Application of Simulation in Warehouse Management

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Abstract

Simulation is becoming a need for the industries nowadays as the businesses are required to take critical decisions frequently. Simulation has various applications in many areas. The current research focuses on simulating the warehouse situation. A simulation model of the warehouse is built by using Witness 2021 simulation software. The model is also validated by comparing it to a real-life situation. After running the model for a certain time, the statistics have been collected for the model. This will help to understand the existing situation for the warehouse. Then the efforts are made to reduce the queues. For that what-if- scenarios are generated. Based on these scenarios, the experiments have been conducted in the Witness experimenter. The results for these experiments are then analyzed and the best results with alternative solutions are provided.

Keywords
Simulation, Warehouse, Warehouse management, Simulation application, Queue management.

1. Introduction
The fourth industrial revolution brought the modern technology into the manufacturing. It integrates various modern technologies which include internet of things, cloud technology, artificial intelligence and machine learning into manufacturing. Industry 4.0 represents a new industrial stage of the manufacturing systems by integrating a set of emerging and convergent technologies that add value to the whole product lifecycle (Dalenogare et al. 2018).
Industry 4.0 has nine technological pillars one of these pillars which are internet of things, augmented reality, simulation, additive manufacturing, system integration, cloud computing, autonomous systems, cybersecurity and big data analysis.

Simulation is one of the most important pillars of the industry 4.0 as it is the only one pillar which deals with the future analysis of the process. Simulation can reduce the cycle times and it can lead to less failures in the start-up phase of production (Simons et al. 2017).Schuhet al. (2014) mentioned that it will be easy and efficient to take decisions and the quality of decisions can be significantly improved by easy and quickly with simulations.
Simulation gives a single point solution to the digital manufacturing. This is because of the multi utility nature of the simulation software which not only allow users to develop the model but also let them experiment with them and validate (Mourtziset al. 2014).

This study deals with the process of simulation by using the DES simulation tool Witness 24 developed by the Lanner group based in UK. Witness is a process modelling and simulation software. Currently witness is used in many industries within different sectors. Witness allows users to build the digital model of the business which can be simulated for any period, and it helps users to analyze the model by generating various reports in the witness.
Witness is very useful for solving real-life problems. In this paper, similar application of Witness in reducing the queue lengths is carried out.

1.1 Case study: Neovia warehouse

Neovia is a third-party logistics company has 100 facilities in more than 20 countries. Their warehouse facility in Thailand operates in the following way,

1. The material is unloaded on the unloading dock with the trucks and sent to the import packaging.
2. At packaging section, the units are packed and sent to the storage via carriers.
3. Whenever the facility receives the order, the units are picked from the warehouse by the carriers and are sent to the export packing area.
4. After packing the material is sent for loading on trucks at loading dock from where it is shipped.

According to the data and observations the queues are getting generated before and after the packing machine. The average queues which are getting generated are 62 units before the packing machine and 220 units after the packing machine. Which are resulting in the reducing the accessibility to various areas in the facility.
Along with that, further problems are encountered.
Improper resource utilization – As the aisles are blocked the carriers cannot move.
Delays in material movement – Average WIP 3732.44 for 1 week.
Reduced throughput – 745 items are shipped in 1 week.

1.2 Objectives

- To build a simulation model.
- To calculate the capacity of existing resources.
- To find the different scenarios which affects the queue lengths.
- To find out the optimum values for parameters for minimum queue length.

2. Literature Review

As simulation is an upcoming trend in the industrial revolution, there are many case studies and research around it. Many of the case studies involve solving the industry problem similar such case studies which helped during this research are discussed further. Prajapat et al. (2016) explained how technological advancements in simulation helps production managers to optimize system performance. Discrete event simulation model was presented in Witness software to optimize the factory processes. Barrera-Diazetal (2018) presented the survey based on simulation projects undertaken in the automotive industry.

Michlowicz and Smolińska (2019) explained how simulation helped to improve the flow continuation in production process. A cell layout is created on Witness using flow diagram. Though this explains how model gives information about after certain time, but the only objective was to see the lead time for the production processes.
Sebestyénováand Kurdel (2019) explained about building model of plant, and they tried to optimize the model. They used two stages of optimization in the first stage they use the genetic algorithm but at the cost of ascending simulation time. In second stage they use the experiment manager to get optimum result. After both stages, they compare both results which explains the advantage of experimenter over the optimization using genetic algorithm.

The simulation tool used in this study is Witness. There are many case studies involving Witness simulation software. Mehtaand Rawles (1999) gave insights related to the use of witness software with the deployment of it in the business for better results. It explains different features and business application of witness with the use of modelling and internal consulting approach. Although the paper is very insightful, but it has limited information about practical application.
Shabayek and Yeung (2001) explained how the simulation has helped to organize the container port business by improving the total throughput. This paper lists complete process of making model considering parameters and possible sources of error in the model. This paper gives the relevant ideas about the creation, analysis, application, and usage of witness software.

Kambliet al. (2020) had elaborated the application of Witness simulation software in management of the queues produced in the dining operations. Though having 8 food stations the CDS (Campus Dining Service) still experiences a lot of queues because of the make-to-order food stations. Thus, the paper elaborates impact of capacity reallocation and queue management. The researchers used DMAIC methodology to build and analyse it on the digital model created by using the witness simulation software. Finally, the idea about various resources and their impact on the queues which are generated in the CDS are discussed.

Khakdaman et al. (2012) did a case study in health center by using Witness simulation software. The process of process mapping, data collection, building the model, verification and validation with different experiments and their results has been discussed in this case study. This case study also aims to reduce the long queue which is reduced by adding extra resources. This similar case study has helped in this process of designing this research.
Wu and Guo (2021) had studied the pedestrian flow through queues and attempted to reduce the same by using the witness simulation software. They have considered various other factors which affect these queues such as intersecting angles and repulsive forces. They also attempted to study the effect of moving obstacles on the movement of pedestrians.

3. Methods

Any study related to simulation project generally follow the steps stated below
1. Data collection.
2. Model building.
3. Report generation.
4. Experimenting with what if- scenarios
5. Results.

In this study, the data is collected from on-ground staff. According to the data, the model has been constructed. After the model completion, it has been run for 10000 min which is around 1 week after running the model the statistics reports have been generated. After collecting the reports, based on it, various scenarios have been created and analyzed and then results are presented.

3.1 Data collection

Data plays an essential role in building the model for any plant in witness. This data generally includes the plant layout, types of machines, machine times, flow charts, resources used, inflows, outflows.
The data regarding to the layout of the system was collected. based on which the flow process chart was created. Figure 1 shows the layout.
CAD - 2D diagram doesn't give the idea of the warehouse for that purpose the flow diagram was created with the description of the areas on it. Though the layout represented in Figure 1 can be helpful while designing the paths and networks in which the lengths to be specified.

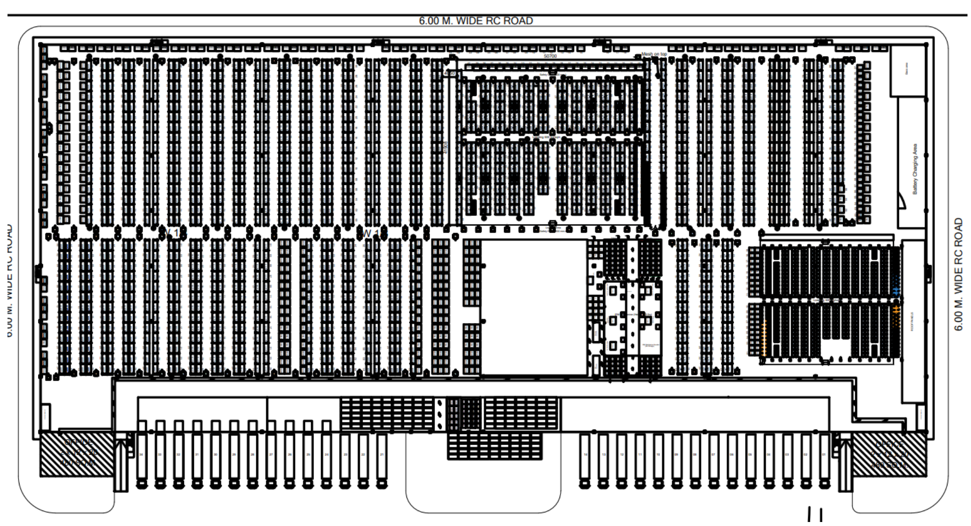

Figure 1. CAD-2D diagram of layout of warehouse

For better understanding of the processes the process flow diagram was created for the warehouse which is represented below in Figure 2.
In the flow process chart, the process flow in the warehouse is mapped. This contains how the units will enter the system, how will they move in the warehouse and how they exit the system.

The material which is unloaded on the inbound dock is sent for the packaging then it is stored then after storage the material is picked and sent to packing stations where is will be packed and sent for loading for outbound logistics. Also, the queues before and after the packing stations are represented by the orange colored ovels. These queues are primary focus.

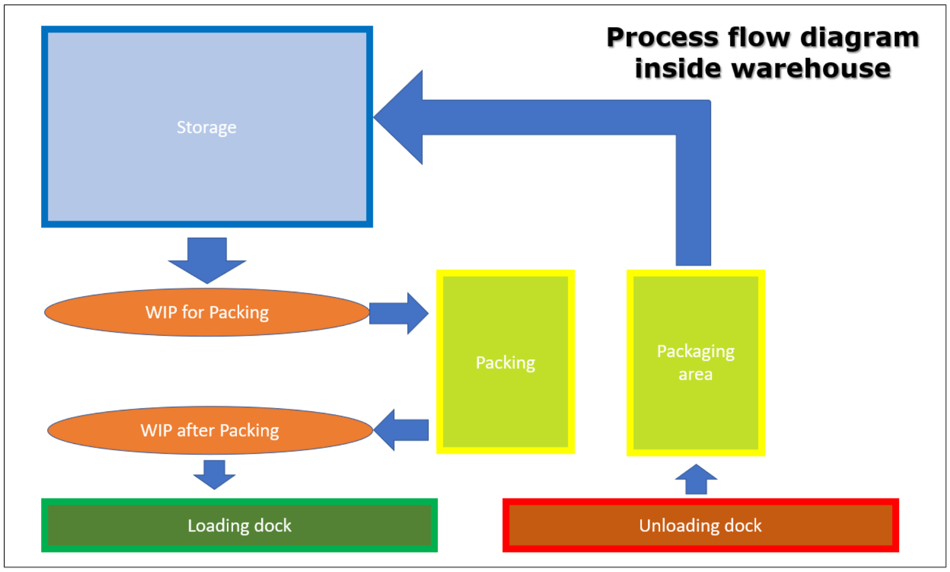

Figure 2. Process Flow Diagram

Along with the layout and process flow some specific data regarding the process was also collected which is mentioned in Table 1.

Table 1. Data collected regarding the processes

Type	**Parameters**	**Values**
Arrival		
1	Inter-arrival time	10 minutes
2	Lot size	25nos.
Distances		
1	Between Unload point to packing machine	10m
2	Between packaging station to storage	3 m
3	Between storage to packing	10.5 m
4	Between packing station to loading point	10 m
Material handling		
1	Number of carriers between unloading to packaging machine	5 nos.
2	Number of carriers between Packaging to storage	3 nos.
3	Number of carriers between storage to packing	2 nos.
4	Number of carriers between packing to loading	3 nos.

5	Capacity of carriers	5 units
Capacities		
1	Storage capacity	10000 units
Machine cycle times		
1	Unloading time from trucks	10 min
2	Packaging machine	1 min
3	Packing machine	1.58 min
4	Loading time	40 min
Machine quantity at station		
1	Packaging station	3 nos.
2	Packing station	3 nos.

4. Model building

After getting all the relevant data the model is generated. For building the model, the witness simulation software 2021 is used. As Kádár et al. (2004) mentioned that model building is cyclical and evolutionary process that is the first version of the model will be frequently changed to get the desired results. This model is in phases and here the final version of the model is discussed.
The designer elements panel in Witness contains the pre-created witness elements which can be used directly into the model. The elements in the witness are smart elements which can be detailed by double clicking on the element.
The types of elements which were used in this model are:
A. Machine elements: These are the digital representation of machines which process parts and send them to destination.
B. Track elements: These are the digital representation of the vehicle tracks on which vehicles (manual or automatic) run.
C. Vehicle elements: These represent the vehicles which transport parts from one location to other.
D. Buffer elements: These represent the queues.
E. Part element: These represent the entity which enters the model get processed and leaves.
Below is the screenshot of actual simulation model of the warehouse which is based on the process flow.

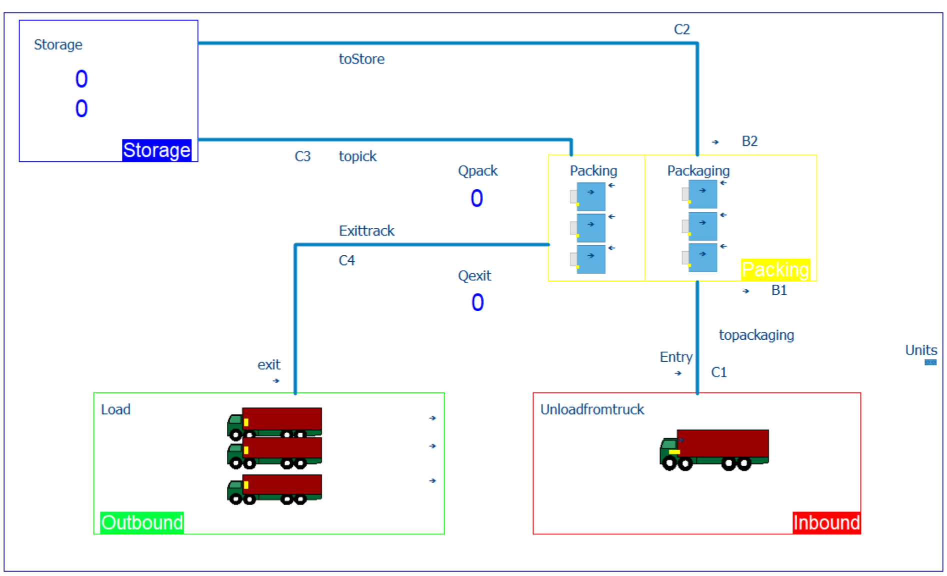

Figure 3. Screenshot of Witness model

The actual simulation model created for analysis is shown in Figure 3. The Units (Part element) is the boxes which are moving inside the warehouse. Entry, B1, B2, Storage, Qpack, Qexit and exit are the buffer elements which store the units. Unload from truck, Packaging, Packing, Load are the machine elements which process parts.C1, C2, C3, C4 are the carriers on tracks to packaging, to Store, to pick and Exit track respectively.

4.1 Model validation

Model validation is the process of validating model by comparing it to real-life situation and checking the results and if the variability will be less than the allowable percentage of error.
Sargent (2010) has mentioned the four major approaches for validating the simulation model. The first approach is simulation team members who develops the model will make the decision regarding the validation. The second approach involves the evaluation of model based of different test during the process of building the model. Third approach is to have external third party which studies the model and give the validation which is usually referenced by term "independent verification and validation (IV&V)". The fourth approach involve the scoring model by using which the model is validated.
This research uses the first approach where the decision regarding the validation is to be taken by the simulation team. For successful validation of the model accuracy of 95% and percentage of error to 5% is set for the current model.
The results of actual scenario and the model for 5 weeks are compared. The model will be run for a week for 5 times the output will be different sometime because of the inherent variability.

Table 2. Comparison for validation

Number	Total shipped unit (Model)	Actual shipped units (Real)	% Of variation
First week	745	776	3.995
Second week	745	738	0.95
Third week	746	750	0.533
Fourth week	745	780	4.49
Fifth week	744	746	0.27

Average percentage:
$(3.995 + 0.95 + 0.533 + 4.49 + 0.27) / 5 = 2.0476 < 5$
As the percentage of variation is less than 5, which signifies the model is valid.

4.2 Experimentation

For purpose of this study, the advanced experimenter is used check the effect of different parameters on the queue lengths. Various what if- scenarios are generated and then experimented for all feasible solutions and then the optimal solution is taken. Such as
What if the number processing stations were increased?
What if the process parameters were changed?
What if the number of carriers between stations were increased?
For each of these questions, the separate experiment has been conducted in Witness advanced experiment mode.

5. Results and Discussion

After conducting the experiments, the results for the queue lengths before and after the packing machines are studied for each of the scenarios in each experiment.

5.1 Numerical Results

Numerical results include the results which have been obtained by the running the model for 10000 minutes of model run time. The below table (Table 2) shows the statistics before conducting the experiments. In which, we can see the average parts in queues Qpack and Qexit as well as other statistics such as maximum parts for designing the layout are also mentioned. Average time a unit spend in the queue and the maximum time a unit spent in the queue is also mentioned.

Table 3. Result before conducting the experiment

Buffer name	Average parts in Queue	Maximum parts in queue	Average time in queue	Max time in queue
Qpack	34.039	69	17.887	35.765
Qexit	100.84	227	53.172	119.19

After conducting the first experiment where the number of machines is changed in between 3 to 10 with the step size of 1 as there are already 3 machines of each are already available. Table 4 shows the statistics for best combination of machines for reducing the queue length.

Table 4. Statistic after conducting experiment for various number of machines

Values	Parameter	Original value	After experiment	% Change
No. of packing machines – 5 No. of loading machines - 4	Average length	134.879	1.004	-99.26%
	Maximum	296	10	-96.62%
	Average Time	71.059	0.528	-99.25%
No. of packing machines – 3 No. of loading machines - 4	Average length	134.879	34.039	-74.76%
	Maximum	296	72	-75.67%
	Average Time	71.059	17.887	-74.82%

In Table 4 the values for average length, maximum length and average time are addition of both the buffers that isQpack and Qexit (i.e., Average length = Average length of Qpack + Average length of Qexit) as both are contributing to the queues and both should be reduced.

Table 3 shows the best possible result for the number of packing and loading machines for least number of units in the queue. Which is combination of 5 machines for packing and 4 machines for loading the table also shows the result of adding one extra loading machine which gives significant reduction of 74.76% in reduction of queues.

The second experiment is conducted by changing the parameters of the machine. In this experiment the processing times of the machine is varied. For packing machine, it has been changed from 1.58 to 2 minutes with step size of 0.1 minute and for loading machines it has changes in between 35 to 45 minutes for 25 units with step size of 1 minute the best statistics which are observed after the experiment are given in Table 4.

Table 5. Statistic after conducting experiment for various cycle times

Values	Parameter	Original value	After experiment	% Change
Packing station processing time – 1.58 min Loading station processing time – 39 min	Average length	134.879	34.039	-74.76%
	Maximum	296	72	-75.67%
	Average Time	71.059	17.887	-74.82%

The third experiment is conducted by varying the number of carriers between the storage and packing station from 2 to 10 with step size of 1 and between packing station to loading station from 2 to 10 with step size of 1. The statistics for the same have been listed in the table below (Table 5).

Table 6. Statistic after conducting experiment for various cycle times

Values	Parameter	Original value	After experiment	% Change
Carriers between storage and packing – 2 Carriers between packing and loading – 8	Average length	134.879	132.235	-1.96%
	Maximum	296	295	-0.33%
	Average Time	71.059	69.064	-2.80%

From the Table 6, it can be observed that, there is no significant difference in the reduction of the queue even by increasing the carriers.

5.2 Graphical Results

This section includes the graphical results for the experiments which were conducted in the previous section. It includes the bar charts which were drawn for the data which was obtained from the witness' experimenter software.

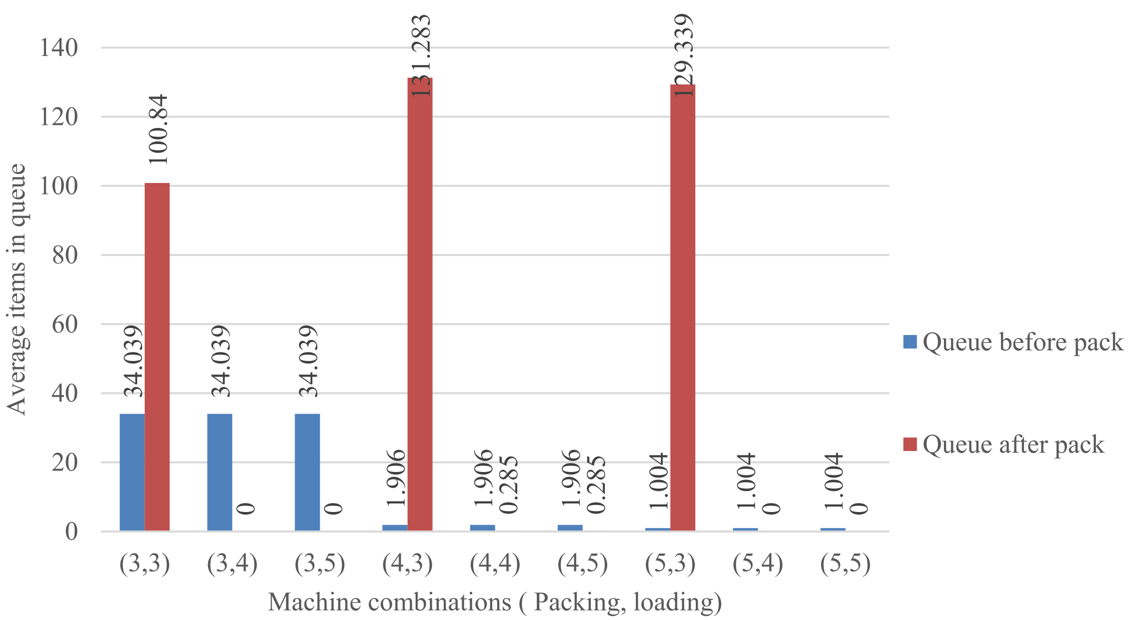

Figure 4. Result after experiment 1

In the graph above (Figure 4), all the possible combinations of the number of machines with their outcome are shown. It is to be noted that the graph shows the average number of items in both the queues that is in Qpack and Qexit separately as the table 3 which is representing the same result does not give all the combination and separate numbers. The red bars show the average items in Qexit and whereas the blue bars show items in Qpack.

Like Figure 4, Figure 5 represents the combinations of different cycle times and the outcome of the average number of parts in the queues.

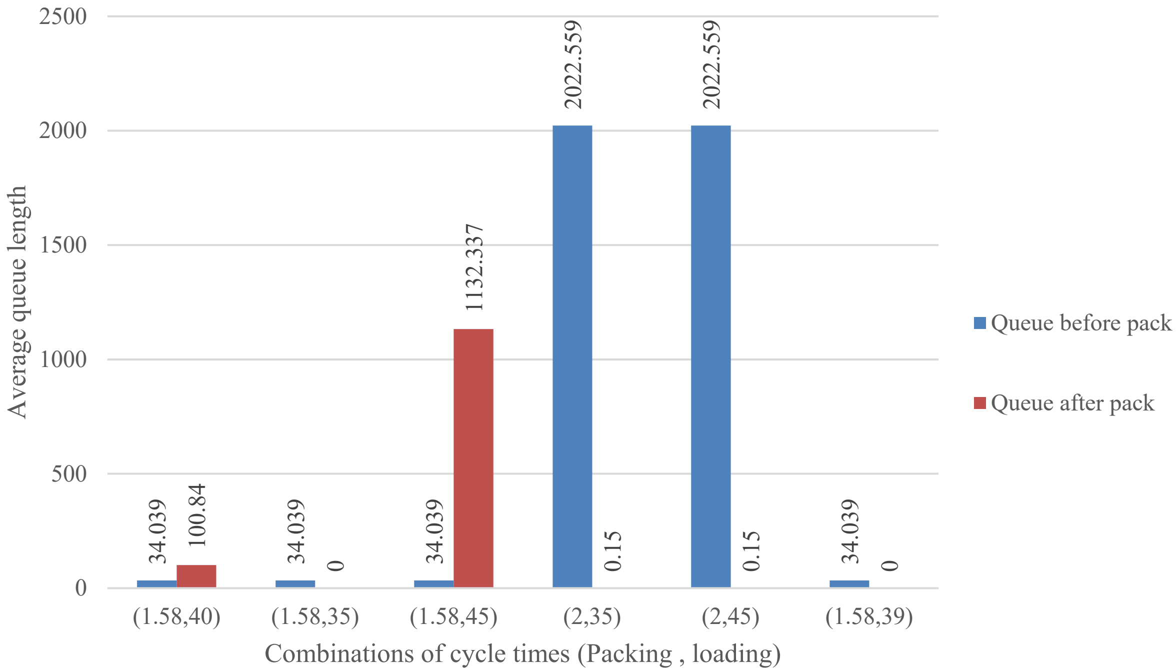

Figure 5. Results after Experiment 2

From the above graph, it can be observed that, even the reduction of 1 min of cycle time of loading machine results into no queue after the packing machine.

6. Conclusion

There are so many advantages of using simulation over doing the calculations manually or with the help of spreadsheet. If we consider it financially the cost of making the prototype of the system and experimenting through it will become rigorous and costly. Whereas the software will provide the exact details.

During this study, simulation has helped in the process of building the model also the experimenter feature of it has helped to optimize and analyse the processes which are being conducted inside the warehouse.

The reports which Witness provided has given us the capacity of our existing system and its utilization. Also, Witness provided the statistics report after adding the processing machines.

Witness also provided the visual interpretation of the processes in a single model which might not be possible as the machines and workstations are huge which helped in the external communication. Witness' visual interface also helped to communicate effectively with the people working at any level with ease irrespective of their knowledge about the witness software.

The dynamic chart inside the model helps to get the report at any specific time also it helps to get the day when the highest number of items were in the queue.

In the optimization process witness has helped to get the scenarios which were possible to analyse also it helped to understand the effect of various parameters on the length of queues. From which it can be understood that the machine number are the most important criteria to reduce queue, the cycle times can help to reduce queues significantly, but the parameters and number of carriers don't help much in reducing the length of the queue.

Finally, this model helps in making critical decisions considering the factors which affect the system. So, it can also be used as a decision-making tool.

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