

Study on implementation of one-piece lean line design using simulation techniques: A practical approach

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Abstract

This paper discusses the simulation study carried out for proposing one-piece lean line layout with features of Lean Manufacturing. The lean initiatives that can be addressed are, introducing Kanban replenishment system, better work-in-process, changing the layout, visual management techniques, standardized work for the reduction of cycle time, number of workers, number of setups. To improve the layout in a pump manufacturing industry, VISIO 2007 and Pro Model-Process Simulator Software are used. Pro Model simulation modeling software is a powerful yet easy-to-use simulation tools for modeling all types of systems and processes. Pro Model software is designed to model manufacturing systems ranging from small job shops and machining cells to large mass production, flexible manufacturing systems, and supply chain systems. The study has discussed the lacuna in the existing flow line and has suggested a new one-piece lean line design using the simulation software. The validation is carried out by creating the wooden prototypes representing the cells and involving the workers to do the assembly of the pump. Standard time study charts are used to calculate the cycle time and change over time.

Keywords: Simulation; Lean line design; Milk run

1. Introduction

The study discusses the implementation of lean line layout for the assembly of the pump with the features of Lean Manufacturing. The layout suggested was based on the Simulation study using PROMODEL software. PROMODEL's simulation modeling products are powerful yet easy-to-use simulation tools for modeling all types of systems and processes. PROMODEL software [8] is designed to model manufacturing systems ranging from small job shops and machining cells to large mass production, flexible manufacturing systems, and supply chain systems. PROMODEL integrates system definition and animation development into one process. While defining routing locations, conveyors, AGV paths, and other elements, the user essentially develops the animation layout.

The layout screen is a virtual screen that can be scaled to represent an actual factory layout. Hence, the study was carried out by using VISIO2007 and PROMODEL SIMULATOR software and a one Piece Lean Line flow design for the assembly of the Pump Unit is proposed. The Pump manufacturing unit is a pioneer industry and has already implemented the tools like KANBAN, Value Stream Mapping, POKAYOKE, 5 S House Keeping techniques in the process of Manufacture. But it had not used the simulation study for optimizing the line. Hence, the study concentrated on improving the Lean Line Design using the concept of simulation. The workers were already exposed to the lean thinking and for the effective utilization of Lean concepts.

Further, there is scope for carrying out the study using PROPLANNER, ARENA software. These

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softwares finds application to carry out studies on line balancing, value stream mapping. In this study, an attempt is made to carry out simulation study using PROMODEL software. The validation of the results is carried out by fabricating the wooden prototype models in the factory and the workers were asked to assemble the pump with the setup proposed. Cycle time, change over time was calculated. A sample withdrawal KANBAN, visual charts were prepared.

2. Objectives of the project

The objectives of the project are as follows:

- To observe the standard lean manufacturing tools used in the process of assembly.
- To study in detail the existing layout for the assembly of the pump
- To carry out survey of engineers, workers for optimizing the layout for the assembly of pump and to suggest alternate layout from lean perspective.
- To test and analyze the lean model with the help of data collected using questionnaires from line engineers, supervisor and workers involved.
- To suggest a modified layout and to simulate using VISIO 2007 and PROMODEL - PROCESS SIMULATOR software. Further it is proposed to carry out the fabrication of prototype model and test run the simulated results. Many trials are carried out to optimize the design in the shop floor for the full scale production.
- Finally, to take inputs from case study organizations for designing “*the new-model of lean manufacturing for success in Indian industries*”.

3. Literature review

According to Czarnecki and Loyd [5], manufacturing factory floor simulations are invaluable tools in the implementation of lean manufacturing. Many manufacturers will not make a change to the process before a simulation is performed to determine the impact of the change. Simulation can be considered as inexpensive insurance against costly mistakes.

Jain and Leong [7] discuss in their paper, simulation provides the capability to evaluate performance of a system operating under current or proposed configurations, policies and procedures.

Lian [8] in his doctoral research paper states, simulation models are the final products of atoms, database and model generator. By changing the data in the database, we can yield a simulation model that corresponds to the new data set without much effort. In this way, different scenarios of value stream mapping (VSM) can be transformed into simulation models in a short time and we can easily obtain feedback and implement improvements to the system after analyzing and comparing the outputs of simulation models. The more important features of the simulation model is that the job volumes, resource levels, performance targets, quality of service targets, etc. could be changed before running the model by a non-simulation expert. Diamond, et. al. [6] discuss identifying and specifying the role of simulation within the lean approach seems valuable and even necessary in expanding the simulation application base.

Manar [9] discusses the guidelines for the effective utilization of simulation tools in the industrial environment to improve productivity. Adams, et al. [1,2] gives an overview of how simulation could be used within the lean manufacturing strategy.

Carria and Carson [4] have discussed the role of simulation in manufacturing activities, discusses the advantages of simulation in solving critical problems in the manufacturing setups.

Altinkilic [3] in his paper on “Simulation-based layout planning of a production plant” discusses the parameters to be considered in carrying out layout design and the benefits gained in carrying out simulation analysis before implementing the actual set ups.

4. Problem definition

The company has got 6 assembly lines in plant 1 for ‘A’ pump. It has implemented an L layout in its assembly unit. The diversification has prompted the industry to implement 1 new layout for the assembly of the pump. Further, no simulation technique was implemented by the organization to validate the proposed layout and to identify the problems faced in the existing layout.

5. Methodology

The methodology for the implementation of Lean Line Design is as follows:

- Data regarding number of activities required and the number of calibration benches is collected mathematically and the logic is based on the number of workers available, space constraint factor, number of pumps to be manufactured.
- Standard time study charts are prepared for collecting cycle time; change over time of the process.
- AUTOCAD 2006 is used to draw the layout plan for the assembly of pump.
- VISIO 2007 software is used to create a model to be simulated using PROMODEL SIMULATOR.
- Pro Model Process Simulator software is used to carry out the simulation study for different runs and to optimize the layout design.
- Prototypes are fabricated according to the layout and carried out test run to validate the simulated results.
- Making modifications based on the feedback information collected from the workers who are involved in the process of assembly of the pumps.

6. Application of lean implementation model

Data regarding number of activities required and the number of calibration benches is collected mathematically and logic is applied. The logic is based on the number of workers available, space constraint factor, number of pumps to be manufactured.

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6.1. Study of the existing layout

The study of the current layout is carried out as follows:

- The company is carrying out the assembly of pumps in 6 lines.
- The number of pumps to be assembled in the existing layout is 2000 per day.
- The number of hours of working is fixed as 20 hours per day.
- Total number of pumps to be assembled is 100 per hour.
- Bottlenecks were observed due to the L layout in the organization. (The assembly of PE standard in-line fuel pumps, distributor fuel injection pumps, axial piston distributor pumps, radial-piston distributors pumps are being carried out in 6 assembly lines.)
- The area occupied by the 1st assembly line unit is around 72 Sq m.
- The current layout existing for the assembly of the pump is shown in Figure 1.

After the study of the layout, it was decided to change the L layout to U layout. This layout design can improve the movement of the materials effectively. It was also observed that the Milk run concept can be easily adopted. Milk run concept works on the principle of replenishing the raw material, finished goods in a planned manner with the help of simple material handling equipments. This will reduce the bottleneck during the process of manufacture remarkably. This concept is popularized by the Pump manufacturing unit. Hence, it was decided to implement the provision of Milk run in the simulation study.

6.2. Simulation model development

The following steps are to be followed before carrying out the simulation study:

- Calculate the number of workbenches required to carry out the activities and categorizing the number of activities required for the assembly.
- Calculate the number of calibration benches required for the calibration of the pumps assembled.
- Calculate the number of supermarkets required
- Provide provision in the layout for the implementation of Milk run for loading and unloading of the component.
- Decide on the distance between one worktable to another worktable to avoid unnecessary bottlenecks.
- Decide on important ergonomic design requirements - the access to the tools, flexibility in the movements of the semi assembled pumps.

A sample data form of PROMODEL software is shown in Figure 2.

6.3. Integrated lean line design

Using AUTOCAD, the layout was drawn & the layout was transferred to VISIO 2007 for carrying out simulation analysis. For simulation, PROMODEL is used. The layout drawn is named here as integrated lean line design which is capable of assembly of 120 pumps (target set by the company). Integrated lean line design layout is shown in the Figure 3. The observations in the Integrated lean line design are:

- This line reduced the number of stations from the existing 21 stations to 20 stations and also the older L layout was changed to the U layout. The activities carried out are shown in Table 1.
- The layout introduced the provision for the introduction of Milk run for the movement of the material. Also, 7 calibration benches, 2 phasing stations, 2 for tightness checking and 3 for pre packing activities are introduced and the details are shown in Table 2.
- The flow is external U for the assembly activities and internal U for the calibration and testing units. This reduces the space constraint to the maximum extent.

- A repair station is introduced.

Table 1 indicates the cycle time required for each process. These cycle times are entered in the PROMODEL software. The simulation analysis was carried out for 40 hrs run.

A sample simulation analysis is shown in Figure 4 (40 hours normal run). The layout is drawn using ACAD 2006 software. The drawing was transferred to VISIO 2007. This is one of the pre-requisites for carrying out simulation analysis using PROMODEL Process Simulator Version 2007.

The cycle time is entered at appropriate stations created. The inter relationships of the workers with stations are established. The number of activities are decided based on the decision taken through the discussions with the line engineers concerned with the case study. The decision regarding the height of the station, distance between the stations, the position of the loading and unloading palettes, the provision for the repair station, the line balancing aspects to smoothen the flow are taken before the simulation analysis is carried out. The appropriate decision was taken based on the prototype models created for visualizing the flow.

The results screen at 50 % Zoom for 40 Hours of normal run for the Integrated Lean Line design is as shown in Figure 5. After carrying out the simulation analysis, the output results are reviewed. It is observed from the output results that, the total exits in the work unit are 366 in 40 hours. But as per company requirements, there is a need for around 260 units. Hence, this line is producing more than the required number of units.

Further, as per the pie chart in Figure 6, the percentage in move logic is around 8.1%, the percentage in operation is 25.2% and the percentage blocked is 66.62%. Hence, there exists need for the modification of the layout by rearranging the layout and reducing the number of workers. The utilization of activities of 1 to 10 is shown in Table 2.

6.4. Final proposal for the lean line layout

The proposal in integrated lean line design had the disadvantage of bottlenecks in the process of assembly increase in idle time. The bottleneck is found in the easy loading of the material and unloading of the material popularly known in the case study industry as Milk run. The Milk run concept is a facility named by the company for loading and unloading the raw material and finished goods inventory from one place to another according to the schedules put forth. This

works according to the principles of Just in Time replenishment of material. This provision helps the workers in easy unloading and loading of the material. A KANBAN card is also attached in the Milk run system.

Hence, it has been decided to improve the layout by creating the prototypes of the layout explained in the Section 7. In order to decide and optimize the layout, brain storming sessions are held involving the Managers, engineers and the workers involved in the process of assembly of the pump.

The issues also discussed the provisions for introducing Milk run, reduction of bottlenecks during the assembly of the pumps, the easy flow of the process, number of multi skilled workers to be used. A modified lean flow line layout is proposed and shown in Figure 7.

The layout has the following advantages.

- The number of workers reduced from 33 to 28.
- The number of stations reduced from 21 to 14.
- Effective implementation of Milk run concept for the smooth flow of in process material.
- This model proposed has the features of arranging the prototype in a sequential order to cater to the needs of easy access to the workers. An internal U and an external U are proposed separately for the assembly unit and calibration unit. This is one of the best layouts from the lean perspective, as it avoids bottlenecks and movement of the material is smooth. There is considerable decrease in the piling up of the material in the line.

After the detailed brain storming, it was decided to prepare the prototype of the activities and validate the simulation results. The simulation of the proposed layout is shown in the Figures 8 and 9.

This layout has the features of effective Milk run activity with a provision for easy loading and unloading of the raw material and finished product without obstructing the workers assembly activities. The components in the assembly unit are effectively carried out with the workers located in the internal U area.

The finished components are unloaded easily with the provision of the workers located in the external U location and also the calibration activities are carried out with the workers located in the external U area.

The bottleneck in the process is reduced. The simulation analysis and output result for the lean line layout is shown in the Figure 10.

It is observed that the %age utilization of the assembly activity is increased and idle time is reduced. There is considerable increase in the multiple activity states. The % of part occupied in the line for the operation is observed to be higher and the operation is idle at the end stages as the assembled pumps are waiting for the calibration purposes.

There is a need for taking up the line balancing issue. The % in move logic is 26% and % in operation is 28% and the % blocked is 45%. There is still scope for the improvement of the lean line layout. But the simulation model has given lot of avenues for optimizing the layout. Taking cue from the simulation study, it was decided to validate the same using the prototype prepared. However a detailed description of the prototype preparation is not discussed in this paper.

7. Development of prototype for the lean line design (wooden model)

The proposed lean line design is fabricated using wooden models. The photographs showed in the Figures 11 and 12 depict the various assembly stations. During the prototype fabrication, industrial engineering concepts of method study, aspects of easy reach, unloading, loading locations (palettes), inspection center, racks, Milk run provisions, easy accessibility are considered. A detailed work was undertaken and questionnaires were prepared to take the feedbacks from the workers to optimize the layout.

8. Conclusion

Simulation is carried out using the VISIO 2007 and Pro Model Process Simulator software. The Models are fabricated. The feedbacks regarding the method study and ergonomic aspects are carried out using survey technique.

Simulation analysis is carried out and proposed a one-piece lean line design. The validation has been carried out by test running using the prototype model fabricated.

This case study carried out has opened up avenues to propose a “*new model of lean manufacturing for success in Indian industries*”. Finally, the validation was carried out by test running using the prototype model fabricated.

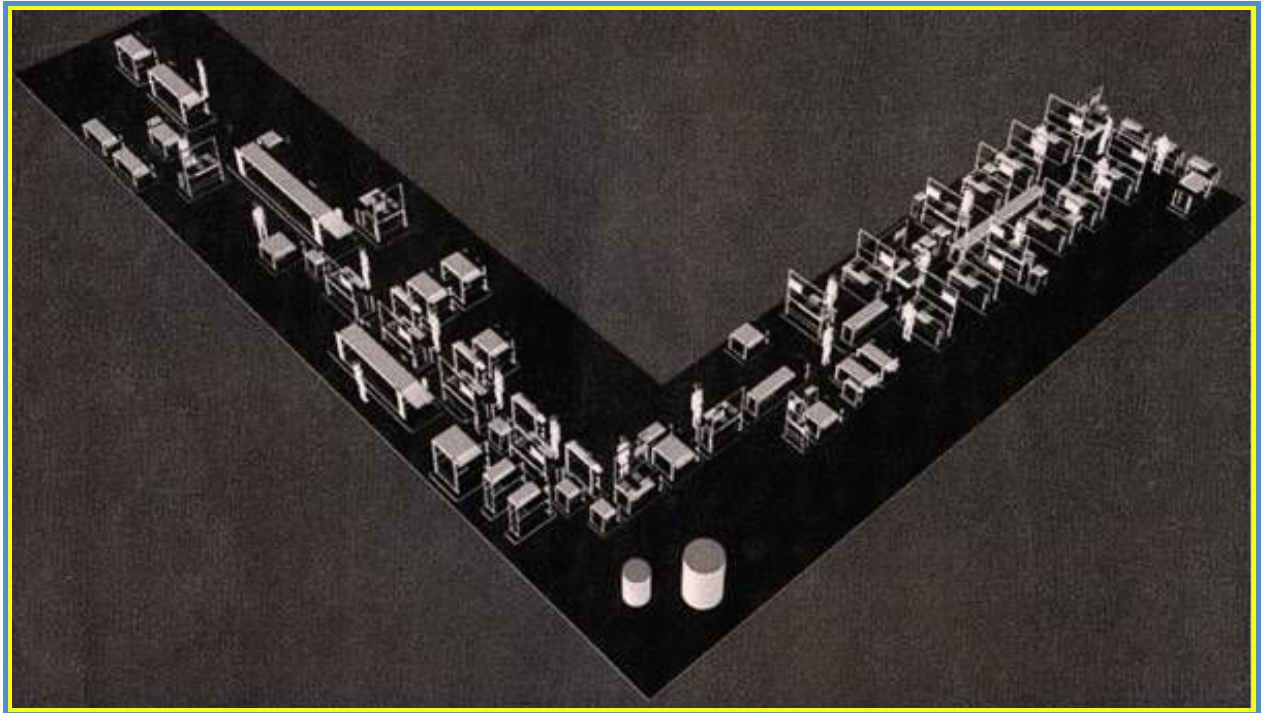


Figure 1. Existing layout for the assembly of pump.

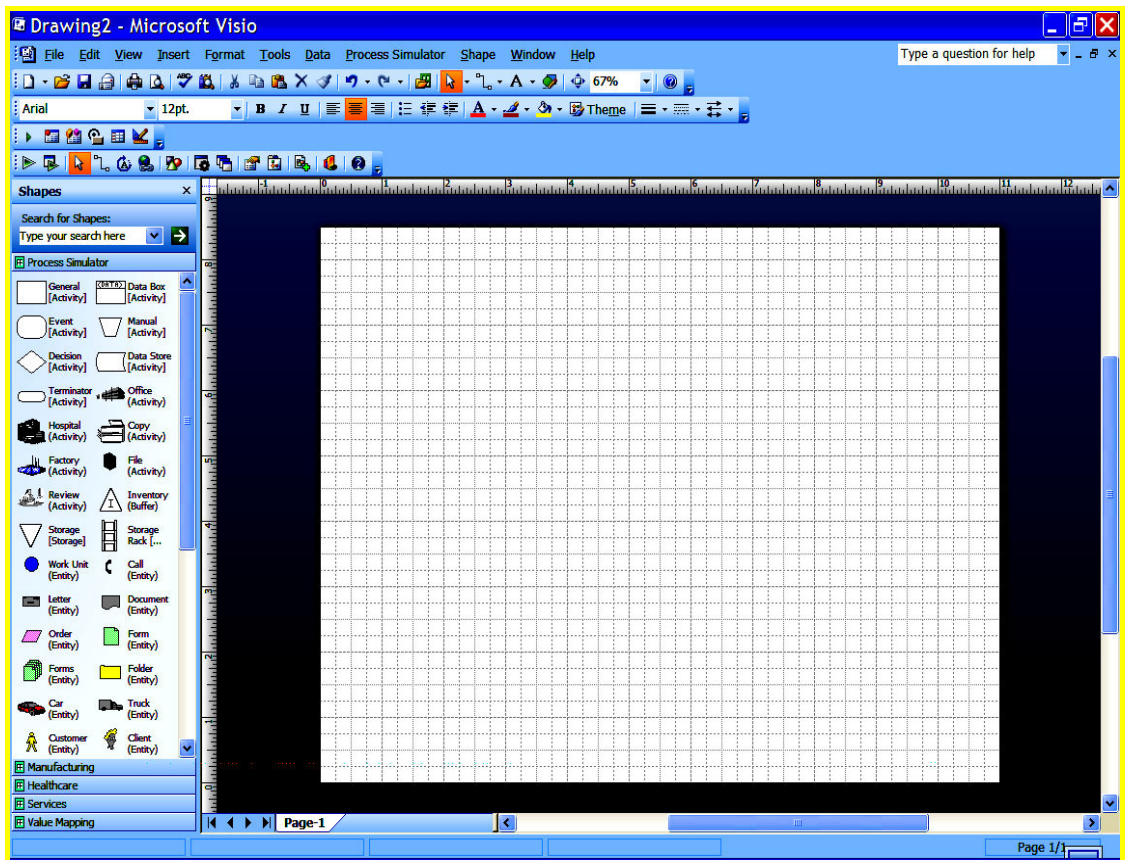


Figure 2. Data input (modeling elements).

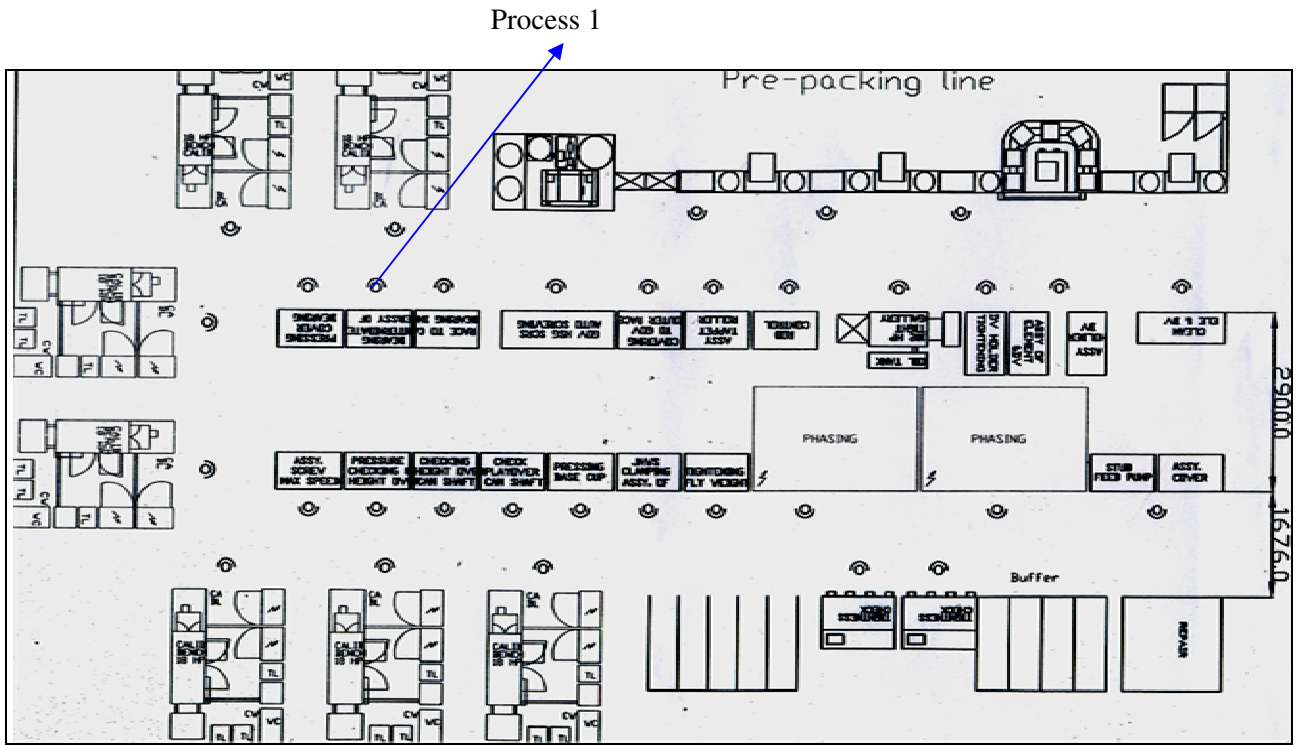


Figure 3. Integrated lean line design.

Table 1. Average cycle time calculated for 10 hours per day for 10 days.

Station No.	Description for the calibration and testing of the assembled pump	Average cycle time
1	Cleaning the element and DV	2.53
2	Assembly of DV holder	2.55
3	Assembly of element and DV	2.51
4	DV holder tightening	1.25
5	Gallery tightness checking	2.83
6	Assembly of control rod and its freeness checking	2.86
7	Assembly of roller tappet and lower spring plate and RT clip assembly	3.25
8	Assembly of inner race of bearing to Gov Housing by pressing and Assembly of gasket on to pump and assembling the Gov Housing to pump	3.58
9	Tightening by auto screwing	3.10
10	Bearing cover flange sub assembly and assembly of bearing inner race to cam shaft	2.25
11	Pressing cover bearing	2.58
12	Assembly of max screws	2.51
13	Pressure checking and height checking	2.25
14	Cam height over checking	1.10
15	Check play over cam shaft	1.20
16	Pressing base cup	
17	Clamping jaw assembly	2.52
18	Tightening fly weight	1.80
19	Stud feed pump	2.25
20	Assembly cover	1.51
	Grand Total Average Cycle Time	44.43 Mins.
21	Phasing 1	4
22	Phasing 2	4
23	Tightness check 1	3
24	Tightness check 2	3
25 to 31	Calibration checks for 7 tables Note: Avg. time= 21 Mins/7 tables	21
32	Pre packing activities (2 Mins each for 3 benches)	6
	Grand Total Cycle Time	41 Mins.

Table 2. Utilization of the activities.

Sl. No.	Activities	% Utilization	% Idle
1	Activity 1 input buffer	42.87	57.12
2	Activity 2 input buffer	42.85	57.14
3	Activity 3 input buffer	28.57	71.43
4	Activity 4 input buffer	28.55	71.45
5	Activity 5 input buffer	28.61	71.39
6	Activity 6 input buffer	28.52	71.47
7	Activity 7 input buffer	54.34	45.66
8	Activity 8 input buffer	53.48	46.51
9	Activity 9 input buffer	53.91	46.08
10	Activity 10 input buffer	26.63	73.36

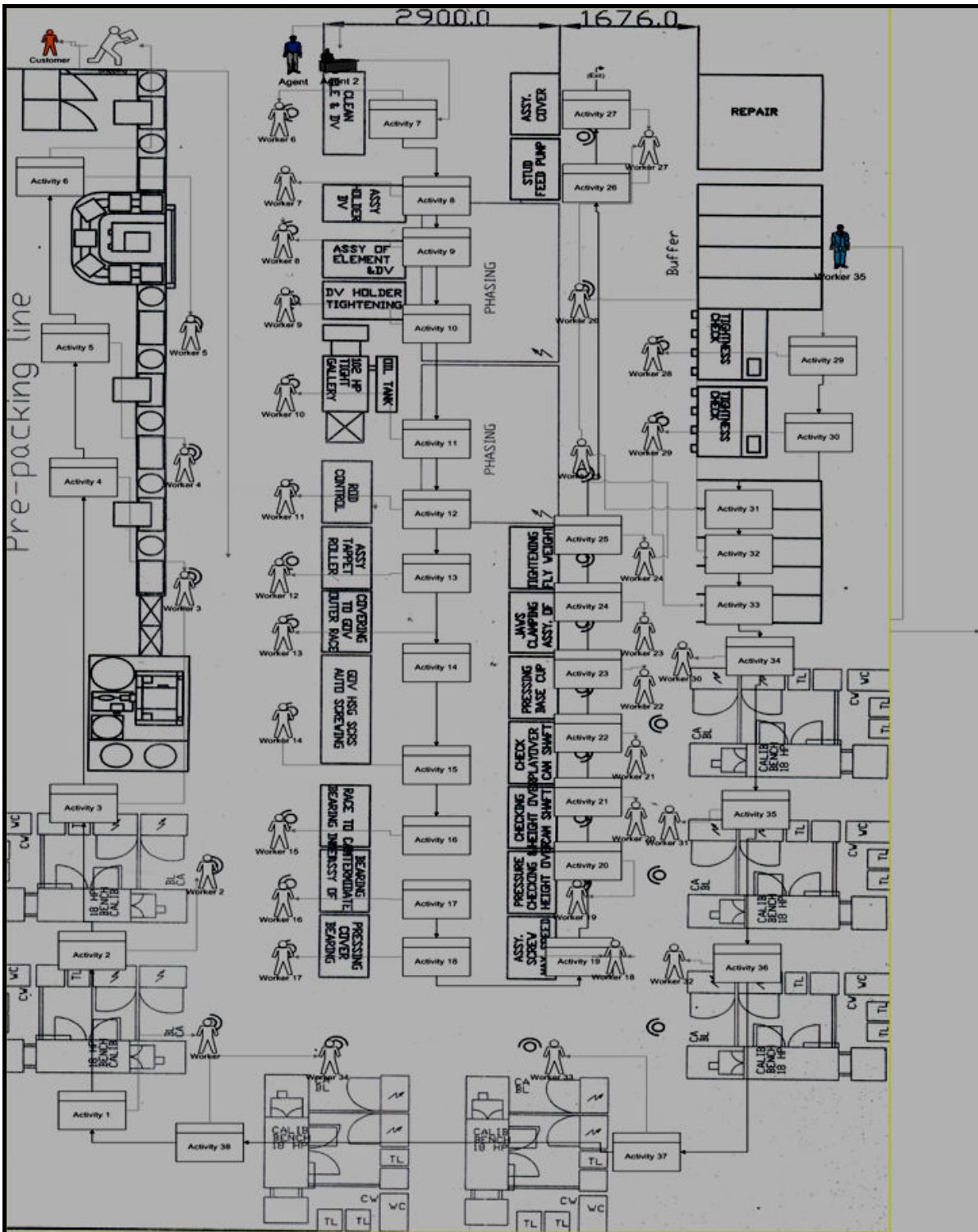


Figure 4. Simulation for 40 hours normal runs.

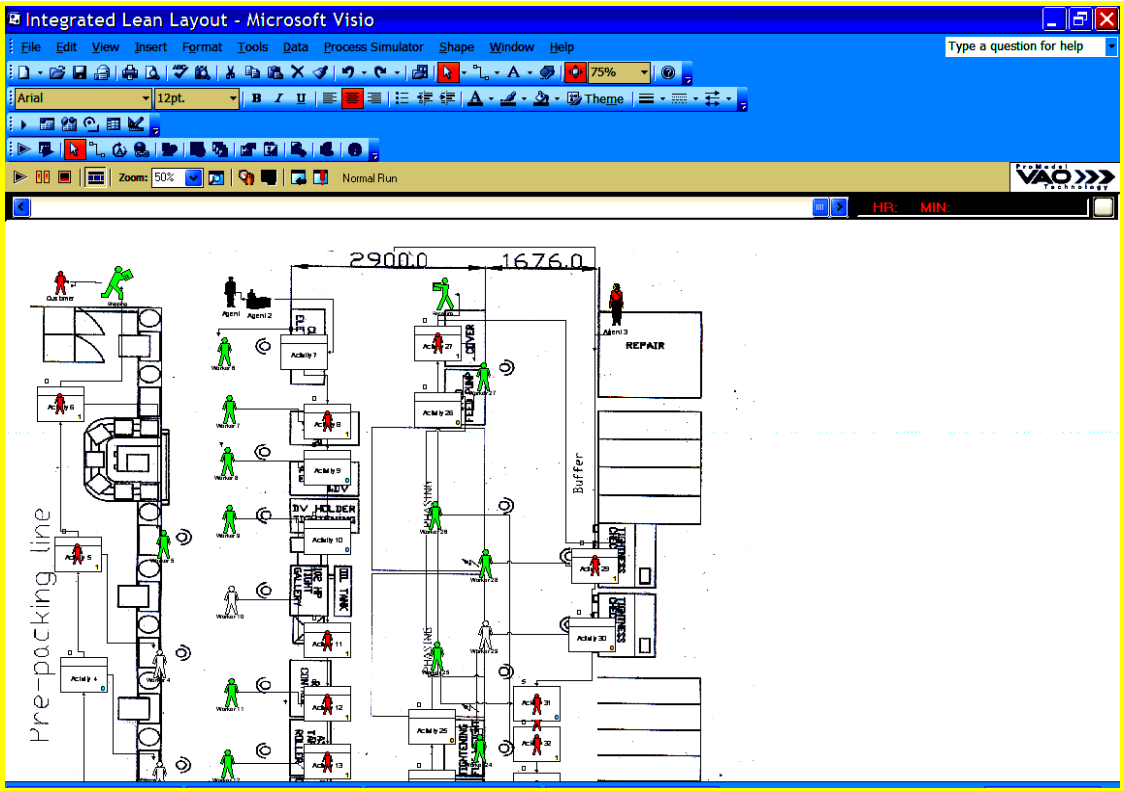


Figure 5. Simulation analysis using PROMODEL Process Planner Simulator.

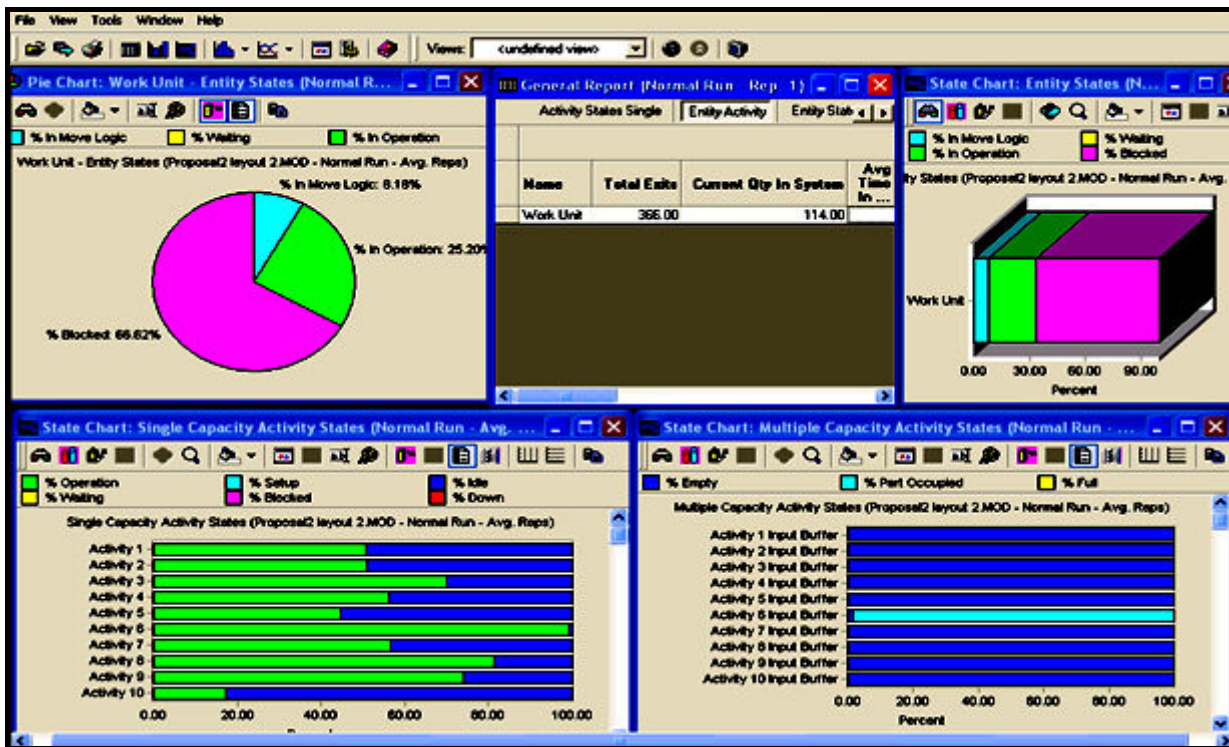


Figure 6. Output results of the integrated lean line layout.

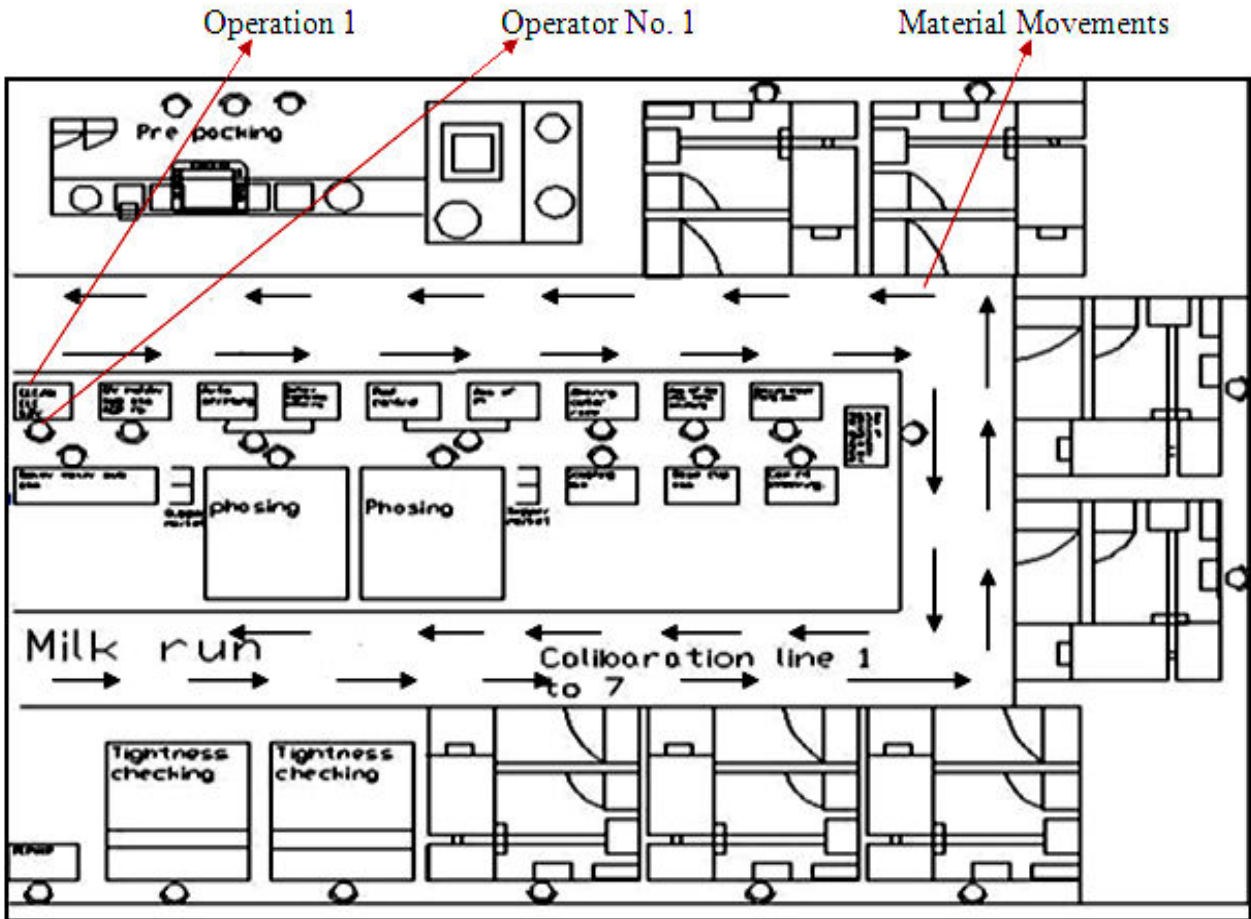


Figure 7. Lean line layout.

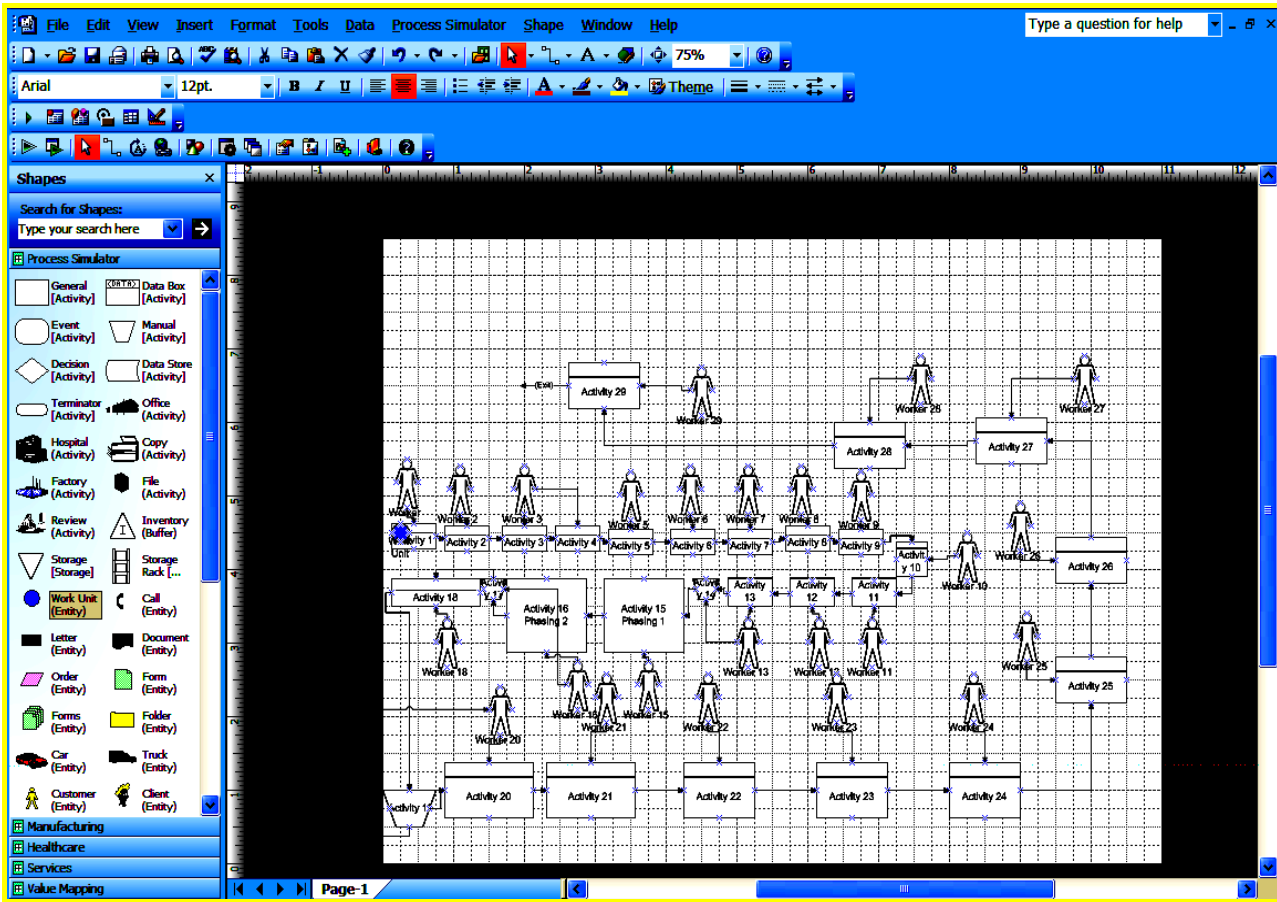


Figure 8. Lean line layout using VISIO 2007.

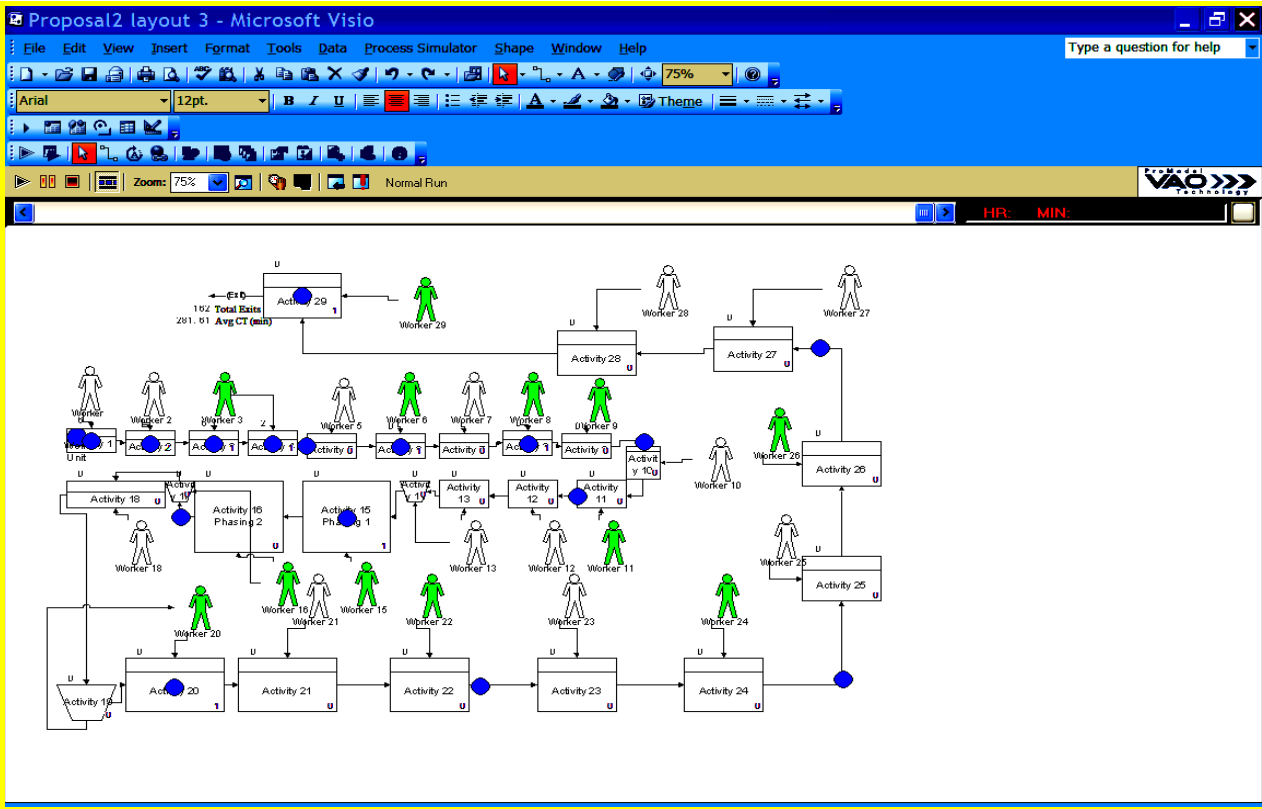


Figure 9. Animation for the lean line layout using process planner simulator software.

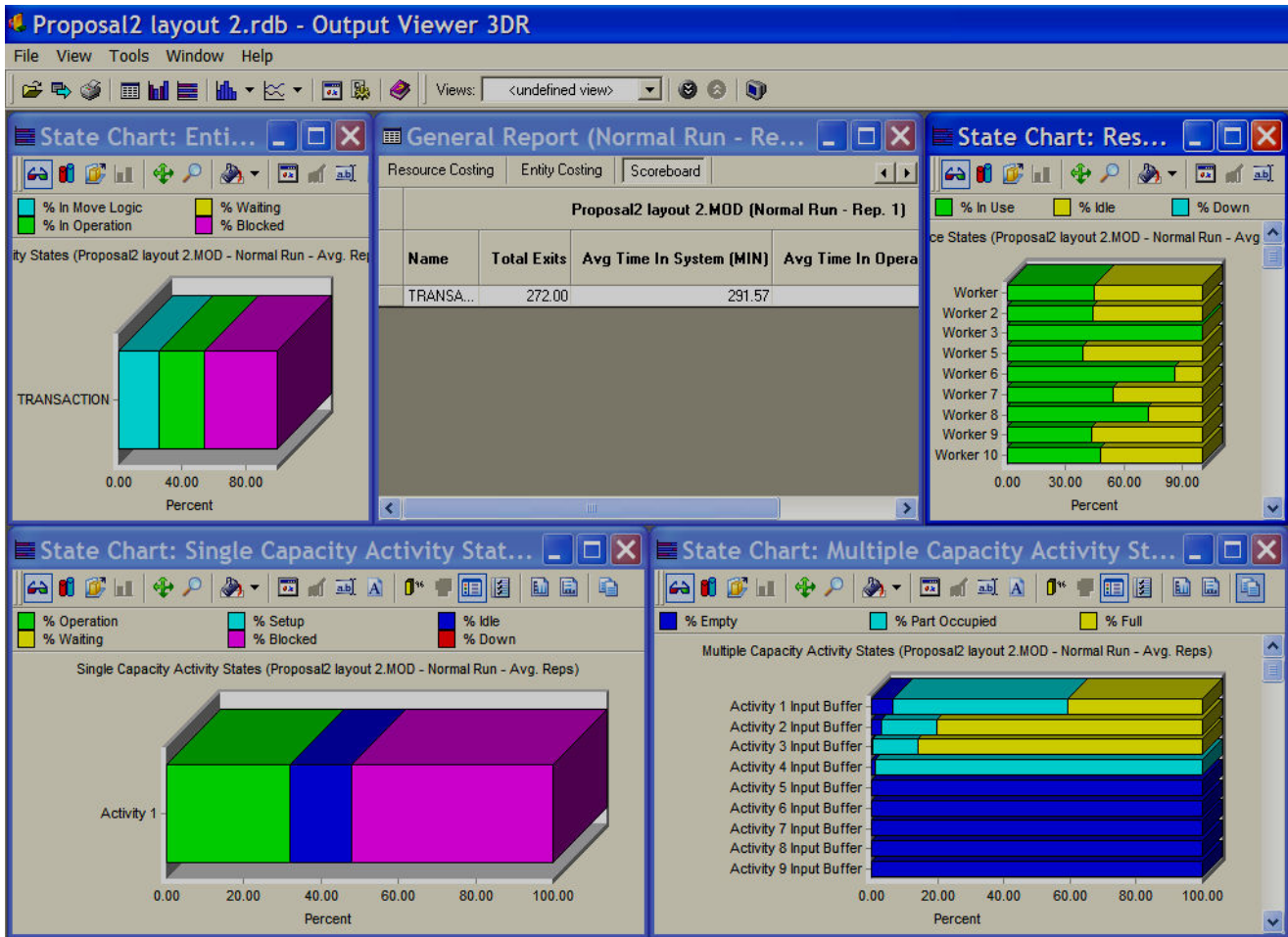


Figure 10. Simulation result using process planner simulation software (40 hours run).

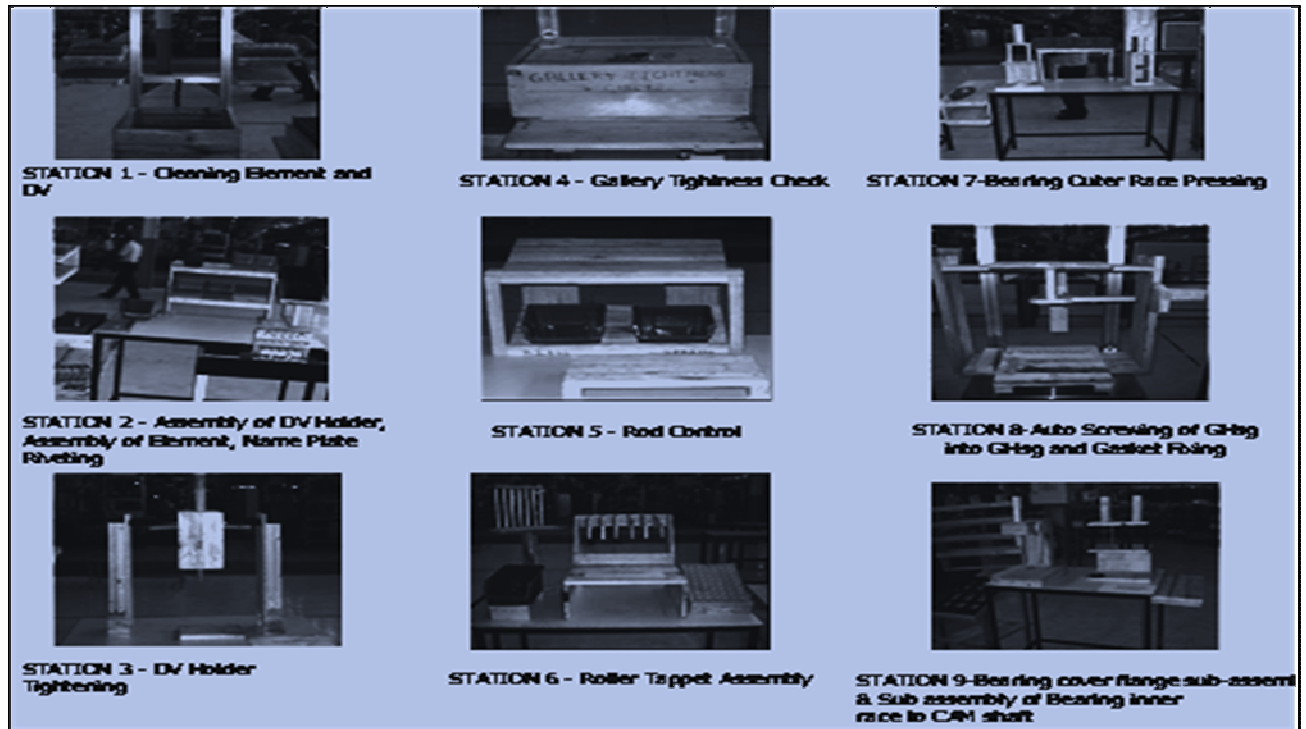


Figure 11. Wooden prototypes (Station 1-9).

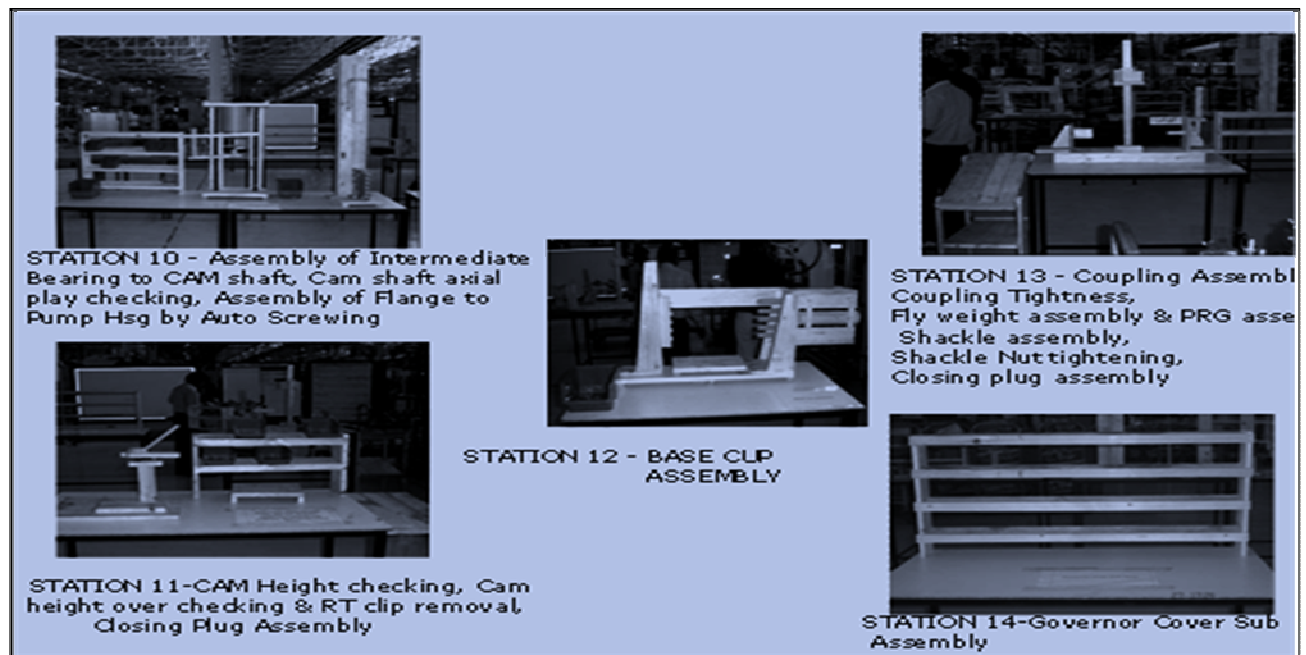


Figure 12. Wooden prototypes (Station 10-14).

References

- [1] Adams, M., Componation, P., Czarnecki, H. and Schroer, B. J., 1999, *Simulation as a Tool for Continuous Process Improvement*. Proceedings of the 1999 Winter Simulation Conference, ed. P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, The Institute of Electrical and Electronics Engineers, Piscataway, N. J. Diamond, R., C. R. Harrell, J., 766-773.
- [2] Adams, M., Componation, P., Czarnecki, H. and Schroer, B., 1999, *Simulation as a Tool for Continuous Process Improvement*. Proceedings of the 1999 Winter Simulation Conference, University of Alabama in Huntsville.
- [3] Altinkilic, M., 2004, *Simulation-based Layout Planning of a Production Plant*. Proceedings of the 2004 Winter Simulation Conference, 1079-1084.
- [4] Carria, A., 1988, *Simulation of Manufacturing Systems*, 176-180, Wiley, Essex Carson, J., Brunner, D., 2000, “*Simulation in the future: a panel discussion*”, Proceedings of the 2000 Winter Simulation Conference, 1568-1576.
- [5] Czarnecki, H. and Loyd, N., *Simulation of Lean Assembly Line for High Volume Manufacturing*. Center for Automation and Robotics University of Alabama in Huntsville Huntsville, Alabama.
- [6] Diamond, R., Harrell, C. R., Henrikson, J. O., Nordgren, W. B., Pegden, C. D., Rohrer, M. W., Waller, A. P. and Law, A. M., 2002, *The Current and Future Status of Simulation Software*. Proceedings of the 2002 Winter Simulation Conference, ed. E. Yücesan, C.-H. Chen, J. L. Snowdon & J.M. Charnes. 1633-1640.
- [7] Jain, S. and Leong, S., 2005, *Stress Testing a Supply Chain Using Simulation*, Proceedings of the 2005 Winter Simulation Conference, 1650-1657.
- [8] Lian, Y. H., *A Simulation Based Method for Analyzing the Effects of Lean Manufacturing*. Ph.D. Thesis.
- [9] Manar, B., 1997, *Guidelines for Effective Use of Simulation*. Brigham Young University Masters Thesis.
- [10] www.promodel.com/products/promodel.