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Performance Evaluation of Reconfigurable Assembly Line

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Abstract: In this dynamic global competitive market era, manufacturing industries were striving hard to meet the demand of the market due to frequent changes in demand and larger product variants with shorter product life cycles. In this paper the case study referred, is a dedicated assembly line with the needs to meet the variation in product demand of variants. To meet this requirement, the assembly line is to be converted into mixed model assembly line using the concept of reconfiguration. Discrete event simulation model of the existing alternator assembly line is developed using ExtendSim. This base model is reconfigured to arrive at a model for the proposed alternator assembly line to meet the requirements of the product variants. The performance measures like, throughput, machine utilization, worker utilization, the average flow time and the average waiting time are estimated through simulation for the existing and proposed reconfigurable assembly line. The results of the simulation are compared and presented in this paper. The results from the simulation models indicate that the performance metrics of the reconfigurable assembly line is optimally superior to the existing assembly system.

Key words: Reconfiguration · Assembly line · Simulation · Performance evaluation

INTRODUCTION

In this dynamic global manufacturing era, manufacturing industries face various challenges like frequent changes in product variants, dynamic fluctuation of demand, shorter product life cycle and uncertainties. To meet these challenges, there is a need of cost-effective and quick responsive manufacturing system with recent technology inclusion. Technology life cycle is also great impact on evolution of manufacturing system to meet the challenges of global and manufacturing firms [1].

Reconfigurable manufacturing system is the paradigm coined by Yoram Koren in 1999. Reconfigurable manufacturing system able to meet the above challenges and uncertainties in an optimized way. RMS is “designed at the outset for rapid changes in structure, as well as in hardware and software components, in order to quickly adjust for the production capacity and functionality within a part family in response to sudden changes in market or in regulatory requirement. RMS has six core inherent characteristics modularity, scalability, integrability, convertibility, customization and diagnosability [2, 3].

To sustain competitive enough in the dynamic market environment the manufacturing system should have the flexibility and scalability to meet the uncertainties. Assembly line system is the process of assembly of components parts and subassemblies together to form the final product. Most of the automotive ancillary units consists of one or more assembly lines, which is the final stage of the product. In all the discrete type manufacturing system assembly line exists, which determines production rate / productivity of the firm.

This paper, presents the study of performance evaluation metrics of assembly line before and after the reconfiguration using discrete event system simulation approach and in what ways reconfiguration can be attempted for an assembly line with respect to the case study.

Literature Review: Assembly line system is the process of assembly of components parts and subassemblies together to form the final product, which are classified based on various criteria’s like number of models (single model line, mixed model line and multi model line), line control (paced line, unpaced asynchronous line and

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unpaced synchronous line), frequency (first time installation and reconfiguration), level of automation (manual line and automated line) and line of business(automobile production system, electronic products production system etc.) [4, 5]. Further assembly is classified based on assembly system reconfigurability as, dedicated assembly line, flexible assembly line and reconfigurable assembly line [2, 3]. In manufacturing unit, assembly cost is 25% to 50 % of total cost of manufacturing and the number of workers involved in assembly line will be 20% to 60% [6].

An assembly system should inherit the characteristics like flexibility, scalability and reliability etc. to meet the present dynamic competitive global market demand. To attain these characteristics the assembly system must follow reconfigurable manufacturing system. The core inherent characteristics of RMS is modularity, scalability, integrability, convertibility, customization and diagnosability, which will facilitate assembly or production system to meet the uncertainties and changes in manufacturing environment with cost effective manner [7].

In assembly line system, assembly system and assembly process are interconnected where, assembly system consist of system layout, system structure and system components and assembly process consists of assembly strategy, assembly structure and assembly operations, which in turn assembles the final product [8, 9]. Review of reconfiguration of the assembly line at several level were at conveyor line, automation of tooling system, fixtureless, system reconfigurability using improved and modular robotic system [10]. A new modular assembly system is designed for the integration between assembly cell with reconfiguration policy to make line flexible, during fluctuation in variants volume and lot size [11].

An in-depth detailed survey on development of reconfigurable assembly system shown, the needs of reconfiguration, critical issues on understanding and implementation of reconfiguration at theoretical and practical level respectively a nd possible future research directions for the benefit of manufacturing industries [10]. From the detailed empirical study on reconfiguration on manufacturing system, it clear that, the questions to be raised during reconfiguration and impact on performance measure of the system to be addressed [12]. Reconfigurable assembly line simulation model is developed to study the performance evaluation of the line, in this reconfiguration is by adding a standby inline robot which can serve more than one workstation, which will be in flow during the breakdown of any of the workstation robot and addressed the error recovery flexibility of repaired robot [7].

Production line with one piece flow (single piece flow) manufacturing pattern, products flow in batches in the system with paced with cycle time is developed to meet the fluctuating demands of products with shorter life cycle. Mathematical model is developed to show the appreciable increase in the effectiveness of the one piece flow production line system [13].

To improve the performance metrics of the manufacturing system and dynamic demand pattern, reconfiguration is the optimal tool. But the concern is “how do we reconfigure? and when do we reconfigure?, it depends on individual practical scenario and varies [4, 14]. The simulation and modeling is a promising tool to study the performances of the assembly line or production line before and after reconfiguration, without prototype modeling, which is of cost effective technique [15]. The performance of a mixed model assembly line is improved by identifying and eliminating the bottleneck stations by reconfiguration by Simulation modeling using ARENA [16].

To meet the customer demand effectively, flexible assembly line developed by converting the conveyor line into assembly cell system (seru system) by reconfiguration and an mathematical model is developed to determine the no of seru needed and no of workers to be assigned to each seru, which is investigated with industrial case study [17]. Simulation based methodology of reconfiguration was proposed in manufacturing system to increase the production capability to meet the fluctuation of demand pattern and efficiency of the system using WITNESS [1].

Various system level issues like capacity planning, process planning production planning etc. can be extended over the performance evaluation of simulation modeling of the assembly line [11]. The factors like fluctuations in dynamic demand and product variety is to considered during assembly system design and human workers to be flexibly assigned to any of the work stations to increase the efficiency and effectiveness of line and worker [18].

Research Objective and Methodology of the Study: The objective of this research is intended to study (i) the effectiveness and performance of the reconfigurable assembly line using discrete event simulation modeling and (ii) how reconfiguration attempted in assembly line at system structure / layout level to convert the line into mixed model assembly line.

The methodology to achieve the objective of the study, the sequence of methodology followed is listed below:

- Assembly line system should be studied in-depth and essential data's related of the assembly line is to be collected (cycle time, no of workers, flow of assembly, precedence relationship between the assembly process etc.)
- A Simulation model is to be developed based on the study, which implicates the real assembly system and its behaviour, which should be verified and validated.
- To study the feasible ways to improve the performance of the assembly lines using the reconfiguration, by developing the simulation model of reconfigurable assembly line.

Case Study: The Case study unit manufactures several types of alternators. The alternators are broadly classified into two types, one is vacuum type and other is non- vacuum. These types of alternators are assembled in ten assembly lines. An assembly line is identified, in which more than 8 types of alternators are assembled. The assembly line is of U- shaped, has 21 work stages (shown in Figure 1) and in which vacuum type alternators uses all the stages and non-vacuum type alternators flow skips 17 to 19 work stage.

An in-depth detailed study was carried out over the assembly line and collected the data on arrival rates, inter-arrival times, setup times and activity times for each stage using the time study technique, for a period of 40 to 60 products at various periods of shift, which refers to cycle time. The throughput time of vacuum type is 88 minutes, whereas for non-vacuum type alternator is 74 minutes.

Simulation Model Development: The objective is to reconfigure the existing assembly line in such a way to handle both vacuum and non –vacuum type of alternators simultaneously as a mixed model assembly line, to improve the performance metrics of the assembly line using discrete event simulation.

Simulation model was developed using ExtendSim Version 6.0 simulation software, which can simulate any simple or complex continuous and discrete manufacturing system. The existing alternator assembly line simulation model is built, which consists of 21 stages using the precedence relationship shown in Figure 2 & 3. The input parameter used in the model is the cycle time, which is collected from the time study technique. From the detailed study of the alternator assembly line,

- Precedence relations between assembly operations are defined for both type of alternator as shown in which is shown in Figure 2 and 3.
- The various stages of assembly line are presented (see Figure 1).
- One-piece flow (or single piece flow) manufacturing exists on the U- shaped assembly line.
- Some of the work stage (8, 10, 11, 12, 13, 14, 18, 19, 20 and 21) combined with inspection.

Input Data Modelling: Input data modelling was carried out over the collected cycle time data using Arena Input Analyser, to estimate the probability distribution and its related parameters of the raw data for each operation/stage. Estimated input data probability distributions with their parameters of the various stages of the assembly line are show in the Table 1.

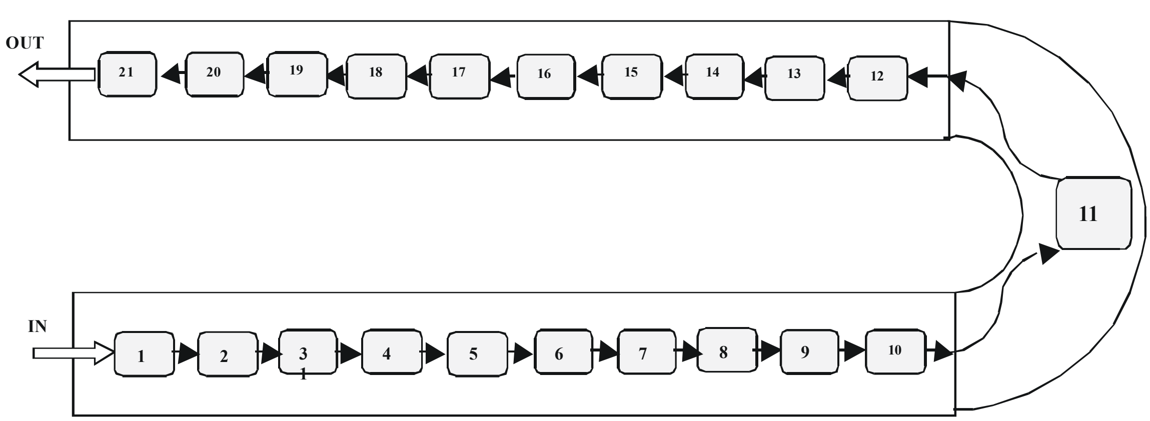

Fig. 1: Layout of the Existing Assembly Line

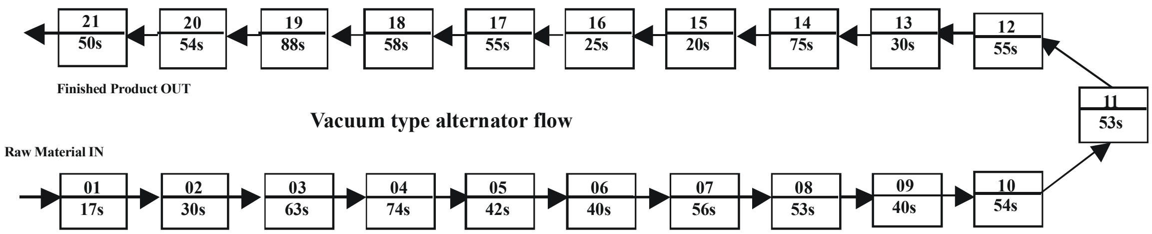

Fig. 2: Precedence relations between assembly operations of vacuum type alternator

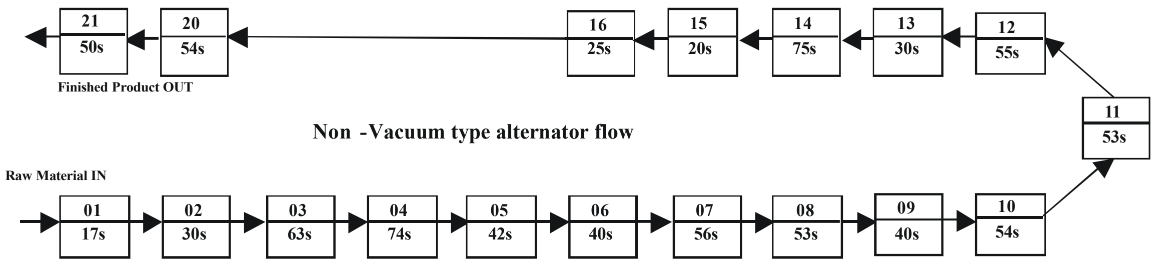

Fig. 3: Precedence relations between assembly operations of non-vacuum type alternator

Table 1: Estimated input data distribution for each stage of assembly line

Stage No	Description of Operation at Stage	Distribution type (seconds)
1	SRE + Split Bush Assembly	12.5 + GAMM(1.48, 2.51)
2	SRE + Lock Disc + Oil Seal Assembly.	19.5 + WEIB(3.67, 3.07)
3	Rectifier Assembly with SRE	TRIA(52.5, 56, 58.5)
4	Stator Leads Trimming Positioning Insertion	66.5 + LOGN(3.32, 2.14)
5	Solder Three Leads of Stator	NORM(39.5, 1.43)
6	Marking + DRE Bracket + Insert Assembly	35.5 + WEIB(2.53, 1.97)
7	DRE Bracket + Bearing Assembly	51.5 + ERLA(0.693, 3)
8	DRE-Bracket Plate Assembly & Torque Checking	45.5 + ERLA(0.627, 6)
9	DRE Bracket + Rotor Assembly	34.5 + ERLA(0.78, 4)
10	Fan & Pulley Assembly & Friction Checking	46.5 + LOGN(3.61, 2.4)
11	Unit Building with Bolt Assembly & Torque Checking	46.5 + LOGN(3.1, 1.93)
12	Regulator & Bush Box Assembly, Torque Checking & Cover Mould Assembly	48.5 + ERLA(0.685, 4)
13	Regulator & Brush Box Assembly.	TRIA(25.5, 29, 30.5)
14	Air Performance Testing	NORM(72.5, 1.95)
15	Deluxe & Bar Code Labelling	TRIA(14.5, 16, 20.5)
16	Greasing and Oil Seal Assembly	19.5 + WEIB(3.67, 3.07)
17	Vacuum Pump Fixing to Alternator	NORM(51.4, 1.2)
18	Vacuum Leak Testing & Static Electric Testing	TRIA(52.5, 56, 58.5)
19	Dynamic performance Testing of Alternator with Vacuum Pump	81.5 + WEIB(4.62, 3.19)
20	Air Pressure Testing & Fixing of Acceptance Stickers	NORM(51.1, 1.54)
21	Final Inspection& Gauging & Dispatch	NORM(47.6, 1.14)

Assumptions of Simulation Model: Assumptions are made to the assembly line to simplify the problem, because it will be too complex to build the real system and to show the specific features considered in the model:

- The line operates for 2 shifts/day and works for 9 hours/shift
- 490 minutes working time/shift without breaks
- Parts are readily available for assembly, setup time are negligible and included in the cycle time itself,
- No maintenance or breakdown process during shift working time
- Using the pallets the parts are manually moved between the stages
- At the beginning of shift, the assembly line begins empty.

Verification and Validation of the Simulation Model: The alternator assembly line simulation model was developed, which consists of 21 stages is verified by step by step running mode and trace and animation techniques to check the flow path of the variants. To check the appropriacy of the model output, several simulation trial runs were carried out under various values of input parameters

Validation of the model is to show whether the developed base simulation model precisely replicates the real system in all the terms within the acceptable level of confidence. In this work, validation was carried out through two sample t-test, which is used to find the testing difference of two means when population variance are unknown but considered equal. Using the F-test, the throughput variance is equal.

By hypothesis tests using the throughput with a 95% confidence interval as given below:

The hypothesis is:

$H_0 \ : \ \mu_{Real} = \mu_{BaseSim\ model}$
$H_1 \ : \ \mu_{Real} \neq \mu_{Base\ Sim\ model}$

The test statistics is if $t_0 < t_{\frac{\alpha}{2}, n_R + nBSm^{-2}}$

The null hypothesis H_0 would be accepted, where t_0 is,

$$t_0 = \frac{\mu_R - \mu_{BSm}}{S_T \sqrt{\frac{1}{n_R} + \frac{1}{n_{BSm}}}}$$

$$S_T^2 = \frac{(n_R - 1)S_R^2 + (n_{BSm} - 1)S_{BSm}{}^2}{(n_R + n_{BSm} - 2)}$$

where,

n_R Is the number of samples of data collected from real system?
N_{BSm} Is the number of runs of basic simulation model?
μ_R Is the mean throughput of real system?
μ_{BSm} Is the mean production rate from the basic simulation model?
S_T^2 Is the pooled mean variance
S_R^2 Is the real system variance
$S_{BSm}{}^2$ Is the basic simulation model variance

The average throughput of 50 shifts of data ($n_R = 50$) collected from the real system study was $\mu_R = 263$ unit with variance $S_R^2 = 139.23$ and that for base simulation model was $\mu_{BSm} = 254$ unit with variance $S_{BSm}{}^2 = 2023.87$ after running the simulation model for 50 times ($n_{BSm} = 50$). Therefore $S_T = 32.88$ which makes $t_0 = 1.3196$ and from the‘t’ statistical distribution table (with confidence interval of 95%).

$$t_{\frac{\alpha}{2}, n_R + n_{BSm} - 2} = t_{\frac{5\%}{2}, 50+50-2} = t_{0.025,98} = 1.96$$

Since, $t_0 < t_{\frac{\alpha}{2}, n_R + n_{BSm} - 2}$, ,

$1.3196 < 1.96$

Hence from the above two sample t-test, there is no significance difference between the means, hence the base simulation model is valid (i.e. replicates the behaviour of the real system) [14].

To Determine the No of Replications: In this study the discrete event simulation is of terminating type [19], hence no of replications to terminate the simulation model is determined using,

$$R \geq \left(\frac{Z_{\alpha/2}{}^2 * S_{R0}{}^2}{\epsilon^2} \right)$$

$$\epsilon = t_{(nR-1),\left(1 - \frac{\alpha}{2}\right)} * \sqrt{\frac{S_{R0}{}^2}{n_{R0}}}$$

where,

n_{R0} Is the number of initial replications (set as higher 500?)
R Is the required number of simulation to terminate the simulation?
$Z_{\alpha/2}$ Is the 100(1-α/2) percentage point of the standard normal distribution?
$S_{R0}{}^2$ Is the variance of initial no runs (R_0=500)
∊ Is the absolute error
α Is the level of confidence, 0.05%?

$$\epsilon = t_{(500-1),\left(1 - \frac{0.025}{2}\right)} * \sqrt{\frac{33.87}{500}}$$

$$\epsilon = t_{(499,),(0.975)} * \sqrt{\frac{33.87}{500}}$$

From the t- distribution table, value of $t_{(499,),(0.975)}$ is 1.96

$$\epsilon\ 1.96 * \sqrt{\frac{33.87}{500}} = 2.97 \cong 3$$

Therefore,

$$R \geq \left(\frac{Z_{\frac{0.05}{2}}{}^2 * 33.87}{3} \right) \rightarrow \geq \left(\frac{1.96^2 * 33.87}{3^2} \right)$$

Minimum of Required runs to terminate the simulations is $R \geq 489.67 \cong 490$ *Runs*

Therefore the simulation model is to run for minimum 490 runs.

Reconfiguration Analysis: In assembly line reconfiguration can be attempted at by changing the assembly system variable assembly process, assembly system and product design for assembly at design level [14, 15], system modularisation, system control and configuration, flexible fixture or fixtureless assembly process, material handling system, worker assignment, assigning robotics for assembly process, flexible assembly machines etc. The reconfigurablity is defined as the ability to repeatedly change and rearrange the components of a system in a cost effective way with the key features like modularity, integratibility, customization, convertibility and Diagnosability to meet the challenges of manufacturing system at various levels [3]. The reconfiguration can be done in the assembly line at system layout level like, changing the flow pattern as series or parallel to some stations, adding or deleting the some stations, reconfiguring the fixtures used in the assembly line station to make it flexible to handle any variants and capacity adjustments, production planning based on the dynamic demand scenario.

In this work, reconfiguration is attempted by changing the assembly system layout and worker assignment, to meet the dynamic demand of the variants in assembly line, where the assembly line is reconfigured to mixed model assembly line. To convert it to a mixed model assembly line, there is need of flexibility and scalability over the line characteristics; this can be achieved by reconfiguration. In the existing assembly line variants can be assembled in batch wise only due to variations in flow of variants in the assembly line. The variant vacuum type flows through all stages 21stages to get final product, but the non-vacuum type flow through 1 to 16 stage and 20 to 21^{st} stage, since the line is U – shaped.

In the existing assembly line, when vacuum variant is in assembly, if non-vacuum enters there will be block at the stage 17 to 19 for the non-vacuum type, due to assembly of vacuum type between the stages 17 to 19.

The existing assembly line is of U shaped layout from stage 1 to 21 as shown in Figure 1. The vacuum type alternator undergoes the assembly process from stage 1 to 21 in orderly flow sequence (shown in Figure 2), but the non- vacuum type alternator assembly process flows (shown in Figure 3) from stage 1 to 16 and stage 20 to 21 in orderly flow sequence.

The difference is non-vacuum type alternator skips the flow through the stages 17 to 19, these stages belongs to vacuum type where vacuum pump is fitted and inspected, which blocks the flow of non-vacuum type hence precedence workstations gets blocked, which in-turn affects the utilization and throughput. And while assembling the non-vacuum type alternator alone, the part and worker has to move through the stage 17 to 19, it's the time consuming for the worker to move from stage 17 to 20. Hence the assembly line system structure or layout level reconfiguration made after the stage 16, which facilitates the vacuum variant and non- vacuum variant to take different path of flow and combines at the from the stage 20 and makes the line as mixed model assembly line.

In this case study, proposed reconfigurable assembly line, is developed by changing the flow pattern of the line into parallel at the stage 17, 18 and 19, (where vacuum is fixed and inspected at this stage) because the vacuum type alternators passes through this stages and the non-vacuum model alternators skipping this stages (17 to 19) and flow enters the next stage (20). By this reconfiguration, the distance travelled to cross the stage 17 to 19, by the worker handling non-vacuum alternator model can be reduced, intern time taken is reduced to complete the assembled products, which makes the line flexible and scalable with respect to handle various variants and capacity adjustment. Here in this case study two type of reconfigurable assembly line is proposed with respect to: (i) first is bypassing the stages 17 to 19 for non-vacuum type alternator and both type flow through common stage 20 and 21 and (ii) second is bypassing the stages 17 to 19 for non-vacuum type alternator and adding separate stage 20 and 21 for non-vacuum type alternator.

Performance Evaluation of the Simulation Models: In this investigation of performance evaluation, based on the reconfiguration analysis, proposed reconfigurable assembly line (RAL) system (Figure 5) is built from the existing base simulation model (Figure 4) using Extend Sim. Based on the reconfiguration analysis the non- vacuum variants takes a different he proposed assembly line.

Since the discrete event simulation is of termination based, hence simulation model of the existing assembly line (Figure 4) is simulated for 490 replications, by assigning workforce strength of 9 workers in the assembly line. Similarly, proposed RAL simulation model, simulated for 490 replications and both the output results like throughput, worker utilization and machine utilization of system etc., were tabulated.

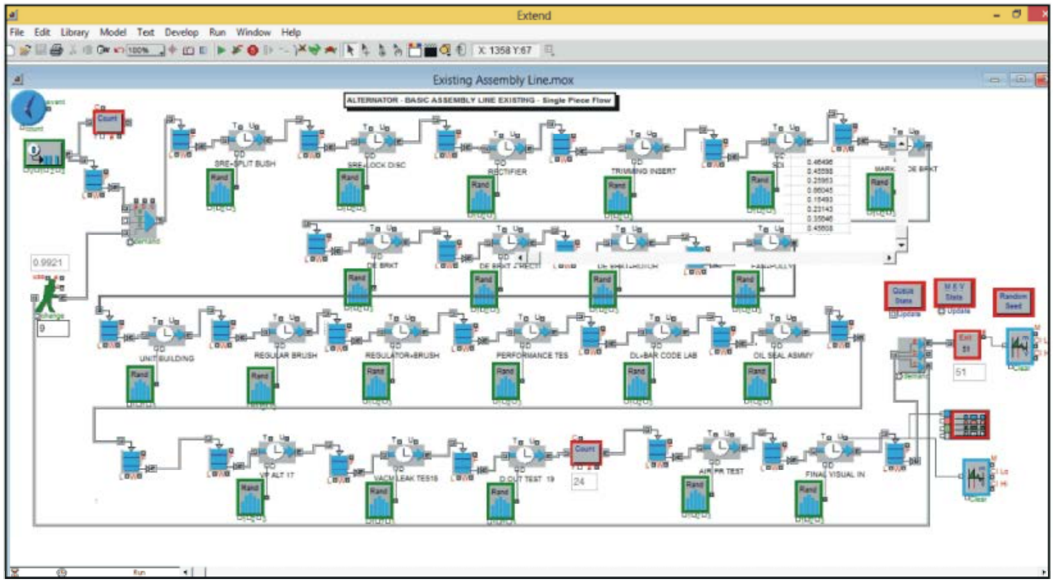

Fig. 4: Snapshot of ExtendSimsimulation model of existing assembly line

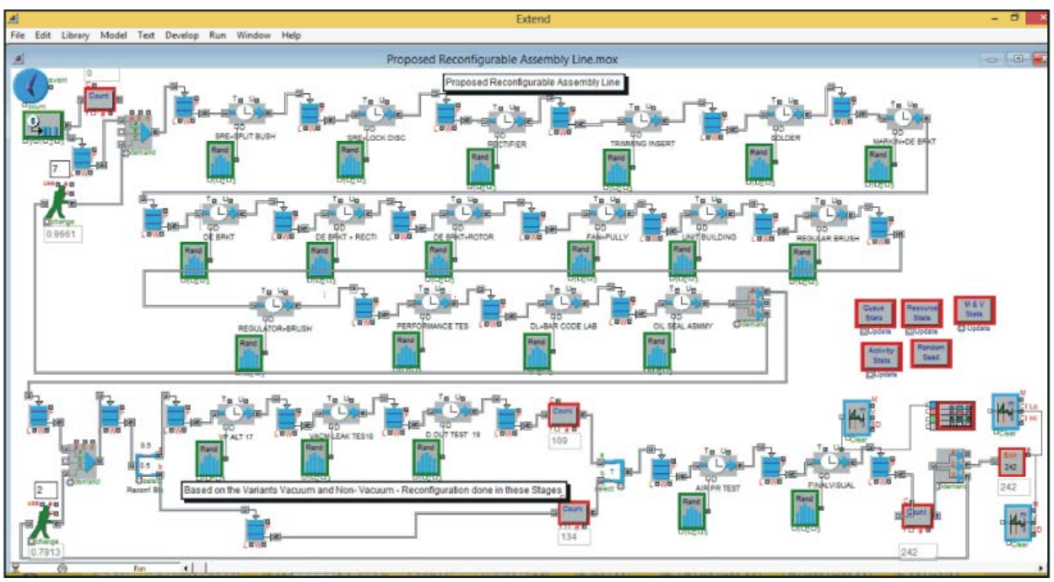

Fig. 5: Snapshot of ExtendSim simulation model of proposed reconfigurable assembly line

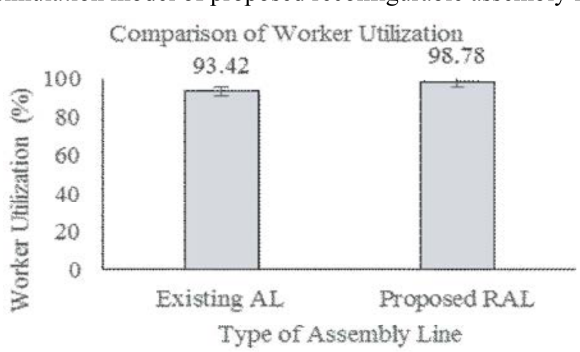

Fig. 6(a): Comparison of Worker Utilization between existing Assembly line(AL) and proposed reconfigurable assembly line (RAL)

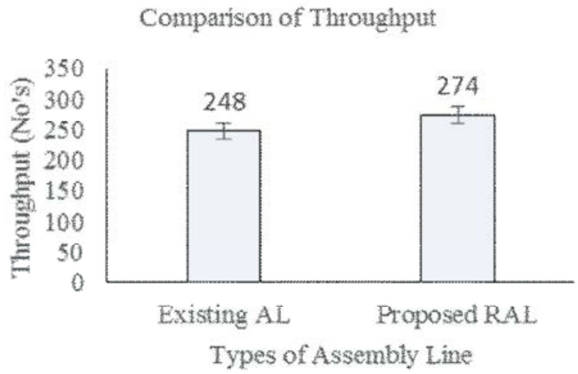

Fig. 6(b): Comparison of Throughput between existing Assembly line(AL) and proposed reconfigurable assembly line (RAL)

Table 2: Comparison of performance of existing and reconfigurable assembly line stage-wise

		Throughput		Utilization	
Stage No	Description of Stage	Existing AL	Proposed RAL	Existing AL	Proposed RAL
1	SRE+Split Bush Assembly	264	285	14.57	14.63
2	SRE+Lock Disc+Oil Seal Assembly	264	285	20.44	20.53
3	Rectifier Assembly With SRE	260	283	33.4	33.79
4	Stator Leads Trimming Positioning Insertion	262	284	49.79	50.1
5	Solder Three Leads	261	284	62.17	62.71
6	Marking+DE BRK + Insert Assembly	260	283	35.03	35.41
7	DE BKT +Bearing Assembly	259	283	46.02	46.66
8	DE+BRK+RET Plate Assembly & Torque Checking	258	282	40.55	41.15
9	DE Bracket+rotor assembly	252	279	19.55	20.01
10	Fan & Pulley Assembly & Friction Checking	257	282	30.92	31.43
11	Unit Building With Bolt Assembly & Torque Checking.	257	281	43.79	44.59
12	Regulator & Bush Box Assembly Torque Checking &Cover Mould Assembly	118	148	20.65	22.43
13	Regulator & Brush Box Assembly	256	281	43.21	44.05
14	Alternator Performance Testing.	255	280	42.72	43.59
15	DLX & Bar Code Labeling.	254	280	24.54	25.08
16	Greasing & Oil Seal Assembly.	253	279	62.54	64.05
17	Vaccum Pump Fixing To Alternator.	253	279	14.62	14.99
18	Vacuum Leak Testing & Static Electrical Testing.	117	148	22.27	24.25
19	Dynamic Performance Testing Of Alternator	116	147	34.06	37.2
20	Air Pressure Testing & Fixing Of Acceptance Stickers	249	274	43.35	44.25
21	Final Visual Inspection & Gauging & Dispatch.	248	274	40.22	41.15
22	9 Workers Assigned	248	274	93.42	98.78

Table 3: Comparison of Overall Throughput and utilization of worker

Parameters	Throughput	Utilization of Worker AL
Existing AL	248	93.42
Proposed RAL	274	98.78

RAL simulation model results optimally with appreciable throughput from 248 to 274 per shift i.e. 10.48 % increase and workers utilization from 93.42% to 98.78 % from Table 3, which is shown graphically in Figure 6(a) and Figure 6(b). Similarly the utilization of all the work stage of proposed assembly line has also improved appreciably from the existing assembly line shown in Table 2.

CONCLUSION

This paper has focused on the development of a discrete-event simulation model of the assembly line that supports the overall operations of alternator assembly line in a case study industry. The proposed reconfigurable simulation model results in increase in throughput and worker utilization when compared to existing assembly line. The reconfiguration of assembly systems based on assembly structure layout with respect to variants flow, facilitates the line to function as mixed model reconfigurable assembly line. Further refinements of the model may include demand variants, with adding more reconfiguration factors like adding new work stage, changing work force (worker), changing the flow of manufacturing etc., could be considered for strengthening the decisions of reconfiguration to meet dynamic demand of variants. The results of the simulation model indicate that the reconfigurable assembly line performance (Throughput, worker and machine utilization) is improved when compared to the existing assembly line.

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