631	8631	0	28
InventoryBeforeInspection3	8560	8560	0	30
InventoryBeforeStrapping1	7819	7775	0	138
InventoryBeforeStrapping2	7767	7689	0	142
InventoryBeforeStrapping3	7702	7662	0	97
InventoryBeforeMicrofilmPrinting3	7660	6419	0	1357
InventoryBeforeBagging1	7773	7166	0	615
InventoryBeforeBagging2	7687	7083	0	609
InventoryBeforeBagging3	6417	6417	0	74
InventoryBeforePacking	20464	19326	0	1173

Figure 5. Inventory results of proposed product layout with increased workers

By increasing the number of workers at packing station, the inventory count is decreased by 992 units as compared to current layout but as compared to the hybrid layout the inventory count is increased by 257 units. The inventory at microfilm printing is still very high with 1357 units (Table 5).

Table 5. Summary of the product layout with increased workers results

Systems throughput	19320 pairs per day
Systems throughput per hour	805
Time spent on workstation	9.44%
Time spent in storage	90.33%
Maximum inventory before microfilm printing	1357 units

A comparison of the simulation results based on the key performance indicators has been given in the tables 6.The results indicate that the Hybrid layout outperforms the others.

Table 6. Comparison of results obtained by simulation

Key Performance Indicators	Current layout	Hybrid layout	Product layout with increased workers
Systems throughput	18539 pairs per day	20322 pairs per day	19320 pairs per day
Time spent on workstation	8.81%	13.48%	9.44%
Time spent in storage	91%	86.7%	90.33%
Maximum inventory before microfilm printing	1243 units	1092 units	1357 units

5. Statistical analysis

One-way analysis of variance is performed for the comparison of the current and the two proposed layouts.The results indicate that the mean throughputs of three layout configurations are not equal.The results of Tukey testand interval plot indicate that the proposed hybrid layout outperform the other two types of layout (see Figure 16). In other words, hybrid layout is more productive compare to the other two considered layouts.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Hybrid Layou - Exisiting La	1532	133	(1212, 1853)	11.50	0.000
Product Layo - Exisiting La	563	133	(243, 884)	4.23	0.000
Product Layo - Hybrid Layou	-969	133	(-1289, -649)	-7.27	0.000

Individual confidence level = 98.05%

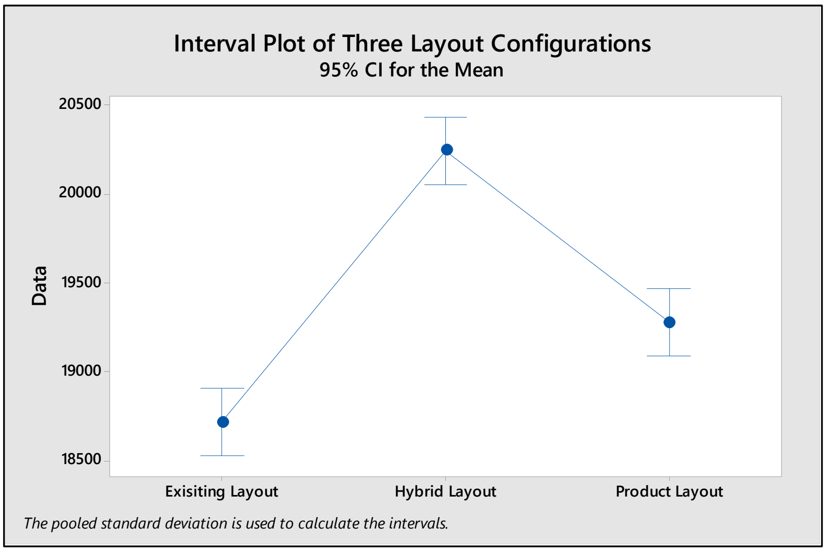


Figure 16. Results for Tukey Test& Interval Plot

5.1. Production loss comparison

The graph shown in figure 17 demonstrates the production loss of the three layouts which is calculated by running the simulation several times and then determining the average daily production. The loss of production in existing layout is 13.36% with 86.64% production. The proposed layout 1 is showing lowest production loss that is 6.27% with 93.73% production.

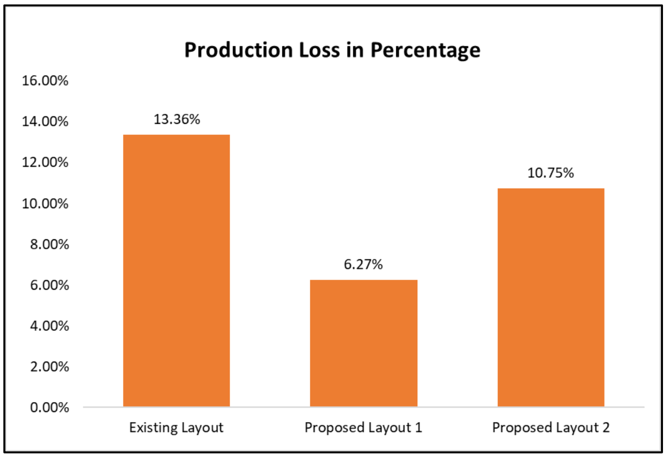


Figure 176. Comparison of production loss of the three layouts

5.2. WIP Inventory Comparison

The Average inventory levels obtained from the simulation are compared using bar chart. (Figure 18)

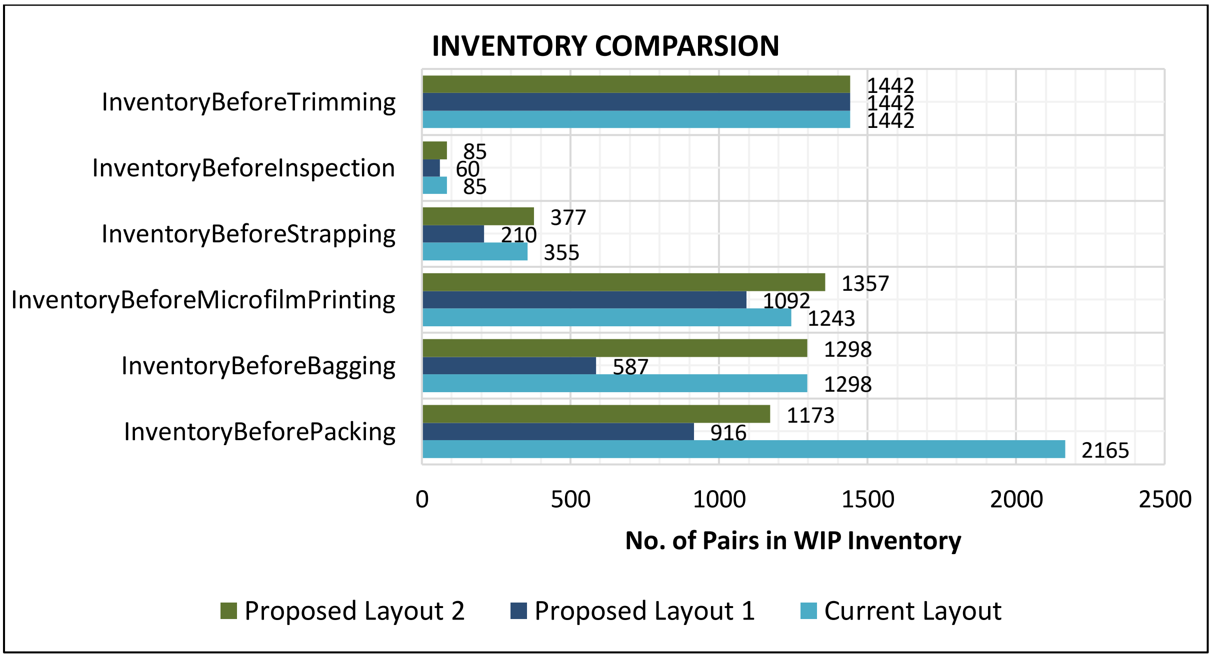


Figure 18. Average inventory levels obtained from the simulation

For determining the best alternative, the inventory levels of the proposed layouts are compared with that of the current layout and percent decrease in inventory was determined. For hybrid layout, the total decrease in inventory is 35%.(Figure 19)

Average Inventory in Current Layout Before Each Station						
Production Line	InventoryBefore Trimming	InventoryBeforeInspection	InventoryBefore Strapping	InventoryBefore MicrofilmPrintin	InventoryBefore Bagging	InventoryBefore Packing
EVA 1	460	27	138	-	615	893
EVA 2	495	28	142	-	609	916
EVA 3	487	30	97	1243	74	356
Total	**1442**	**85**	**377**	**1243**	**1298**	**2165**

Average Inventory in Proposed Layout 1 Before Each Station						
Production Line	InventoryBefore Trimming	InventoryBeforeInspection	InventoryBefore Strapping	InventoryBefore MicrofilmPrintin	InventoryBefore Bagging	InventoryBefore Packing
EVA 1	460					
EVA 2	495					
EVA 3	487					
Total	**1442**	**60**	**210**	**1092**	**587**	**916**

Percent Decrease in Inventory	0%	0%	44%	12%	55%	58%
Total Decrease	35%					

Figure 19. Comparison of the inventory levels current layout and proposed layout 01

For the Proposed Layout 2, the total decrease in inventory is 23%. It can be observed that Inventory before Microfilm Printing has increased 9% in this Layout, while significant improvement is observed in inventory before packing. (Figure 20)

Average Inventory in Current Layout Before Each Station						
Production Line	InventoryBefore Trimming	InventoryBeforeInspection	InventoryBefore Strapping	InventoryBefore MicrofilmPrintin	InventoryBefore Bagging	InventoryBefore Packing
EVA 1	460	27	138	-	615	893
EVA 2	495	28	142	-	609	916
EVA 3	487	30	97	1243	74	356
Total	**1442**	**85**	**377**	**1243**	**1298**	**2165**

Average Inventory in Proposed Layout 2 Before Each Station						
Production Line	InventoryBefore Trimming	InventoryBeforeInspection	InventoryBefore Strapping	InventoryBefore MicrofilmPrintin	InventoryBefore Bagging	InventoryBefore Packing
EVA 1	460	27	138		615	
EVA 2	495	28	142		609	
EVA 3	487	30	97	1357	74	
Total	**1442**	**85**	**377**	**1357**	**683**	**1173**

Percent Decrease in Inventory	0%	0%	0%	-9%	47%	46%
Total Decrease	23%					

Figure 20. Comparison of the inventory levels current layout and proposed layout 02

Table 7 shows the comparison results based on the production losses and percentage of average WIP decrease. The results indicate that the Hybrid layout outperforms the others.

Table 7. Layouts Comparison based on Production losses and Average WIP decrease (%)

	Current layout	Hybrid layout	Product layout with increased workers
Production Lost in %			
Production lost	13.6	6.27	10.75
Average work in process inventory decrease in %			
Average WIP inventory		35%	23%

6. Conclusion:

In this study, we evaluate the current production and two proposed facility layouts based on the throughput rate, time spent on workstation, WIP and production losses. The current system arrangement was simulated first to analyse the statedkey performance indicators. Afterwards two new design configurations, hybrid and product-oriented layout with increased workers weresimulated. The results supported hybrid layout arrangement compare to current layout and Product layout with increased workers.

The footwear company is planning to shift its manufacturing facility to a new location. This new layout could help the industry to increase its productivity by controlling the work in process inventory. The same tool could be applied to other design's production line as well to develop an overall optimize system of manufacturing.

References:

Abraham, A., Krömer, P., & Snášel, V. (2015). Afro-European Conference for Industrial Advancement: Proceedings of the First International Afro-European Conference for Industrial Advancement AECIA 2014. *Advances in Intelligent Systems and Computing*, *334*, 283–284. https://doi.org/10.1007/978-3-319-13572-4

Barnwal, S., & Dharmadhikari, P. (2016). Optimization of Plant Layout Using SLP. *International Journal of Innovative Research in Science, Engineering and Technology*, 3008–3015. https://doi.org/10.15680/IJIRSET.2016.0503046

Blaga, F., Stanăşel, I., Hule, V., & Pop, A. (2017). Balancing the manufacturing lines through modelling and simulation using Tecnomatix Plant Simulation. *MATEC Web of Conferences*, *112*, 1–7. https://doi.org/10.1051/matecconf/201711206012

Fedorko, G., & Vasil, M. (2018). *Application of the Tecnomatix Plant Simulation Program to Modelling the Handling of Ocean Containers using the AGV System*. 230–236. https://doi.org/10.17818/NM/2018/4SI.12

Feng, Y., & Gao, G. (2019). Design and simulation study on logistics planning in automatic plant factory based on tecnomatix plant simulation. *2019 2nd World Conference on Mechanical Engineering and Intelligent Manufacturing, WCMEIM 2019*, 667–671. https://doi.org/10.1109/WCMEIM48965.2019.00141

Gosavi, A., Cudney, E. A., Murray, S. L., & Masek, C. M. (2016). Analysis of Clinic Layouts and Patient-Centered Procedural Innovations Using Discrete-Event Simulation. *Engineering Management Journal*, *Volume 28*(3). https://doi.org/https://doi.org/10.1080/10429247.2016.1195664

Hassan, M. M., Kalamraju, S. P., Dangeti, S., Pudipeddi, S., & Williams, E. J. (2019). Simulation improves efficiency and quality in shoe manufacturing. *31st European Modeling and Simulation Symposium, EMSS 2019*, 231–236. https://doi.org/10.46354/i3m.2019.emss.33

Izadinia, N., & Eshghi, K. (2016). A robust mathematical model and ACO solution for multi-floor discrete layout problem with uncertain locations and demands. *Computers and Industrial Engineering*, *96*, 237–248. https://doi.org/10.1016/j.cie.2016.02.026

Jaffery, V., Mohamed, N. M. Z. N., & Rose, A. N. M. (2017). *Improvement of productivity in low volume production industry layout by using witness simulation software*. https://doi.org/10.1088/1757-899X/257/1/012030

Kikolski, M. (2016). Identification of production bottlenecks with the use of Plant Simulation software. *Ekonomia i Zarządzanie*, *8*(4). https://doi.org/10.1515/emj-2016-0038

Kliment, M., Radko, P., & Janek, J. (2014). Analysis of the Production Process in the Selected Company and Proposal a Possible Model Optimization Through PLM Software Module Tecnomatix Plant Simulation. *Procedia Engineering*, *96*, 221–226. https://doi.org/https://doi.org/10.1016/j.proeng.2014.12.147

Kovács, G. (2020). Combination of Lean value-oriented conception and facility layout design for even more significant efficiency improvement and cost reduction. *International Journal of Production Research*, *58*(10), 2916–2936. https://doi.org/https://doi.org/10.1080/00207543.2020.1712490

Laosiritaworn, W., Pinchai, N., & Jarupuncharadsri, P. (2020). Job Shop Layout Improvement with Simulation Technique : A Case of Metal Sheet Production Job Shop Layout Improvement with Simulation Technique : A Case of Metal Sheet Production. *2020 4th International Conference on Manufacturing Technologies (ICMT)*, 012023. https://doi.org/10.1088/1757-899X/842/1/012023

Lee, K., Shin, J. G., & Ryu, C. (2010). Development of simulation-based production execution system in a shipyard: a case study for a panel block assembly shop. *Production Planning & Control*, *20*(8), 750–768. https://doi.org/https://doi.org/10.1080/09537280903164128

Nadiah, T. S. F. (2007). *Design Of An Improved Production Layout For A Shoe Making Factory: A Case Study Of A Company*. https://www.semanticscholar.org/paper/Design-Of-An-Improved-Production-Layout-For-A-Shoe-Nadiah/76213d27650c603d7b855565f31d714379ca0c30

Naranje, V., Reddy, P. V., & Sharma, B. K. (2019). Optimization of Factory Layout Design Using Simulation Tool. *2019 IEEE 6th International Conference on Industrial Engineering and Applications (ICIEA)*, 193–197. https://doi.org/10.1109/IEA.2019.8715162

Petrila, S., Brabie, G., & Chirita, B. (2016). The use of Tecnomatix software to simulate the manufacturing flows in an industrial enterprise producing hydrostatic components. *IOP Conference Series: Materials Science and Engineering*, *145*(4). https://doi.org/10.1088/1757-899X/145/4/042032

Rafiq, U. (2016). Analysis of Major Factors Impacting the Footwear Export of Pakistan. *Journal of Management and Research*, *3*(2). https://doi.org/https://doi.org/10.29145/jmr/32/0302004

Russkikh, P. A., & Kapulin, D. V. (2020). Simulation modeling for optimal production planning using Tecnomatix software. *Journal of Physics: Conference Series*, *1661*(1), 012188. https://doi.org/10.1088/1742-6596/1661/1/012188

Septiani, W., Divia, G. A., & Adisuwiryo, S. (2020). Warehouse Layout Designing of Cable Manufacturing Company using Dedicated Storage and Simulation Promodel. *IOP Conference Series: Materials Science and Engineering*, *847*(1). https://doi.org/10.1088/1757-899X/847/1/012054

Shahbandeh, M. (2020). Leading 10 footwear producers worldwide from 2013 to 2019, by country. In *Statista*. https://www.statista.com/statistics/227256/leading-10-global-footwear-producers-by-country/

Siderska, J. (2016). Application of Tecnomatix Plant Simulation for Modeling Production and Logistics Processes. *Business, Management and Education*, *14*(1), 64–73. https://doi.org/10.3846/bme.2016.316

Sobrino, D. R. D., Ružarovský, R., Holubek, R., & Velíšek, K. (2019). Into the early steps of Virtual Commissioning in Tecnomatix Plant Simulation using S7-PLCSIM Advanced and STEP 7 TIA Portal. *MATEC Web of Conferences*, *299*, 2005. https://doi.org/10.1051/matecconf/201929902005

Suhardi, B., Eldiana, J., & Rahmaniyah, A. D. (2019). Facility layout improvement in sewing department with Systematic Layout planning and ergonomics approach. *Cogent Engineering*, *Volume 6*(Issue 1). https://doi.org/https://doi.org/10.1080/23311916.2019.1597412

The Pakistan Business Council (PBC). (2019). Enhancing the Competitiveness of Pakistan's Footwear Industry - Make-in-Pakistan Series. In *The Pakistan Business Council*. https://www.pbc.org.pk/research/enhancing-the-competitiveness-of-pakistans-footwear-industry/

Zhang, Z., Wang, X., Wang, X., Cui, F., & Cheng, H. (2019). A simulation-based approach for plant layout design and production planning. *Journal of Ambient Intelligence and Humanized Computing*, *10*(3). https://doi.org/https://doi.org/10.1007/s12652-018-0687-5