To develop Lean Systems in Electronic Automotive Parts Manufacturing Industry: A System Dynamics Modelling Approach

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***Abstract*—The Electronic Automotive parts manufacturing company produces different types of components that are stored in different buffers. Kanban method is the most standard control methods in practice. The alternative method for this would be Heijunka approach or the production levelling approach which focuses on neutralizing the demand variation. A dynamic systems approach is proposed in this paper to investigate the challenges of implementing production levelling. A model is developed using system dynamics to stabilize the production units. The results obtained in this paper illustrate the concept of Heijunka which helps reduce the fluctuation in the upstream supply chain. Converting of uneven customer demand into predictable manufacturing process leading to better results in the buffers and maintaining minimal inventory is a challenge to be tackled effectively, which has been considered in this research to be the primary objective. The research has resulted in the backlog reduction strategy at the two strategic locations, smoothening of shipment rate, meeting of the desired production rate, better anticipating of order rate, minimization of inventory, better order fulfilment rate, and faster production adjustment.**

***Keywords*—Lean Manufacturing, Production Levelling, Kanban, backlog, Inventory Management, Productivity, Efficiency**.

I. Introduction

Implementing suitable improvement techniques will ensure optimized production with low inventory holding cost and space utilization. Usually, in any company, the material flow will be through a push system. Implementing a pull system will help us reduce the unnecessary stock. Production of big lot sizes, the material will be pushed through production. Unexpected demands will always cause problems in the entire value chain. There should be good communication between the departments to have a fluent flow of information and ease the work. If the communication isn't good enough, then there will be no quick response to changes in the demand which causes fluctuations in the production leading to overproduction or backlogs. Due to all these problems, there came a concept of Heijunka [1] which was introduced by the Toyota Production System (TPS). Heijunka is mainly a Japanese word for levelling the production or distributing the volume evenly [2]. This concept can reduce the maximum wastes, or the non-value-added processes generated during the production. The main principle of lean manufacturing concentrates on determining the value of each specific product with respect to the customers need, distributing the production of various products evenly over a period of time [3]. Instead of producing the same type of products in the same batch, a smaller batch of different products can be produced alternatively. The more the mix is levelled, the more will be the ability of a company to respond to the customers' various requirements [4]. Achieving a levelled production could reduce lead times. This would affect the production rate of the products and achieve an early production cycle. Due to scheduled productivity, the products to be manufactured and the number of units to be manufactured would be known well in advance, and hence the company could produce the products according to the schedule which is prefixed. The schedule usually will be given on a daily basis or a weekly basis. This is set according to the company's requirements, which is decided in the Heijunka meet. Due to the levelling, there would be enough Inventory turns and also reduces overtime and freight costs. That is, the inbound and outbound logistics can also be controlled through levelled production. The more the level of the mix, more consistent can be the customer service. Utilization of assets and capital would be higher, and there would be sustained continuous improvement due to levelled production achieved through lean manufacturing. Implementing Heijunka would help the company to achieve "Every Part Every Interval". To accomplish this, a system dynamics tool can be used which mainly concentrates on solving complex problems with a focus on analysis and design.

The focus of this project is on Electronic Automotive parts manufacturing industry which includes various operations: Supply, Production, Distribution, Inspection, Remanufacturing, Recycling and Disposal. The plant faces problems in the production as there are high fluctuations in demand and also the storage space is very less to hold the present demand. The other problems arising are the changeover time is too high and has to aim in minimizing the process time and cycle time of each machine to achieve higher OEE.

Hence, implementing Heijunka would be a better idea for levelling the production and also reducing the unnecessary waste generators. However, the problem here is, the produced FG is being transported to a warehouse at location two keeping a three days' stock there. Further, as the demand varies, the inventory management in location two as well as a warehouse in location one becomes complex and leads to backlogs. Lack of knowledge of the stock present in both the warehouses causes undefined production.

In particular, the project aims to develop a model on production and inventory along with the daily demand and supply data and also maintain a minimum stock in warehouse location two using a system dynamics simulation modelling approach and to study the influence of demand on the inventory and to evaluate the present system.

Purpose of study

- To develop production to meet the customer demands
- To optimize inventory levels at any given point of time.
- To maintain evenly distributed and steady workflow.
- To apply Heijunka Flow concept.

II. Literature Review

Based on the literature review, the paper recommends that the Lean evaluation devices empower a general review of the execution of lean practices and can recognize lean enhancements. In this article, system dynamics is utilized as a lean evaluation device to survey and enhance lean implementation for a print bundling fabricating framework [5]. This is an examination on System Dynamics Modeling in production network administration concentrates on stock choice and approach improvement, time pressure, request enhancement, inventory network plan and mix, and universal store network administration [6]. The paper showed by acquainting a frame- work progression display with catch the diverse segments of the generation framework. The stock elements of the displayed framework are inspected against various generation situations under stochastic request. The paper proposes some particular administration strategies for fruitful lean application inside the extent of the displayed producing framework [7].

The paper talks about on choices with respect to the time interim for the survey of the limit developments and what amount must be added to the limit considering the venture cost. The concentrate of the paper is on the investigation of survey period interim of the closed loop supply chain framework, to mimic the impact of the audit time frame interim on request, generation limit, overabundance, stock, reuse rate and aggregate benefit [8]. This exploration examined the difficulties of executing generation levelling and related expenses. The model catches different lean tools affecting generation levelling. Relative cost examination between different levelling execution approaches for stochastic request with various items is led. The created display encourages in lean professionals to settle on when and how to execute generation levelling and additionally decide creation parcels sizes [9]. In the paper, it shows a generation and stock framework for remanufacturing utilizing a System Dynamics simulation modelling approach. The point is to investigate the elements of the remanufacturing procedure and to assess system enhancement techniques.

In particular, the examination concentrates on the impacts of scope organization and lead times on the framework which presents push and pull inventory approaches driven fundamentally by the stock coverage. The inquiry about discoveries uncover proficiency in the remanufacturing procedure with a higher remanufacturing limit if the amount of re-manufacturable returns and the remanufacturing lead time are expanded and diminished separately. In addition, an expansion of the generation lead time highly affects the framework execution than a proportional increment in the remanufacturing lead time. Furthermore, we give a contextual investigation both to bolster these discoveries and to additionally approve the created display [10].

III. Methodology and Model Construction

System Dynamics tool is used as the methodology for analysis of previous, current and future situations of production levels. A base model is identified, and the necessary changes can be made to the same model, or a new model can be developed. In this research, a base model is being identified and is being related with the present study and a corresponding new model is being constructed in the following manner.

Identifying the problems where we should work on is the initial step in the system dynamics modelling. Then defining the scope of the project is done and is as important as that of identifying the problems. A theoretical model that is related to the work is built. Once the theoretical model is developed, Identifying the Independent and dependent variables involved must be done which further helps in constructing a conceptual model which becomes the next step. Data pertaining to the study is a collection and is analyzed. Finally, the Simulation of the model developed is done followed by model verification and validation of the results. The following steps are being adopted: Define the problem to be solved; Identify the Dependent and Independent variables and their relationships; Select the suitable software to model; Construct the stock and flow diagram; Formulate the model; Simulate the model; Verify the model; and Validate the model [11].

The Electronic Automotive Parts Manufacturing Company is being considered in this research. Here, the Initial production capacity of MDPS components per day is 2500 per variant. Based on the number of components available in the inventory, further products are being manufactured and are sent to the back-end for final assembly. Once the final assembly is done, it is sent to the warehouse for packaging and shipment. The inventory is a storage unit for each product. Based on the stock available in the inventory the products are being pulled and is sent to the next station.

There is a minimum stock to be held at inventory failing which should be brought to notice to the supervisors or the production head. Z window is being implemented to know the inflow and outflow of the magazines in the inventory. This is maintained through tokens where once the magazine is pulled out from the chute, a token is removed from the Z window and once the magazine is kept in the chute a token is added to the Z window. An upper and lower limit is fixed which tells us the minimum and maximum stock to be maintained in the inventory.

A. Manufacturing Unit Model

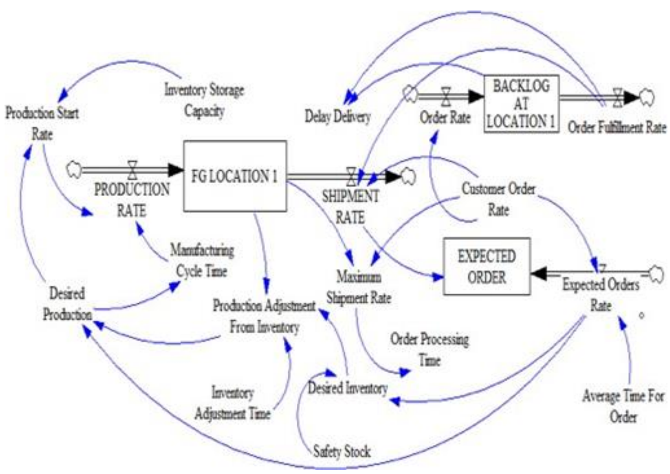

Fig. 1. Stock and Flow Diagram of Bangalore Warehouse Inventory

$$\textit{FG Location 1} = 300000 + \int_0^t (\textit{Production Rate} - \textit{Shipment Rate}) \quad (1)$$

$$\textit{Backlog at location } 2 = 0 + \int_0^t (\text{Incoming Orders} - \text{Order Fulfilment Rate}) \quad (2)$$

$$\textit{Expected orders} = 100000 + \int_0^t (\text{Expected Order Rate} + \text{Shipment Rate}) \quad (3)$$

As shown in figure 1, Finished Goods (FG) LOCATION 1Equation (1) is the FG Inventory Local Body and is viewed as the stock variable whose conduct will be broken down through the chart. The Production Rate (PR) and the Shipment Rate (SR) are the two flow variables. To touch base at the required outcomes, we have to consider the backlogs and the average demand from the customers with the goal that you will know alternate factors influencing the Inventory. FG Inventory Local Body graph is relied upon to have a diminishing cure, and the accumulation diagram additionally diminishes whereas the Expected order rate ought to contain a straight increment or exponential increment curve so that the levelled generation could be accomplished in the FG location 1.

B. Warehouse Model

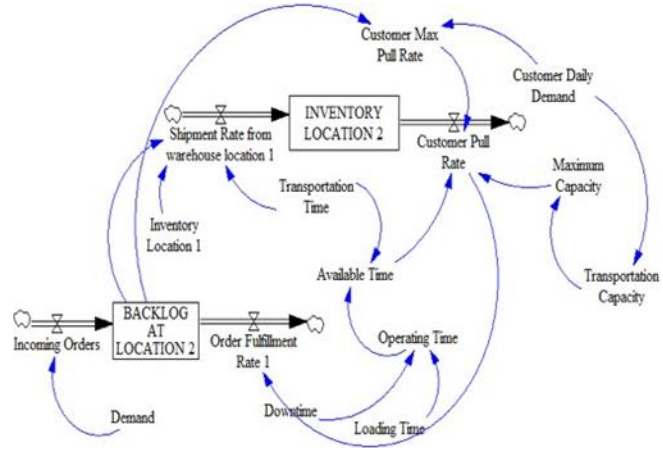

Fig. 2. Stock and Flow Diagram of Chennai warehouse Inventory

$$\textit{Inventory Location 2} = 100000 + \int_0^t \textit{Shipment Rate from Warehouse Location 1} - \textit{Customer Pull Rate} \quad (4)$$

$$\textit{Backlog at Location } 2 = 0 + \int_0^t (\textit{Incoming Orders} - \textit{Order Fulfilment Rate } 1) \quad (5)$$

From the figure 2, it can be referred that inventory location 2 Equation (4) will have an effect on the shipment rate from warehouse location one and furthermore the customer pull rate. Inventory location two is relying upon the shipment rate, available time, transportation time and the customer pull rate. These factors help us break down the conduct of the FG Inventory and settle on the stock to be kept in the inventory location 2. Shipment rate from warehouse location 1 is the major influencing factor on the inventory at location 2 and the order fulfilment rate 1. As the shipment time is reduced the inventory at location 1 is reduced hence making a way to maintain minimum inventory levels helping the company cut the inventory holding cost.

C. Inventory and Kanban model

$$\textit{Inventory} = 5000 + \int_0^t (\textit{Production Rate } 1 - \textit{Magazine Outflow}) \quad (6)$$

$$\textit{Inventory Location } 1 = 1200 + \int^t (((\textit{Production Orders} - \textit{Production Completion Rate}) / \textit{Shipment Rate } 1) \times \textit{Total Number of Kanbans}) \quad (7)$$

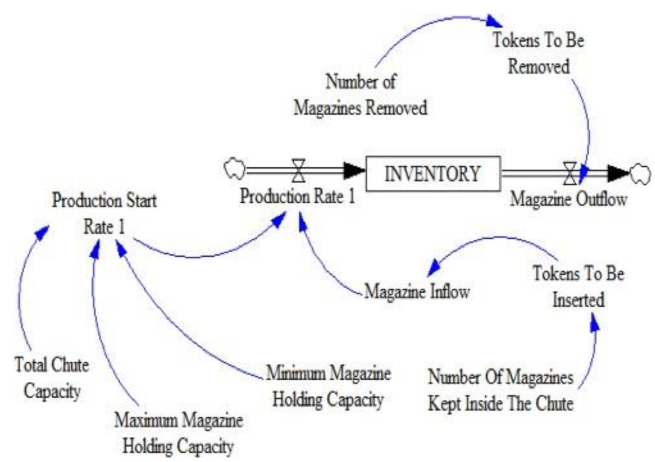

Fig. 3. Stock and Flow Diagram for Inventory

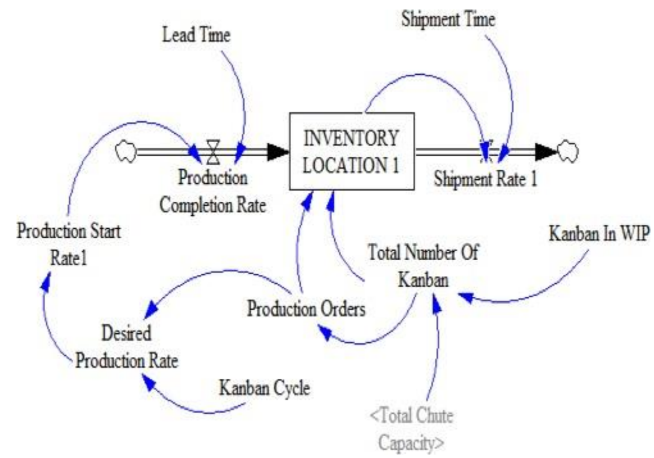

Fig. 4. Stock and Flow Diagram of Kanban System

These models will further be consolidated and will be recreated to check the conduct among each other and think of a delightful outcome where it demonstrates the stock to be levelled with least consumption on Quality. We will likewise take a look at how the Kanban framework is influencing the generation rate, and the shipment rate, what is influencing the creation rate and how it can be adjusted and furthermore to beware of is there a huge impact of stock on the generation begin to rate. The application of the same can be seen in figure 3 and 4.

The above model shows the impact of expected order rate on FG location 1 and the desired production. One might say that, although there is an expansion in the backlog at location 1, there is an equivalent impact of it on the stock. Because of average time for orders, the shipment rate from warehouse location 1 to warehouse location 2 will have a more prominent effect and will permit us to recognize what ought to be the base time for the requests. If the travel time is decreased, then the stock in the stock can be kept up as per the customer demand. The essential idea here is to keep up least stock and satisfy the customer demand any time of time. Regardless of whether there is any adjustment in the timetable or high variance with the customer demand, the point is to take care of that demand. Henceforth creating different items in little groups in a solitary day, rather than delivering extensive clusters of a similar item around the same time, would permit us to have a load of different items and will have the ability to satisfy the prerequisite of any result of any variation at any given purpose of time. Planning is a piece of Heijunka flow system, where the organization sets the amount and the item to be created in the whole week by careful exchange with the bosses, administrators, generation head, line head, plant head, extend head and every one of them together concurring with the arrangement, they set the calendar and is shown on the Heijunka board in the shop floor and in like manner the plant works.

IV. Simulation and Analysis

Various graphs that are influencing the stock variables are also plotted along with the graphs for the stock variables. The other variables having very high effect apart from the stock variables are also plotted. To achieve best results in Heijunka implementation, the major role is played by the inventories and the ability of the company to fulfil the desired demand of the customer at any given point of time.

Reducing backlog would help the company eliminate the unnecessary stock in the warehouse. But in this case, there are two warehouses which we are calling local body and foreign body, i.e., FG location 1 and FG location 2.

A. Backlog at location 1

Figure 5 shows that the backlog at location 1Equation (2) has a direct effect on the customer order rate at location 1 and customer pull rate at location 2, and previous orders to reach the end customers would take much time before the next order is received, and not knowing which product to produce prior to the order received, and the product stock is not available on the basis of order received, the backlog piles up at location 1ence should be ready with the products. Hence to minimize the cost of inventory at location 1, a concept called the supermarket is being included where the inventory will be maintained as per the supermarket's inventory. Hence, the graph below of the backlog at location 1 increases. As there is a high influence of backlog at location 1 on customer order rate, which intern affects expected order rate, will have a close impact on the FG location 1. Maintaining FG through an additional inventory concept which works on the basis of Kanban would help reduce the backlog.

B. Backlog at location 2

Because of the shipment rate from warehouse location 1 and the average time for orders, the backlog at location 2 Equation (5) will be influenced definitely. It can be inferred from figure 6 that initially, there is an upstream in the chart, and on a slow scale, the diagram diminishes and achieves a point where the backlog is streamlined. This has perfect conduct where excess increments quickly at the underlying stage in the wake of actualizing heijunka and on a later period the diagram kills and achieves a standard check, which implies there is no overabundance. As indicated by the chart, the backlogs get disposed of only after the 32nd week in the wake of actualizing Heijunka. For the initial 32 weeks, the excess increments. The diagram begins diminishing at the twelfth week and achieves an enduring state at the 32nd week. From 12th week to 28th week the diagram diminishes quickly.

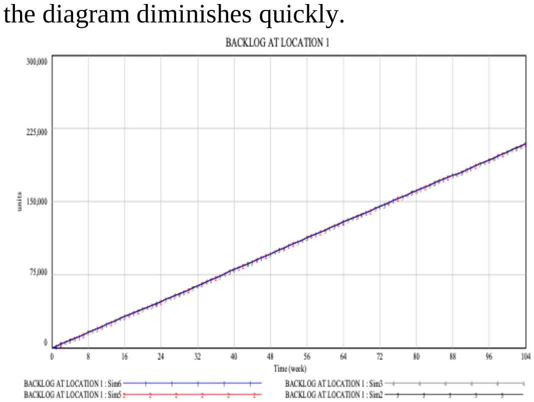

Fig. 5. Backlog at location 1

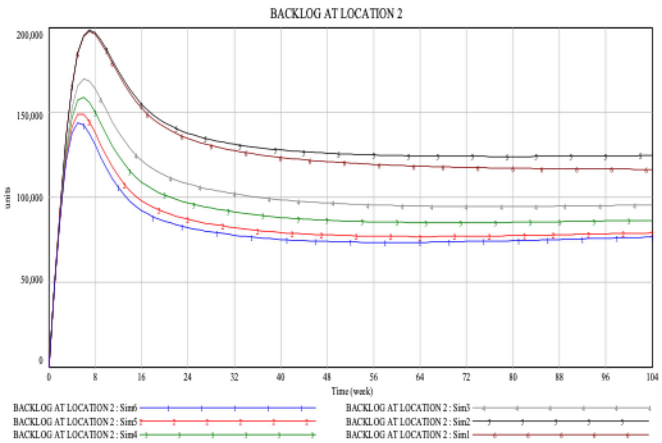

Fig. 6. Backlog at location 2

C. *Shipment rate from warehouse location 1*

Finished goods from the warehouse at location 1 is sent to the warehouse at location 2. Figure 7 shows that the time taken for the FG to achieve warehouse 2 is at first considered to be three days, and the conduct is checked. It is seen that there is adjusted conduct for four back-to-back outcomes. At the fifth and sixth outcome, it is understood that the diagram begins taking a jump. Given this conduct, one might say that the shipment time ought not to surpass 15 hours. If the transit time expands then the overabundance at location 2 additionally increments in like manner. Because of the impact of transit time on different parameters, for example, order fulfilment rate and backlog at location 2, there is a noteworthy impact on the inventory location 2. In this diagram, it is observed that, if the average time for orders increments and goes past 60 hours the chart begins expanding once more. Subsequently, we can construe that the average time for orders ought not to go past 60 hours.

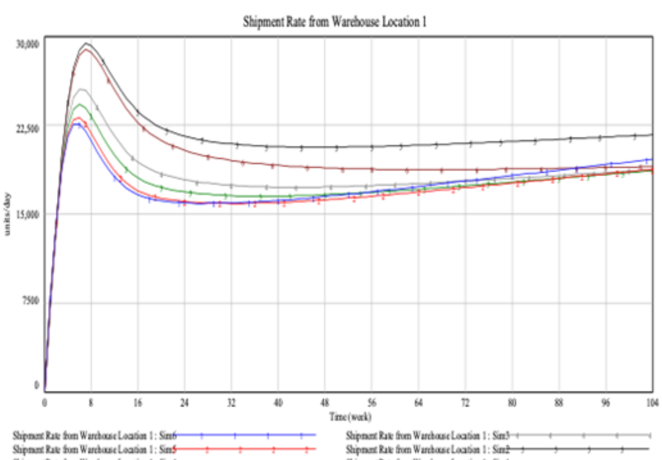

Fig. 7. Shipment rate from warehouse location 1

D. *Desired Production*

The desired production is an influencing factor on production start rate and manufacturing cycle time. It is based on the orders received from its customers. According to the orders received, a schedule is generated in a contract meeting for a week or a month or on a daily basis as per the comfort of the company. Once the schedule is generated the production takes place according to the plan hence meeting the customers' requirements. As in figure 8, it can be seen that there is a growth in the production for a certain period, precisely for eight weeks after the implementation and it is also seen that after 28 weeks, the production levels come down and there would be minimum production in the plant. Allowing which would cause less additional stocks to pile up. Hence, maintaining minimum stocks and producing just what is required and how much is required. After the 32nd week, the desired production has minimal variations; still the target production is reached at every stage.

E. *Expected Order Rate*

This is a natural phenomenon where the orders keep increasing. Hence, the expected order rate graph, as shown in figure 9, keeps increasing. The aim must be to fulfil the expected orders Equation (3) at each time interval. For the first eight weeks, the growth is equal for all the inputs. After the 8th week, there is a gradual increase in the expected orders.

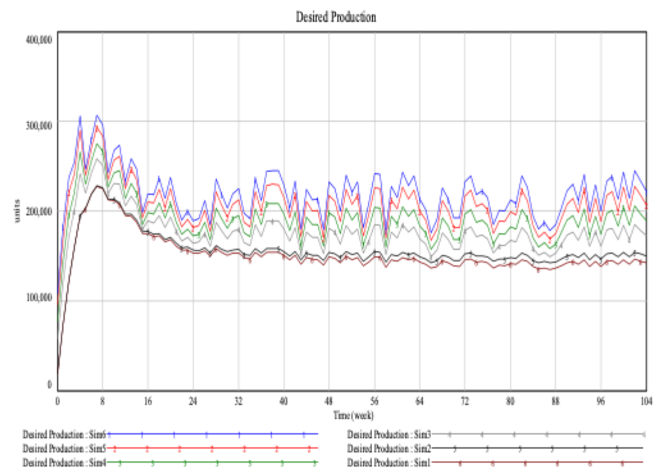

Fig. 8. Desired Production

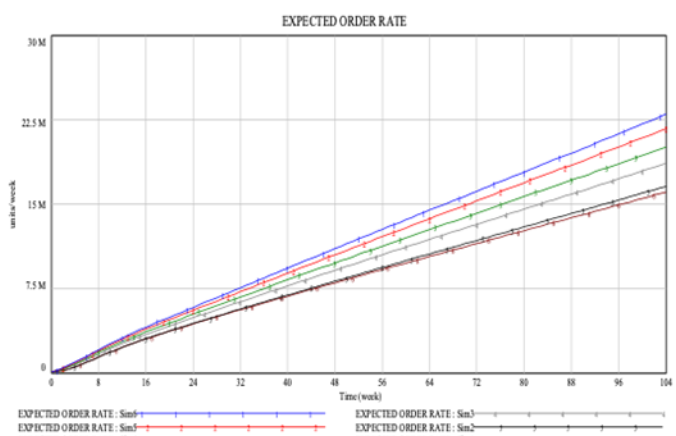

Fig. 9. Expected Order Rate

F. *FG Location 1*

As shown in figure 10, the finished goods at location 1 decrease in as respects because of use of supermarket concept and the Kanban process. The increase in backlog at location 1and the Inventory gets nullified due to the continuous shipment of goods from the FG location 1 to FG location 2. The aim was to achieve the Heijunka concept at location 1, and hence the FG location 1 graph serves the purpose and defines the required result with absolute results. The production rate and the shipment rate of previous m/c influences the production at location 1 when simulated for 104 weeks, its seen that the graph is continuously decreasing and reaches a minimum value of 75000 units per week. This shows that in the further weeks the inventory will be as minimum as possible and simultaneously the orders are being fulfilled immediately without having any backlog.

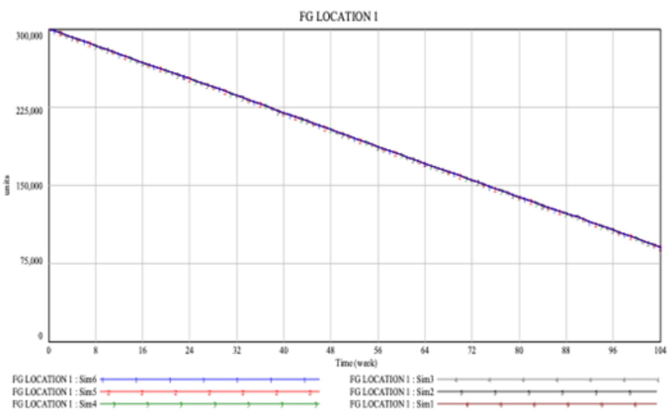

Fig. 10. FG Location 1

G. *Inventory Location 1*

Figure 11 indicates the warehouse at location 1Equation (7). There is a gradual increase in the graph which indicates that the stocks in the warehouse are increasing with respect to time. This increase remains only till the stocks are shipped to the warehouse at location 2. Once the shipment is carried out, the graph drops down, and the stocks in the inventory go down making a place for new stocks to take over the place.

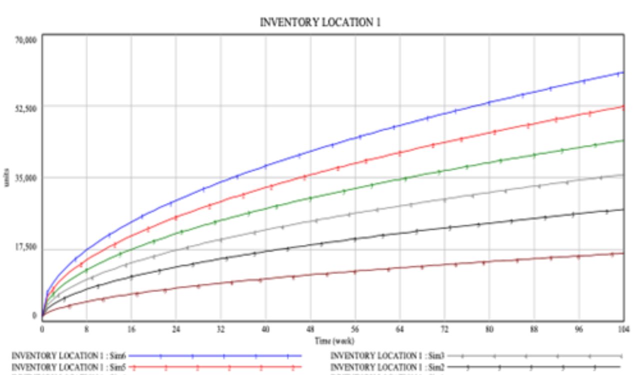

Fig. 11. Inventory location 1

H. *Inventory*

Inventory here is an additional storage unit where the FG from the front end is kept as a buffer before it is sent to the assembly end Equation (6). As shown in figure 12, the stocks in the inventory going down indicate there is minimum buffer maintained. As the inventory is going down, it describes that the production is going as per the plan, and the target for each day is reached and the demand is met at each stage.

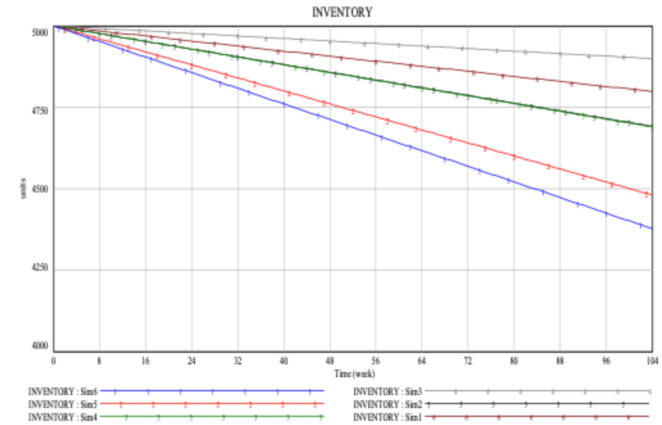

Fig. 12. Inventory

I. *Order Fulfilment Rate 1*

The rate at which the incoming orders are being fulfilled is the order fulfilment rate. The rate at which the end product is reaching the end customer from the warehouse at location 2 gives the order fulfilment rate 1. In figure 13, initially the graph is rising rapidly till 60000 units. For the first 8-9 weeks, the graph increases and with a smooth curve it starts decreasing at the 9th week and reaches a steady point where there will be no increase or decrease in the graph. This is the stage where the plant has achieved the proper Heijunka flow system. This shows that in the future the process continues without any disturbance. Hence, could be told that demand is met by the company at every point of time after the 9th week of implementation of Heijunka.

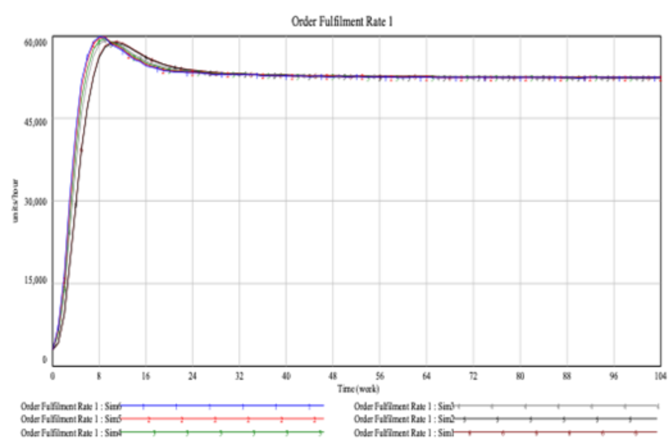

Fig. 13. Order fulfilment rate 1

J. *Production adjustment from inventory*

Figure 14 shows that there is not much inventory adjustment required after the implementation of Heijunka. There are very minute adjustments to be done in the inventory to meet the demand. Till Heijunka is achieved successfully, there is a lot of adjustments in the inventory. As we can see in the graph, starting, the inventory adjustment is too high, and gradually it decreases over time, and after 8th week the adjustment is very low and from then keeps decreasing. At 104th week it can be seen that there is not much of adjustment required. In the above graph, it can be stated that the Heijunka is implemented successfully and all the production levels are stabilized.

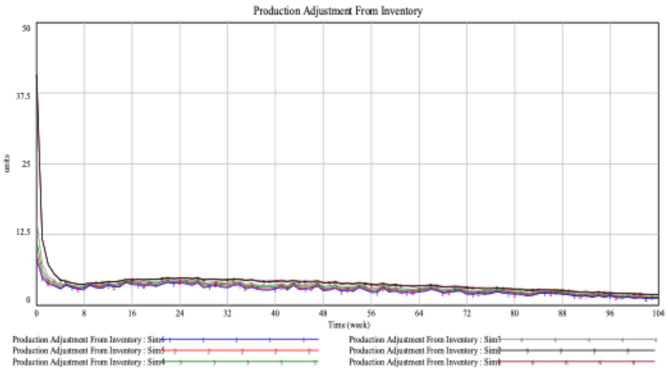

Fig. 14. Production adjustment from inventory

K. Managerial Implications

Backlog at location 1 has a direct effect on the customer order rate at location 1 and customer pull rate at location 2 and previous orders to reach the end customers would take much time before the next order is received, and not knowing which product to produce prior to the order received, and the product stock is unavailable on the basis of order received, the backlog piles up at location 1. Because of the shipment rate from warehouse location 1 and the average time for orders, the backlog at location 2 will be influenced definitely. Because of the impact of transit time on different parameters, for example, order fulfilment rate and backlog at location 2, there is a noteworthy impact on the inventory location 2. In this diagram, it is observed that, if the average time for orders increments and goes past 60 hours the chart begins expanding once more. Subsequently, we can construe that the average time for orders ought not to go past 60 hours. The growth in the production for a certain period, precisely for eight weeks after the implementation and it is also seen that after 28 weeks, the production levels come down and there would be minimum production in the plant. Allowing which would cause less additional stocks to pile up. This is a natural phenomenon where the orders keep increasing. Hence, the expected order rate graph keeps rising. The aim was to achieve the Heijunka concept at location 1, and hence the FG location 1 graph serves the purpose and defines the required result with absolute results.

There is a gradual increase in the graph which indicates that the stocks in the warehouse are increasing with respect to time. This increase remains only till the stocks are shipped to the warehouse at location 2. Once the shipment is carried out, the graph drops down, and the stocks in the inventory go down making a place for new stocks to take over the place.

This shows that in the future the process continues without any disturbance. Hence, could be told that demand is met by the company at every point of time after the 9th week of implementation of Heijunka. There is not much inventory adjustment required after the implementation of Heijunka.

V. Conclusion

The primary objective of this study was to optimise inventory levels by using Heijunka flow concept. Stock and flow models were constructed using the system dynamics methodology for analysing factors related to inventory management. Apart from the other findings, as illustrated in the analysis, one of the primary findings of the study is that it would take less shipping time to go for small batches of delivery of different/unique items rather than going for bulk delivery of a single item. It is recommended through the study that additional inventory need to be maintained for minimizing backlog. It is found that Heijunka is the most effective technique to stabilize the stock levels. The research has effectively identified the critical weeks of operation for each of the parameter under consideration, which may be used by the electronic automotive company under study.

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