Proceedings of the 10th Annual World Conference of the
Society for Industrial and Systems Engineering,
2021 SISE Virtual Conference
September 23-24, 2021

Development of a Mixed Model Conveyor System Using a Simulation Based Lean Six-Sigma Approach for Assembly of Servers

R. Rout[1], S. Patra[1], S. Mashaareh[1], D. L. Santos[1], C. M. Greene[1], G. Pandiarajan[2], and K. Srihari[1]

[1]Watson Institute for Systems Excellence,
Binghamton University-State University of New York
Binghamton, New York, USA

[2]SMART Modular Technologies,
Newark, California, USA

Corresponding author's Email: rrout1@binghamton.edu

Author Note: Raghabendra Rout, Swagatika Patra, and Samaher Mashaareh are all Graduate Research Project Associates with the Watson Institute for Systems Excellence (WISE), Binghamton University and are all currently pursuing Ph.D. degrees in Industrial Systems and Engineering. Dr. Daryl Santos is a Distinguished Service Professor in the Department of Systems Science and Industrial Engineering (SSIE), Binghamton University. Dr. Christopher Greene is an Assistant Professor in the SSIE Department, Binghamton University. Dr. Krishnaswami "Hari" Srihari is a Distinguished Professor and Dean of the Thomas J. Watson College of Engineering and Applied Science, Binghamton University. Dr. Ganesh Pandiarajan is Senior Staff NPI Engineering Manager at SMART Modular Technologies, California.

Abstract: A material handling system is an integral part of any manufacturing and assembly facility and aids in enhancing the productivity of the enterprise. In a semiconductor manufacturing company, offering high performance computing solutions with customized built-to-order server assemblies and special hardware requirements is challenging. It is particularly challenging to integrate continuous improvement with productivity and enhanced throughput with growing demand and high-volume assembly needs, specific to the customer requirements. This work focused on performing a simulation-based approach to compare a, primarily, manual server assembly process with an automated conveyor line setup for the same process with a goal of maximizing productivity. A comparative simulation study has been performed by taking into account two different conveyor line setups, i.e., a single line conveyor setup versus a two line customized conveyor setup. The results of the study aided in providing a pathway to understand the productivity of the manufacturing system by integrating different setups for material handling to support product mix parts for server assembly. A lean six-sigma approach was used to identify and eliminate the wastes that affects the productivity of the process. The results showed that the use of two conveyor lines with customized setup increased the throughput of the system twice as much as the manual assembly line. In other words, the proposed model, with two conveyor lines along with one customized conveyor line for supporting customized build, increased the throughput under different inter-arrival times and replication lengths as simulated during a peak mass production schedule.

Keywords: Conveyor System, Data Server Assembly, Simulation Study, SIMIO, Throughput

1. Introduction

Material handling systems have become an integral part of manufacturing units in many industries and they play a significant role in enhancing the productivity of the company. The deployment of material handling systems in a manufacturing plant is quintessential to achieve continuous improvement goals and overall productivity of the company (Gunal, Williams, & Sadakane, 1996). In order to gain a competitive advantage in the computing assembly industry, it is vital to have an agile manufacturing system to assemble high performance computing clusters (or supercomputers). This agility enhances the productivity as well as product delivery to the customer in the shortest possible time to meet the demands (Garcia, Zuniga, Bruch, Moris, & Syberfeldt, 2018).

Supercomputers consist of a large network of servers to communicate and execute the computations. The server assembly process involves a large variety of components that are assembled onto the server based on different configurations and customer requirements (Ramakrishnan, Tsai, Drayer, & Srihari, 2008). An efficient assembly process is important for assembling servers per customer configuration requirements, and expectations within the targeted time of delivery (Uilgen & Upendram, 1995). In this paper, the simulation based approach is studied in a manufacturing facility delivering high performance customized data server solutions to its customers. The current assembly process involves manual handling of parts and different products for assembling the servers. The process has its limitations owing to several inefficiencies due to the presence of non-value added activities such as unnecessary motion, longer cycle time, excess inventory and excess transportation (George, 2002). The purpose of the modelling and simulation based approach has been adopted in this study to simulate a proposed scenario using an automated conveyor line system to reduce the operator's fatigue, avoiding the risk of damaging the server parts, in order to perform server assembly within an allocated time schedule. Simulation studies have been used many times in the past in the electronics assembly domain, see Santos et al. (1997) as one example, to aid in justifying proposed systems without disrupting business as usual.

Productivity in the case of a server assembly manufacturing line primarily refers to the number of server chassis assembled and sent into the racking unit per unit time with the resources available. In order to achieve this goal of meeting the customer specific requirements, continuous efforts are met to improve the assembly line. It is observed that the material handling systems play a critical role when it comes to handle complex products. Owing to the complex design of the products, efficient handling becomes more important to avoid potential defects and damage to the products.

2. Problem Description

The server assembly process in the facility is a manual process which may create pathways for product damage and unnecessary movement during the assembly process, not to mention operator fatigue during lifting and assembly process of the server chassis. This results in decreasing the throughput of the assembly system. Thus, taking into consideration the above-mentioned bottlenecks in the manual assembly process, a single conveyor line setup was considered to be deployed to contribute towards a better and efficient method of material handling system. The simulation study also takes into account the single conveyor line setup with the use of a crane with grips for loading of the parts to maximize productivity of the assembly process thus minimizing the bottlenecks, and avoiding operator fatigue concerns.

3. Methodology

The system studied for the simulation study was done for a manufacturing assembly factory for assembling different server components to a server chassis that form a cluster racking system to offer high speed computing services. The objective of the simulation study focused on optimizing the following factors as a part of key performance measures:

1. Number of conveyor lines;
2. Number of workstations;
3. Waiting time in the system; and
4. Throughput of the system, i.e., total number of servers assembled.

The outcomes of this simulation study resulted in deciding and making a recommendation regarding redesigning the conveyor system. The input parameters to be taken into consideration include assembly operation time (processing time) and inter-arrival time of the server chassis.

Assumptions considered for the simulation model generation are the following:

1. The server chassis are moving into a conveyor line through 3 stations with probability of 1;
2. The server chassis are following the FIFO rule at each station on the conveyor line;
3. The path lengths are independent and are of 10 meters in length;
4. Initial buffer capacity is infinite from source;
5. The workstations are running in full condition without any breakdown or maintenance need during simulation analysis;
6. The workstations are independent and not related to get influenced by any other natural cause or physiological effects.
7. The processing time follows a triangular distribution;
8. The inter-arrival time follows an exponential distribution;
9. When proposing two conveyor lines, the server chassis are moving to either of the two conveyor lines with probability of 0.5;
10. Similar assembly operations are carried out at conveyor 1_server 1 and conveyor 2_server 1 (two line conveyor model); and

11. One operational shift of 8 hours is implemented to run the model.

The phases of the simulation study are described in Figure 1.

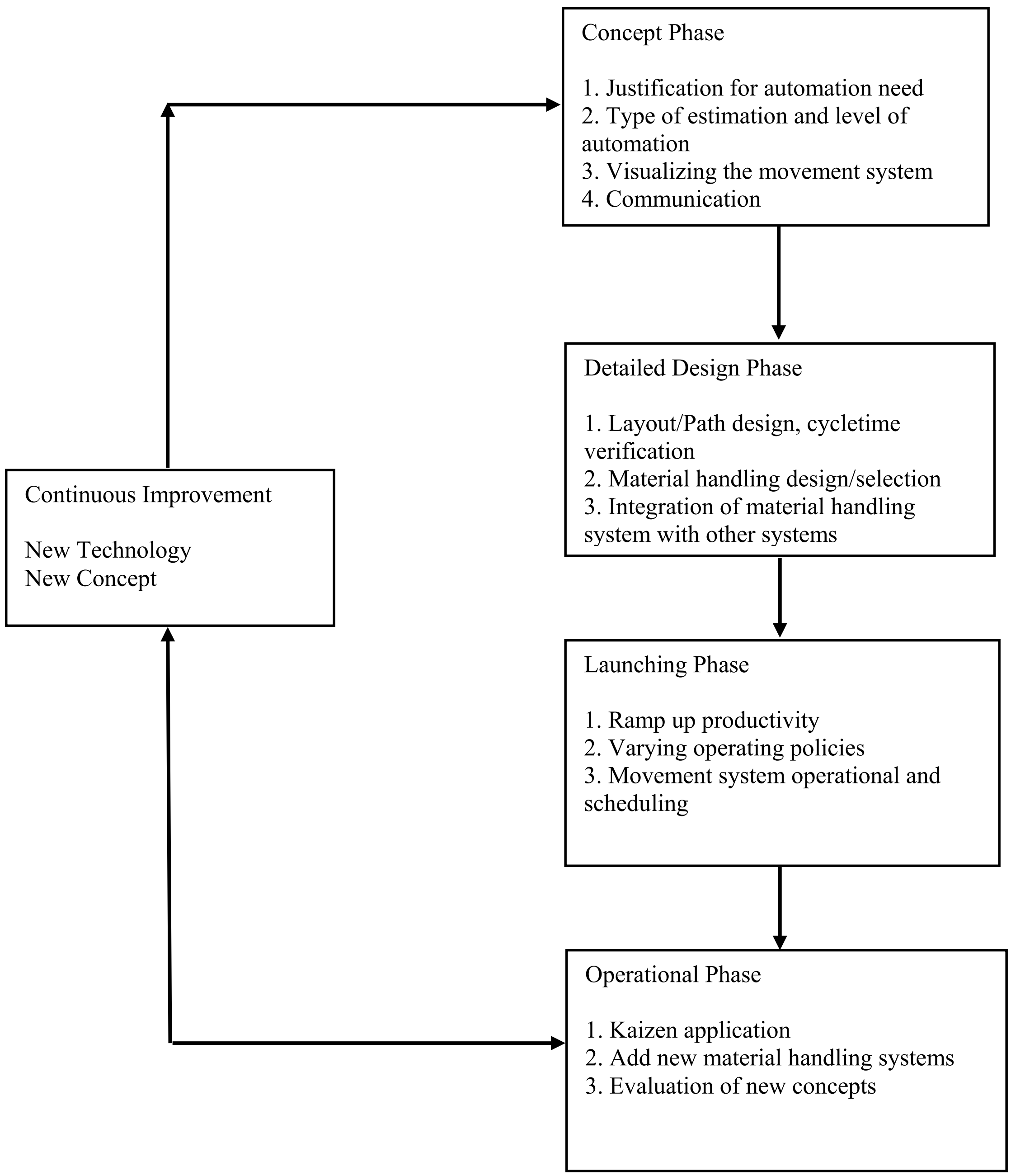

Figure 1. Different Phases of Simulation Study

The elements used in this study are as follows:
1. Model entity name: Server_Chassis;
2. Source name: Source;
3. Server name: Station; and
4. Sink name: Sink.

The study focuses on comparison of two simulation systems. Each system comprised of multiple server and one sink. The servers in the proposed system were designated by the respective counting numbers. i.e., Station 1, Station 2 and Station 3 etc.

4. Simulation Study

The simulation study was performed using SIMIO software to evaluate both conveyor line setups, i.e., a single line conveyor setup and a two-line customized conveyor setup.

4.1 Model with Single Conveyor Line

The current model at the manufacturing unit uses a single conveyor assembly line for assembling of the parts on the server chassis. The 3D view of single conveyor assembly line is shown in Figure 2. There were two processing stations in the conveyor line, i.e., Station 1 and Station 2 and a final quality inspection station. The parameters of each station in simulation model are described briefly in Table 1, and a definition of activities in each station are as follows:

1. Station 1: Installation of motherboard, PCIe cards and hard drives;
2. Station 2: Installation of CPU, heatsink and memory modules; and
3. Final QC: Inspection of the assembled parts at Station 1 and Station 2.

The simulated model of the current single line conveyor system had the following characteristics:
1. Duration of the model run: 8 hours; and
2. Inter-arrival time: 15 minutes (Scenario1) and 20 minutes (Scenario 2).

Table 1. Details of Each Station in the Simulation Model

Elements in system	Distribution followed	Parameters selection
1. Source (Server_Chassis)	Exponential	Scenario 1: μ = 0.06 (15 minutes) Scenario 2: μ = 0.05 (20 minutes)
2. Station 1	Triangular	(8.9,10)
3. Station 2	Triangular	(9,11,12)
4. Final QC	Triangular	(10,12,13)
All the units of time are in minutes.		

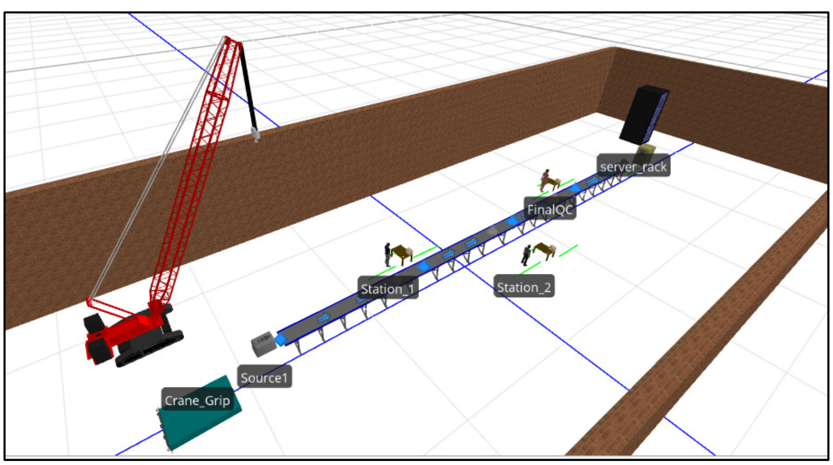

Figure 2. 3D View of Single Line Conveyor System

Although the single line conveyor system was created to overcome the demerits of the manual process, it was observed that the throughput was reduced during high volume production scenario. The reason for the reduced productivity in the single line conveyor system was due to increase in idle or waiting time of parts for assembly as compared to manual process, thus resulting in longer lead time. Hence, in order to address the productivity challenges in case of single line conveyor system, a new conveyor model was proposed and evaluated.

The new setup of the conveyor line was intended to serve as an alternative to single line conveyor setup with increased throughput. The new setup also takes into consideration the assembly of customized box build products during mass production.

4.2 Alternatives

Some of the alternatives that can be considered to be implemented in the future models can be:

1. Apply the concept of group technology in the sequence of assembly operation to optimize the material handling of the parts: application of group technology concept to the conveyor lines would help avoid identical operation at workstations on conveyor lines;
2. Implementing a new conveyor line with more work stations; and
3. Introducing a separate conveyor line to support customized new product introduction builds during peak mass production time.

In order to address the throughput issues during mass production of the server assembly, addition of a second conveyor line was proposed with new workstations. The 3D view of proposed simulation model is represented in Figure 3.

The model incorporates the following assumptions:

1. The server chassis after being loaded at the source is distributed to conveyor 1 and 2 with a probability of 0.5;
2. Both the conveyor lines have equal number of workstation with each of the respective stations performing similar assembly operations, i.e., Station 1 (Conveyor 1) and Station 2 (Conveyor 2) perform same set of assembly operations. Similarly, Station 4 (Conveyor 1) and Station 8 (Conveyor 2) perform similar assembly operations; and
3. The inter- arrival time for the third conveyor is 40 minutes.

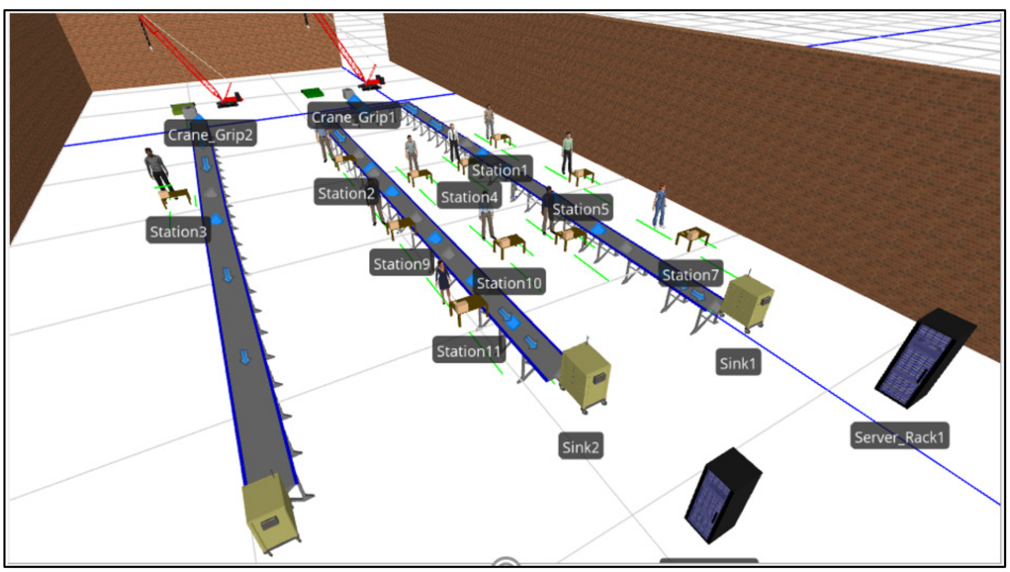

Figure 3. 3D View of Proposed Model (Two Conveyor Lines From One Source and One Extra Conveyor Line for Server Assembly)

5. Results and Output Analysis

The results of the simulation study of a single conveyor line setup and the double conveyor are shown in Table 2 and Table 3, respectively. It is observed that the new setup has throughput doubled (78 units) as compared to the throughput of the single conveyer model (39 units). For the current model, the total time in system is 252.04 minutes whereas for the proposed model, the total time in system is 245.92 minutes. It was observed the throughput of the system was doubled and overall waiting time in the system was reduced after addition of a second conveyor setup with more workstations. Moreover, the use of the third conveyor line facilitated to support the new product introduction builds which are designated customized builds with an inter-arrival time of 40 minutes.

5.1 Sensitivity Analysis

There are two cases considered in a sensitivity analysis that was conducted.

Case 1: Considers two scenarios for inter-arrival times as 15 minutes and 20 minutes in both the current model as well as the proposed model. Table 2 and Table 3 explain the total time in system, throughput, and details of other station waiting times for both inter-arrival time conditions.

Table 2. Current Model with Two Scenarios for Inter-Arrival Times

Current model (Single conveyor line for server assembly)		
Responses	**Scenario 1 (15 minutes)**	**Scenario 2 (20 minutes)**
Totaltimeinsystem	252.04	252.20
Throughput	39	39
Station1Waitingtime	236.49	236.12
Station2Waitingtime	35.69	36.45
FinalQCWaitingtime	20.30	19.38
All values are in minutes except throughput in numbers		

Table 3. Proposed Model with Two Scenarios for Inter-Arrival Times

Proposed model (Two conveyor lines from one source and one extra conveyor line for server assembly to support demand)		
Responses	**Scenario 1 (15 minutes)**	**Scenario 2 (20 minutes)**
Totaltimeinsystem	245.92	250.19
Throughput1	39	39
Throughput2	39	39
Throughput3	15	15
Station1	230.61	232.58
Station2	230.76	233.13
Station3	231.82	231.38
Station4	2.77	3.24
Station5	44.12	44.17
Station6	2.87	2.70
Station7 (Final QC)	128.80	128.79
Station8	3.14	2.97
Station9	45.04	44.20
Station10	2.91	2.29
Station11(Final QC)	128.85	128.33
Totaltimeincustombuild	4.12	4.11
All values are in minutes except throughput in numbers		

Case 2: Considers five scenarios with replication lengths as 10, 20, 40, 50 and 100 in both the current model as well as the proposed model. Table 4 and Table 5 explain the total time in system, throughput, and details of other station waiting times in terms of different replication lengths for both models.

Table 4. Current Model with Five Scenarios for Different Replication Lengths

Responses	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
	Replication length =10	**Replication length = 20**	**Replication length = 40**	**Replication length = 50**	**Replication length = 100**
Total time in system	251.40	251.77	252.10	252.01	251.97
Throughput	39	39	39	39	39
Station1Waitingtime	236.00	235.95	236.03	235.90	235.99
Station2Waitingtime	35.40	36.76	36.95	37.15	36.78
Final QC Waiting time	20.29	20.51	19.88	19.56	19.48
All values are in minutes except throughput in numbers					

Table 5. Proposed Model with Five Scenarios for Different Replication Lengths

Proposed model (Two conveyor lines from one source and one extra conveyor line for server assembly to support demand)					
Responses	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
	Replication length =10	**Replication length = 20**	**Replication length = 40**	**Replication length = 50**	**Replication length = 100**
Totaltimeinsystem	249.62	249.60	249.55	249.37	249.74
Throughput1	39	39	39	39	39
Throughput2	39	39	39	39	39
Throughput3	15	15	15	15	15
Station1	230.21	230.25	230.73	230.73	230.96
Station2	231.16	231.37	231.25	231.28	231.24
Station3	229.73	230.86	231.00	232.07	231.54
Station4	3.06	2.97	3.25	3.31	3.01
Station5	43.57	44.36	44.03	43.93	43.77
Station6	2.41	2.10	2.80	2.81	2.67
Station7 (Final QC)	128.78	128.41	128.36	128.23	128.68
Station8	2.03	2.36	2.58	2.79	2.85
Station9	44.48	44.25	44.46	44.13	44.29
Station10	2.11	2.42	2.35	2.52	2.49
Station11 (Final QC)	128.88	128.74	128.72	128.59	128.76
Total time in custom build	4.08	4.10	4.10	4.12	4.11
All values are in minutes except throughput in numbers					

5.2 Verification and Validation of the Model

The model was designed using the ‘depth first’ modeling approach where each section of the model was individually built and tested for any programming logic errors. For verification purposes, pilot runs of the model were conducted to see if the various entities followed the desired paths based on the observed probabilities. For validation purpose, different output measures like throughput and total processing times were compared with real world scenarios and the results were found to be in accordance with actual results. Figure 4 and 5 show the throughput and total time in system for the different process types.

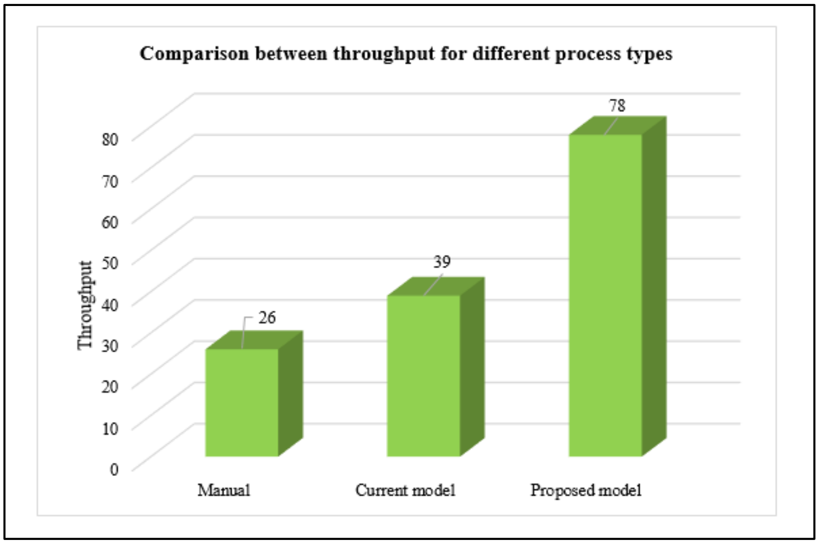

Figure 4. Comparison of Throughput for Different Process Types

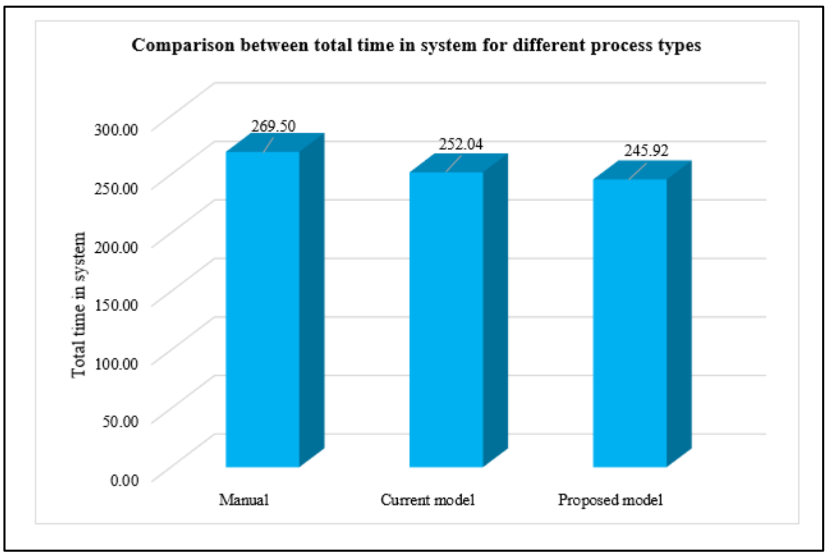

Figure 5. Comparison of Total Time in System for Different Process Types

6. Conclusion

Conducting the simulation runs under different inter-arrival times and replication length, it was observed that the proposed model with two conveyor lines along with one customized conveyor line for supporting customized build during peak mass production schedule increased the throughput. The main goal of this study is to facilitate efficient material handling of the parts using conveyor system to reduce operators' fatigue and avoid any damage to the parts during handling process with the use of crane. Further studies should be done to implement the group technology concept for grouping similar operational activities at the stations as this can also help to optimize the process in order to get better throughput with available resources.

7. References

Garcia, E. F., Zuniga, E. R., Bruch, J., Moris, M. U., & Syberfeldt, A. (2018). Simulation-based Optimization for Facility Layout Design in Conditions of High Uncertainty. *51st CIRP Conference on Manufacturing Systems* (pp. 334 - 339). Stockholm, Sweden: Elsevier.

George, M. (2002). *Lean Six Sigma: Combining Six Sigma Quality with Lean Speed.* McGraw-Hill.

Gunal, A., Williams, E., & Sadakane, S. (1996). Modeling of chain conveyors and their equipment interfaces. *28th Conference on Winter Simulation*, (pp. 1107 - 1114). California, USA.

Ramakrishnan, S., Tsai, P.-F., Drayer, C., & Srihari, K. (2008). Using Simulation with Design For Six Sigma in a Server Manufacturing Environment. *Proccedings of 2008 Winter Simulation Conference*, (pp. 1904-1912).

Uilgen, O., & Upendram, S. (1995). The Role of Simulation in Design of Material Handling Systems. *AUTOFACT Conference Proceedings*, (pp. 259 - 273). Chicago, USA.