

# **Delivery Service through an Integrated Inventory Management Model using a System Dynamics Model**

P.Raghuram<sup>1</sup>, Mridula Sahay<sup>2</sup> and P.G.Saleeshya<sup>3</sup>

<sup>1,2</sup>Department of Mechanical Engineering,  
Amrita School of Engineering  
Amrita Vishwa Vidyapeetham University  
Coimbatore, T.N., India

<sup>2</sup>Amrita School of Business  
Amrita Vishwa Vidyapeetham University  
Coimbatore, T.N., India

Corresponding Author - <sup>2</sup>[mridulasahay2001@hotmail.com](mailto:mridulasahay2001@hotmail.com), [mridulasahay@gmail.com](mailto:mridulasahay@gmail.com)

## **ABSTRACT**

A pull production system is a make-to-order environment where manufacturing is started only after customer order is received and hence demand is confirmed. In an environment having dominant flow path for the products, it offers challenging scope for the management and control of raw material, work-in-process and finished goods inventory. Literature and industrial practice suggests a variety of heuristic models used to control inventory to optimal levels. Estimating and knowing the current and future inventories to be maintained is essential to sustain the material flow throughout the planning period. In this paper, we develop an integrated inventory control model integrating the demand and component material flows in a multi-customer, multi-product environment using system dynamics simulation modeling. We have simulated the model in a pull production system where the complete cycle depends on the customer order. The inventory level and structure are linked to delivery service and in effect to competitive advantage.

## **Keywords**

Inventory Management, Delivery, system Dynamics

## **1. INTRODUCTION**

Inventory is a double-edged sword in the manufacturing world. When the capacity is not able to produce to customer requirement, it is a boon; when things are flowing smooth, inventory is a waste of money (Verwater-Lukszo & Christina, 2005). Whatever the cost incurred, companies are expected to offer the right products at the right time in right quantities. Customized design and order fulfillment in a make-to-order system offers a day-to-day challenge in controlling inventory for the manufacturer. Stable demands, varying operation times, varying setup times, intermittent material flows, lack of transparent internal and external communication and high product mix are some of the characteristics of manufacturing which increase inventory (Minner, 2003). Two main objectives to be fulfilled are, primarily the level of inventory required to maximize customer order fulfillment, specified in terms of customer demand and finished goods inventory and secondly, the amount of in-process inventories specified in terms of flow of material and the amount of inventories must be able to keep up to the delivery service (Vastag & Montabon, 2001). Regulating the input flow on work released to production and the output flow to the customer based on the volume of work and flow times determines the trade-off between these two contradictory objectives. When the range of requirement is larger, the greater is the number of problems of investment, procurement, storage, holding, accounting, shortage and stock out deterioration (Wanke, 2010).

Inventory accumulation and management has been studied in isolation as a manufacturing domain problem rather than as a systemic domain problem (Angerhofer & Angelides, 2000). System dynamics (Forrester, 1958, 1997; Richardson, 2011) offers a platform to include the many variables of the system which affect the inventory. The model allows us to understand the feedback from each of the variables. In most realistic stock management situations, the complexity of the feedbacks among the variables precludes the determination of the optimal strategy (Sterman, 2000, 2001). The objective of this paper is to formulate a model to optimize the total system inventory by simulating a system dynamics (SD) model considering the systemic domain. The metrics used to optimize the SD model are customer order fulfillment and the actual amount of material inventories at the various stages, viz., raw materials, work-in-process and finished goods. The fundamentals of inventory management, system dynamics and various inventory models in system dynamics literature are briefly dealt with through a literature survey. We define the problem of inventory control in pull manufacturing and model formulation in SD. The simulation of the SD inventory model and the obtained results are also discussed.

## 2. LITERATURE REVIEW

Considering the importance of inventory control, there is a vast amount of literature that deals with inventory classification, inventory control and inventory reduction. There is a need to understand the factors affecting the three types of inventories, the conventional inventory control mechanisms and models, the framework of system dynamics modeling and the inventory models dealt with by the system dynamics literature.

### 2.1. Inventory Management

Inventory management deals with management of stock either on value or quantity basis. Here, we are considering the inventory on quantity basis. There are two types of factors affecting inventory management, viz., external and internal factors. The external factor arises from market conditions, credit availability and government regulation. The external factors are not easily controllable while the internal factors are under the control of the management. The internal factors influencing the inventory decision of an organization are lead time and supplier selection criteria (Bottani & Rizzi, 2008). Lead Time, defined as the period that elapses between the order and its fulfillment. Inventories of raw materials have to take care of normal consumption during procurement lead time (Rego & Mesquita, 2015). Procurement lead time is dependent on external suppliers, where the reliability of the supplier, stability of lead times and quality should be taken care of while negotiating the order and supply detail. Having a tested supplier selection criteria will ensure a stable flow of raw material inventory.

Inventory can be classified as raw material (RM) inventory, work-in-process (WIP) inventory and finished goods (FG) inventory. This classification is useful in tracking the material flow as the product moves downstream. The inventory can be classified based on the stage of processing and the point of entry and use as follows.

**Raw material (RM) Inventory:** The unprocessed parts waiting to be manufactured in the stores or inside the shop floor is called as RM Inventory. Raw materials are those units that are converted in to finished products through manufacturing or are purchased and stored for future.

**Work-in-Process (WIP) Inventory:** It refers to goods which are semi-finished products in the intermediate stage of production. WIP inventory is dependent on the throughput and cycle time of the job. It depends on the production rate, processing times, setup times and throughput rates. It should be understood that WIP inventory cannot be eliminated fully and some buffer is needed to be maintained. This is to ensure that we do not run out of parts in case of production stoppages for machine downtime or material shortages. Paradoxically, we should also ensure that excessive WIP inventories are not maintained since it may increase the lead time, unnecessary stock and the holding cost. Other issues such as obsolescence of the product, bottlenecks and obstructive flow of work can be avoided.

**Finished Goods (FG) Inventory:** The number of products waiting to be delivered to the customer is called as FG Inventory. In a pull system, as in a job shop where we process jobs only on the basis of customer demand, finished goods consist of final products that are ready for sale. Finished goods are those completely manufactured products which are ready for sale. Stock of material and WIP inventories facilitate production, while stock of finished goods is required for smooth marketing operations. Thus inventories serves as a link between production and consumption of goods.

The factors affecting the three types of inventories are as listed in Table 1.0. The inventories at the previous stage affect the quantity at the next stage.

**Table1: The factors affecting various types of inventories**

RM Inventory	WIP Inventory	FG Inventory
Ordering frequency	• Flow time	• Product mix
Volume of Work	• Cycle time (Setup time + Operation time)	• Safety Stock
Variety of Work (Product mix)	• Frequency of setups	• Lead time demand
Supplier lead time	• Product mix	• Actual Sales
Reorder Level	• Capacity	
RM Safety Stock	• Throughput	
Lot sizing policy	• Customer demand	
	• Forecast demand	

## **2.2. Inventory Control In Manufacturing**

Inventory in the shop floor is maintained on the basis of departmental segregation. The different managers maintain the inventory based on their individual calculations and judgment, and hence may result in interdepartmental dynamics, similar to the bullwhip effect across the supply chain. Centrally maintained inventories based on the customer order fulfillment will result in a better coordinated system. Having a systemic view of the inventories across departments will help the shop floor in decreasing the cost of the total inventories in the system. Optimal levels of the inventories throughout the material and operation flow will enhance the shop floor's capacity to estimate and maintain accurate costs, remain flexible, improve responsiveness, optimize production capacity, track inventories and remain committed to customer orders.

In earlier periods, periodic inventory system was prevalent. Inventory used to be accounted for physically at the end of the year by taking stock and a physical verification of inventory is done. In this non-continuous system, it may not be possible to account for the calculation of work in process inventory. With the advent of computerized accounting system, purchases are entered immediately and point-of-sale records are maintained on a continuous basis. This ensures that the physical inventories and the inventories on record are the same any time of the year. This system of maintaining inventories is known as perpetual inventory system. In the perpetual inventory system, the calculation of inventory depends on the amount of purchases, current inventories and the shipments made and can be calculated easily. Of course, we assume that these entries are made correctly and also immediately. (Golini & Kalchschmidt, 2011; Kreng & Chen, 2007; Pejić-Bach & Čerić, 2007).

## **2.3. System Dynamics in Inventory Control**

### **2.3.1. System Dynamics**

Developed by Forrester in 1961, system dynamics is a way of thinking about the system as a whole. Instead of focusing on the discrete events, we need to move back deliberately and see the system as a whole for behavior patterns. System dynamics has created complex dynamic models and has affected policy decisions in the areas of climate change (Kunsch & Springael, 2008; Sahin et al., 2014), population control (Forrester, 1971), public policies (Sterman, 2000; Wolstenholme, 1983), environmental studies (Kaneko & Nojiri, 2008), social systems (Forrester, 1971), management (Warren & Langley, 1999; Zhang et al., 2012) and supply chain management (Angerhofer & Angelides, 2000; Masoumi et al., 2012). Selective abstractions of reality are used to construct mental models based on historical data and then test them on current data so that we can foresee futuristic results for different scenarios.

All dynamic systems are characterized by interdependence, mutual interaction, information feedback, and circular causality (Sterman, 2001). When we take decisions for individual events, it is called as reactive thinking; when we see the behavior patterns and adjust our approach accordingly, it is called as adaptive thinking; when we see the system as a whole and focus on policy decisions, it is called as systemic thinking. Having a systemic perspective helps us to perceive decisions as affecting not only the individual events, but the system as a whole (Thompson et al., 2014). Also, systemic structure affects the decisions we take decisions for events (Richardson, 2011). In effect, we can say that the performance of the system is dependent on the architecture of feedbacks and time delays. It is especially suited to inventory management since material flow as well as information flow has time delays. Feedback is an important aspect of system dynamics. Taking feedback from the system, systems thinking helps in redesigning the structure of the system. Feedback which causes the observed behavior is explicitly included in the system dynamics model. Using reinforcing and balancing loops of causality, it generates dynamic patterns of behavior (Sweeney & Sterman, 2000).

### **2.3.2. Inventory Control in System Dynamics Literature**

Applied widely in the area of supply chain, system dynamics is well suited to the study of inventory management. The material flows and the effects of feedback can be studied in the context of inventory management and shipping policies. Feedback maintains the balance of the system or keeps it within limits and acts as a control mechanism. It usually dampens oscillatory behavior – stock-outs, long supply, or obsolete inventory items, for instance. Inventory flow is similar to a bathtub (Sterman, 2001) as water flows in at a certain rate, and exits through the drain at another rate. We can model and forecast the level of inventory based on the flow rates. Airline's management of fuel inventory is usually found to be in excess to avoid stockouts which increases the cost of the inventories (Al-Refaie et al., 2010). This is similar to many manufacturing industries which maintain excess inventories in view of fluctuating demand requirements. Poles (2001) has explored closed loop supply chains in which the residence time of the product with the customer and customer behavior in returning the products is considered in increasing the efficiency in the management of inventories (Poles, 2001). In the next section, we formulate integrated inventory control model integrating the demand and component material flows in a multi-customer, multi-product environment that will ensure customer order fulfillment and delivery service requirements.

### 3. PROBLEM AND MODEL FORMULATION

The model formulation approached through system dynamics modeling keeps track of the amount inventory and work flow throughout the system as it is converted from raw material to finished goods. In this model, we are not using sale cash flows and purchase costs which are normally used in accounting. We also assume that the purchase of inventories is owned by the companies and are to be solely used for the manufacture of finished goods. Arrays are widely used throughout the model. The following arrays are defined in the hypothetical model. Customers are defined as 'Customers' dimension with three elements, products as 'Products' dimension with three elements, stock keeping unit as 'SKU' dimension with four elements, raw material inventory as 'SKU Inv' dimension with one element and safety stock as 'SS' dimension with one element. A hypothetical scenario is assumed to define the problem and can be summarized as follows.

Multiple products (three products, viz., Prod 1, Prod 2, Prod 3) are manufactured by a company. A number of customers (three customers, viz., Cust 1, Cust 2, Cust 3) are ordering varying volumes of the products. Here, it is assumed to be a steady demand throughout the year. Different monthly demands can also be incorporated into the model. The products are made of four parts, called as stock keeping units (SKU#1, SKU#2, SKU#3 and SKU#4) in the model. Varying combinations of the SKUs are required for each product. In this scenario, finished goods are manufactured to fulfill the customer orders. A maximum shipping limit is taken and the goods can only be delivered to the customer up to the maximum shipping. Safety stock of finished goods as well as raw materials is assumed. The raw material inventory (RM Inventory), work-in-process inventory (WIP Inventory) and finished goods inventory (FG Inventory) are to be calculated in this scenario. The resulting levels are tabulated along with graphs showing the time-variance of the inventories. A stock and level diagram, drawn using ISEE System's iThink software v10.1.2, is used to represent the formulated problem and is described in detail along with the formulae used in the model in the following section.

#### 3.1. Causal loop diagram

The integrated inventory management model is depicted in the causal loop diagram shown in Fig. 1.

#### 3.2. Stock and Flow Diagram

The formulated inventory model is represented as a stock and flow diagram as shown in Fig. 2. These initial values and the formulae are represented by the following sample equations, as shown through the description of the system dynamics model. Similarly, the other formulae are entered. The inventories of raw materials, work-in-process and finished goods at the end of each month is to be determined. The inventories at the end-of-year are found out and the flow of material can be tabulated, as shown in Table 1. These inventories are given initial values, as RM INVENTORY[SKU#], WIP INVENTORY[PRODUCT] and FG INVENTORY[PRODUCT].

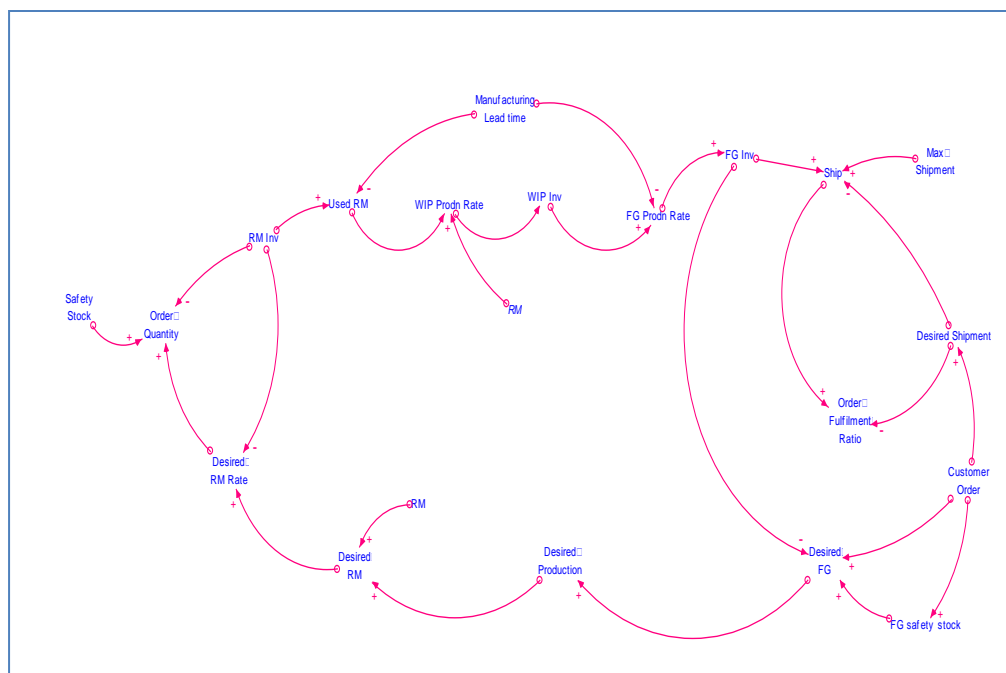
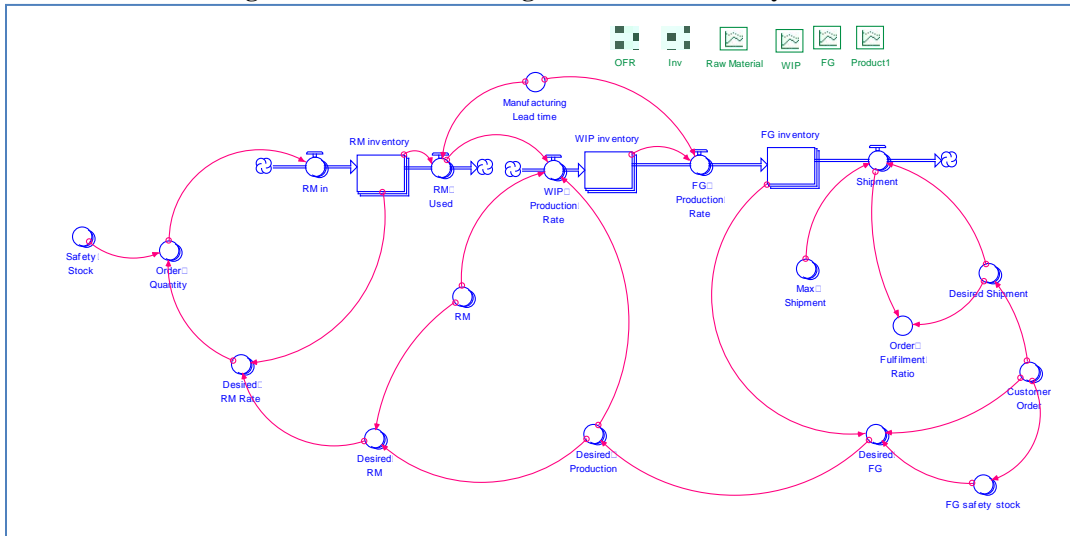
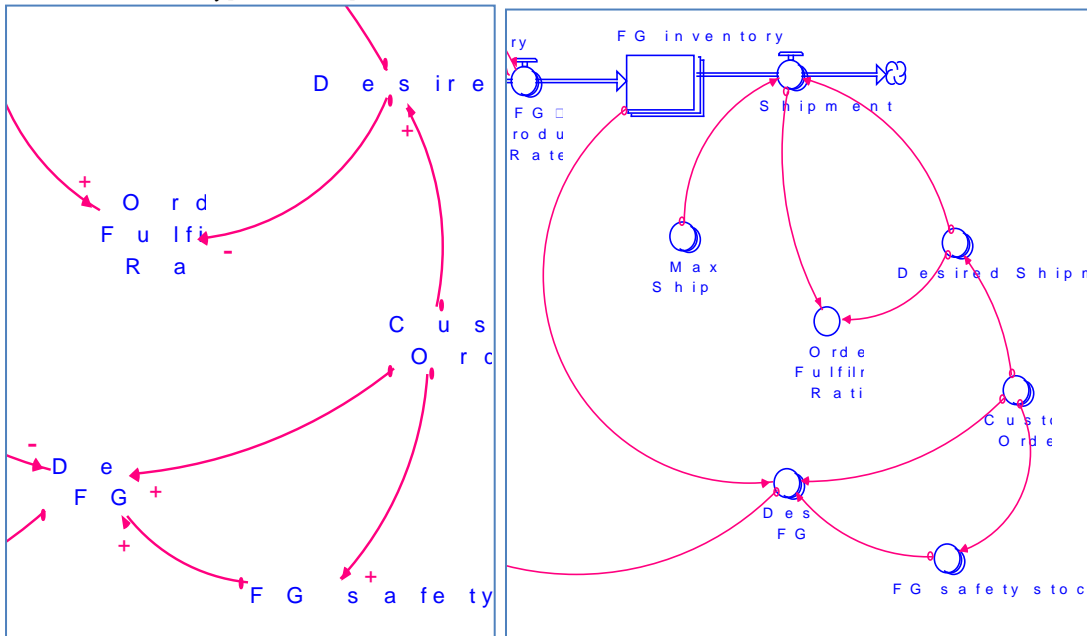


Fig. 1. Causal loop Diagram for the Inventory model

**Fig. 2. Stock and Flow Diagram for the Inventory Model**



*INIT RM\_inventory[SKU#1] = 20*  
*INIT WIP\_inventory[Product\_1] = 10*  
*INIT FG\_inventory[Product\_1] = 100*



**Fig. 3. Customer Order Module – Causal loop and Stock and flow diagrams**

As already discussed in the previous section, the customer orders are given by various customers for a number of products. In this model, we have considered three customers who order three different products with varying amounts. The customers are represented through an array along with the products that they are ordering as CUSTOMER\_ORDER[CUST, PRODUCT].

*Customer\_Order[Cust\_1, Product\_1] = 100*

**Table 2. Customer order for each product**

	Customer	Product 1	Product 2	Product 3
Customer Order	Cust1	100	50	200
	Cust 2	150	30	230
	Cust 3	250	100	100

The customer order for each product is given as shown in Table 2 and are defined in the array as seen in Fig. 3. Then the safety stock of finished goods, FG\_SAFETY\_STOCK[PRODUCT] is calculated and added for each product.

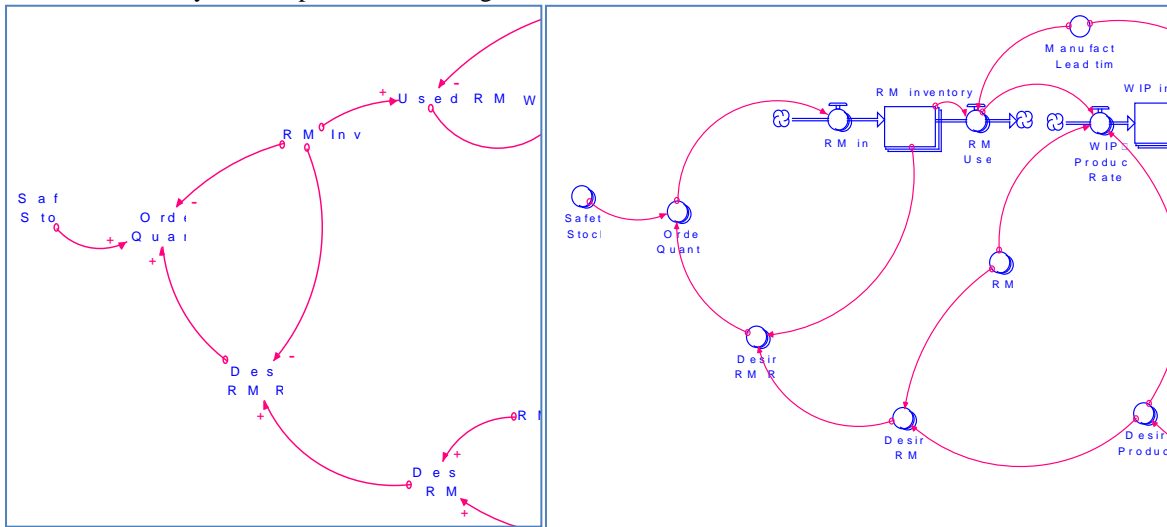
$$FG\_safety\_stock[Product\_1] = .1*(Customer\_Order[Cust\_1, Product\_1]+Customer\_Order[Cust\_2, Product\_1]+Customer\_Order[Cust\_3, Product\_1])$$

The customer orders and the safety stock can be added to get the desired number of finished goods, DESIRED\_FG[PRODUCT]. Since we already have finished goods inventories, FG INVENTORY[PRODUCT], we need to subtract this from the desired number of finished goods.

$$Desired\_FG[Product\_1] = (Customer\_Order[Cust\_1, Product\_1]+Customer\_Order[Cust\_2, Product\_1]+Customer\_Order[Cust\_3, Product\_1])+FG\_safety\_stock[Product\_1]-FG\_inventory[Product\_1]$$

### 3.2.1. Raw Material Subsystem Loop

The requirement of the finished goods is converted to the desired raw materials in the first subsystem, viz., the raw material subsystem loop, as shown in Fig. 4.



**Fig. 4. Raw Material Subsystem Loop – Causal loop and Stock and flow diagrams**

The finished goods requirement is passed on to DESIRED PRODUCTION[PRODUCT] and then is converted into the number of raw material required, DESIRED RM[SKU#], which gives the number of stock keeping units (SKU#1, SKU#2, etc.) that are required.

$$Desired\_Production[Product\_1] = Desired\_FG[Product\_1]$$

$$Desired\_RM[SKU\#1] = (Desired\_Production[Product\_1]*RM[Product\_1, SKU\#1])+(Desired\_Production[Product\_2]*RM[Product\_2, SKU\#1])+(Desired\_Production[Product\_3]*RM[Product\_3, SKU\#1])$$

These values can be calculated from the array which gives the number of raw materials that are required to produce each product. Here, we require 3 units of SKU#1, 1 unit of SKU#2, 1 unit of SKU#3, and 2 units of SKU#4, and likewise for the other products. This is defined as

$$RM[Product\_1, SKU\#1] = 3$$

which can also be defined as shown in Table 3,

**Table 3. Stock keeping units (SKU#) requirement for each product**

	SKU	Product 1	Product 2	Product 3
Raw Material	SKU#1	3	2	0
	SKU#2	1	2	2
	SKU#3	1	1	1
	SKU#4	2	2	1

The desired raw material inventories, DESIRED\_RM\_RATE[SKU#] are then calculated taking into account the currently available raw material inventories and subtracting them.

$$\text{Desired\_RM\_Rate[SKU\#1]} = \text{IF} (\text{RM\_inventory[SKU\#1]} < \text{Desired\_RM[SKU\#1]} ) \\ \text{THEN Desired\_RM[SKU\#1]} \text{ ELSE } 0$$

The safety stock of each of the raw material, SAFETY\_STOCK[SKU#, SAFETY\_STOCK] is entered.  
 $\text{Safety\_Stock[SKU\#1, Safety\_Stock]} = 20$

The order quantity of each SKU, ORDER\_QUANTITY[SKU#] can be calculated by adding the respective safety stock, to that of the required raw materials. The safety stock is defined as an array, SS.

$$\text{Order\_Quantity[SKU\#1]} = \text{Desired\_RM\_Rate[SKU\#1]} + \text{Safety\_Stock[SKU\#1, Safety\_Stock]}$$

The raw material inventory, RM\_INVENTORY[SKU#] is calculated from the rate of flow of raw materials, RM\_IN[SKU#] from the supplier. The variations that may be present in the supplier lead time or quantity are not taken into account, i.e., it is assumed that all the required parts are completely supplied. The raw materials are used to make the finished products according to the requirement of each product. Thus the raw materials that are used, RM\_OUT[SKU#] is calculated as per the total requirement.

$$\text{RM\_in[SKU\#1]} = \text{Order\_Quantity[SKU\#1]}$$

$$\text{Manufacturing\_Lead\_time} = 0.2$$

$$\text{RM\_Used[SKU\#1]} = \text{RM\_inventory[SKU\#1]} / \text{Manufacturing\_Lead\_time}$$

$$\text{RM\_inventory[SKU\#1]}(t) = \text{RM\_inventory[SKU\#1]}(t - dt) + (\text{RM\_in[SKU]} - \text{RM\_Used[SKU]}) * dt$$

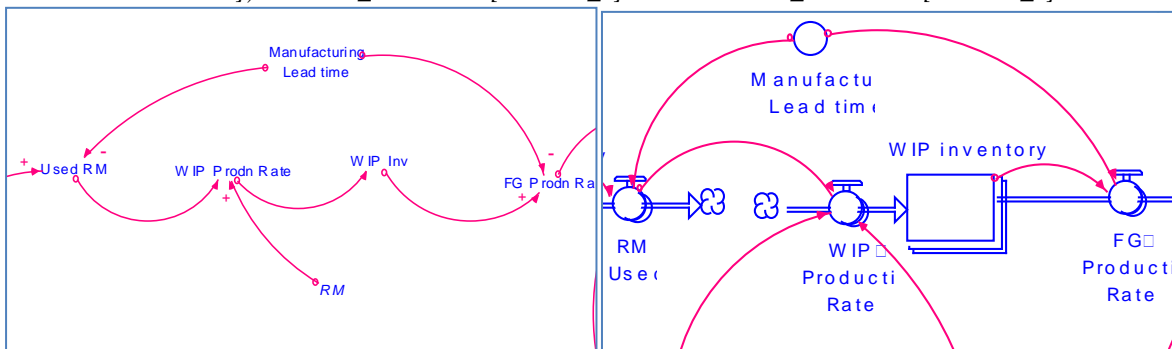
### 3.2.2. Work-in-process (WIP) Subsystem Loop

The conversion of raw materials into finished goods consumes raw materials as per the requirements of the products. This is then fed into the next loop, viz., WIP subsystem loop, shown in Fig. and the WIP inventory level, WIP\_INVENTORY[PRODUCT] is calculated.

$$\text{WIP\_inventory[Product\_1]}(t) = \text{WIP\_inventory[Product\_1]}(t - dt) + (\text{WIP\_Production\_Rate[Products]} - \\ \text{FG\_Production\_Rate[Products]}) * dt$$

The desired WIP, DESIRED\_WIP[PRODUCT] is obtained from the number of finished goods that are required to be produced and the amount of in-process inventories, WIP\_INVENTORY[PRODUCT] in the shop floor. The amount of WIP inventories, WIP\_PRODUCTION\_RATE[PRODUCT] that are produced are then fed into the finished goods inventories, FG\_INVENTORY[PRODUCT].

$$\text{WIP\_Production\_Rate[Product\_1]} = \text{IF} (\text{RM\_Used[SKU\#1]} / \text{RM[Product\_1,} \\ \text{SKU\#1]} > \text{Desired\_Production[Product\_1]} \text{ THEN Desired\_Production[Product\_1]} \text{ ELSE } 0$$



**Fig. 5. Work-in-process (WIP) Subsystem – Causal loop and Stock and flow diagrams**

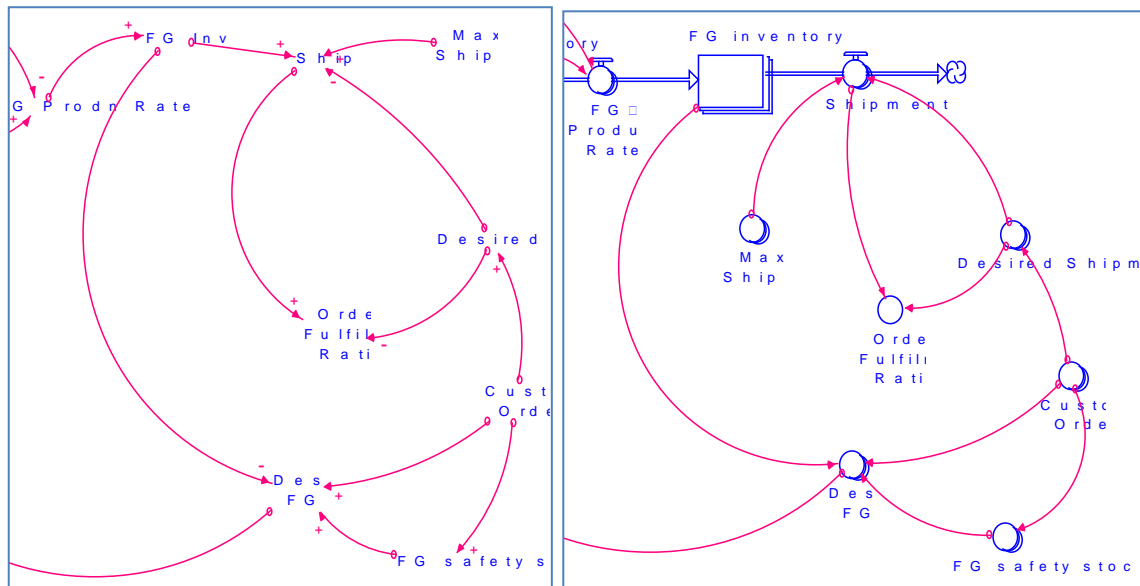
### 3.2.3. Finished Goods (FG) Subsystem Loop

As mentioned in the previous section, the WIP produced and stored as WIP inventories will give the rate at which the finished goods are produced, viz.,  $FG\_PRODUCTION\_RATE[PRODUCT]$ . These are then stored as finished goods inventories,  $FG\_INVENTORY[PRODUCT]$  in the finished goods subsystem loop, viz., FG Subsystem loop as shown in Fig.

$$FG\_Production\_Rate[Product\_1] = WIP\_inventory[Product\_1]/Manufacturing\_Lead\_time$$

$$FG\_inventory[Product\_1](t) = FG\_inventory[Product\_1](t - dt) + (FG\_Production\_Rate[Products] - Shipment[Product\_1]) * dt$$

Shipment of these products depends on the desired shipment to customers, according to the customer orders. The maximum shipment rate for each product,  $MAX\_SHIPMENT[PRODUCT]$  is defined and shipment to the customer is done based on the minimum amount between the desired shipment,  $DESIRED\_SHIPMENT[CUST, PRODUCT]$  and the maximum possible shipment.



**Fig. 6. Finished Goods (FG) Subsystem – (a) Causal loop and (b) Stock and flow diagrams**

$$Desired\_Shipment[Cust\_1, Product\_1] = Customer\_Order[Cust\_1, Product\_1]$$

$$Max\_Shipment[Product\_1] = 500$$

$$Max\_Shipment[Product\_2] = 250$$

$$Max\_Shipment[Product\_3] = 400$$

$$Shipment[Product\_1] = \min(Max\_Shipment[Product\_1], Desired\_Shipment[Cust\_1, Product\_1] + Desired\_Shipment[Cust\_2, Product\_1] + Desired\_Shipment[Cust\_3, Product\_1])$$

The order fulfillment ratio,  $ORDER\_FULFILMENT\_RATIO$  can be calculated depending on the percentage of customer orders delivered, i.e., actual shipment, to the orders placed by the customers and is limited by the maximum shipment possible for each product.

$$Order\_Fulfilment\_Ratio = ((Shipment[Product\_1]/(Desired\_Shipment[Cust\_1, Product\_1] + Desired\_Shipment[Cust\_2, Product\_1] + Desired\_Shipment[Cust\_3, Product\_1])) + (Shipment[Product\_2]/(Desired\_Shipment[Cust\_1, Product\_2] + Desired\_Shipment[Cust\_2, Product\_2] + Desired\_Shipment[Cust\_3, Product\_2])) + (Shipment[Product\_3]/(Desired\_Shipment[Cust\_1, Product\_3] + Desired\_Shipment[Cust\_2, Product\_3] + Desired\_Shipment[Cust\_3, Product\_3])) * 100/3$$



Thus the stock and flow diagram is defined and then it is simulated using the system dynamics software, iThink v 10.1.2. The results of the simulation are discussed in the next section.

#### 4. SIMULATION RESULTS AND DISCUSSION

The inventory management model has been developed as described in the previous section. From the results obtained, we can measure the level of inventories of the raw materials, i.e., the inventory levels of each SKU and the work-in-process inventories of each product as shown in Table and the finished goods inventories of each product as shown in Table 4. As the order

**Table 4. Raw material (RM), Work-in-Process (WIP) and Finished Goods (FG) inventories**

Months	RM inventory[SKU# 1]	RM inventory[SKU# 2]	RM inventory[SKU# 3]	RM inventory[SKU# 4]	WIP inventory[Product 1]	WIP inventory[Product 2]	WIP inventory[Product 3]	FG inventory[Product 1]	FG inventory[Product 2]	FG inventory[Product 3]
Initial	20.00	30.00	40.00	50.00	10.00	10.00	10.00	100.00	200.00	50.00
1	346.43	347.55	222.00	350.07	100.00	23.81	97.88	50.78	62.11	118.83
2	371.31	343.92	220.92	360.61	99.94	33.76	83.24	50.23	26.10	171.28
3	375.14	342.36	220.17	361.75	99.99	35.59	80.59	50.04	19.49	180.85
4	375.84	342.07	220.03	361.95	100.00	35.92	80.11	50.01	18.27	182.61
5	375.97	342.01	220.01	361.99	100.00	35.99	80.02	50.00	18.05	182.93
6	375.99	342.00	220.00	362.00	100.00	36.00	80.00	50.00	18.01	182.99
7	376.00	342.00	220.00	362.00	100.00	36.00	80.00	50.00	18.00	183.00
8	376.00	342.00	220.00	362.00	100.00	36.00	80.00	50.00	18.00	183.00
9	376.00	342.00	220.00	362.00	100.00	36.00	80.00	50.00	18.00	183.00
10	376.00	342.00	220.00	362.00	100.00	36.00	80.00	50.00	18.00	183.00
11	376.00	342.00	220.00	362.00	100.00	36.00	80.00	50.00	18.00	183.00
12	376.00	342.00	220.00	362.00	100.00	36.00	80.00	50.00	18.00	183.00

Quantities change for each customer, the raw material inventories for the various SKUs are calculated. This requirement is then compared to the available raw material inventories and then the needed quantities are purchased along with the safety stock. Graphs of the variation of different inventories, viz., Raw material inventories (Fig. 7), Work-in-process inventories (Fig. 8) and finished goods inventories (Fig. 9) have been plotted through the software to understand the variations of stock over the period.

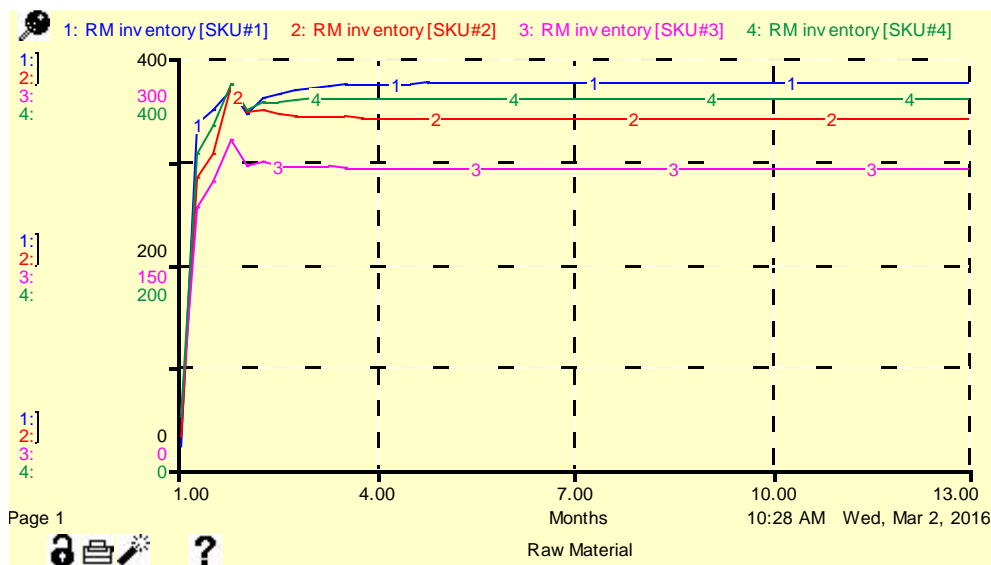


Fig. 7. Raw material inventories of all products

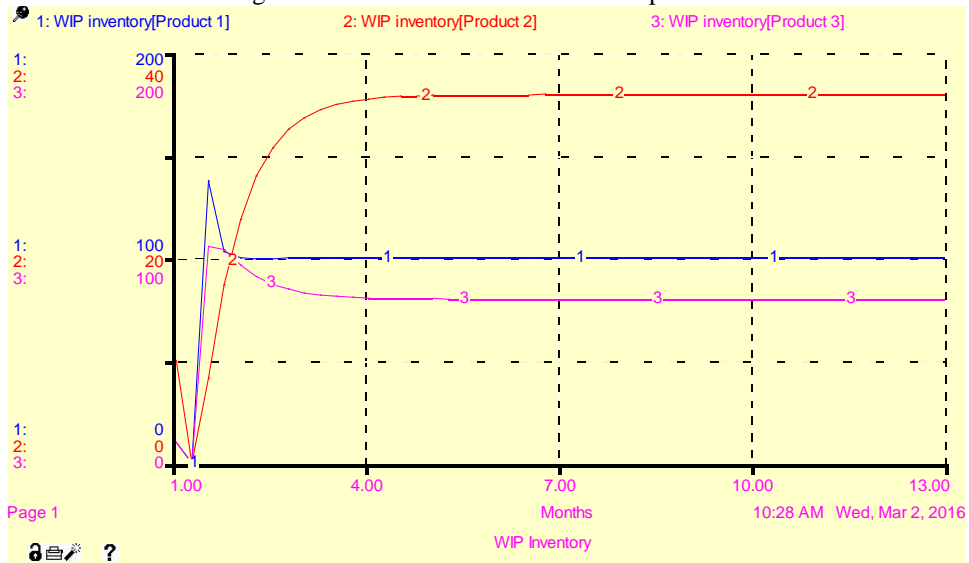


Fig. 8. Work-in-process inventories of all products

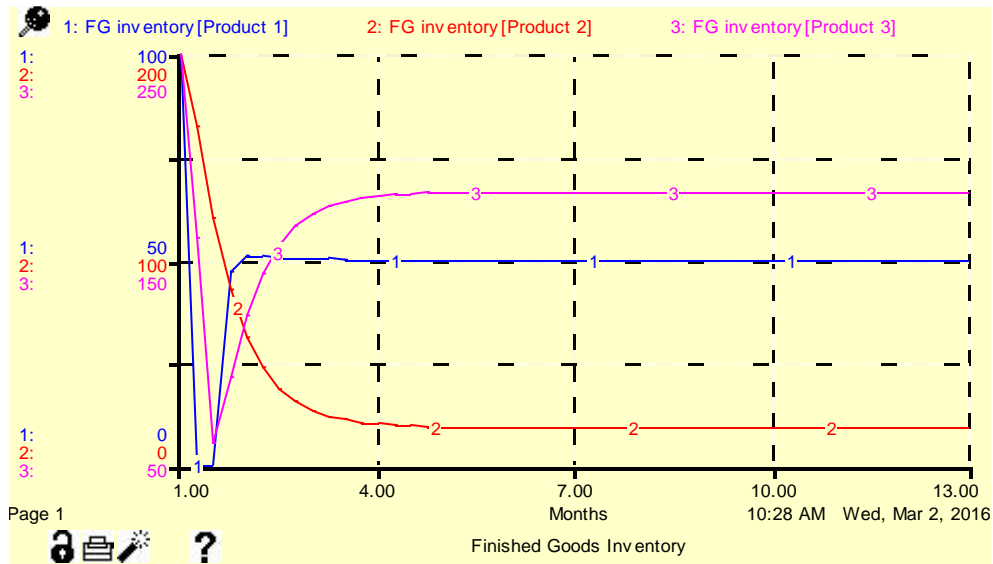


Fig. 9. Finished goods inventories of all products

The inventories of raw materials and the resulting work-in-process inventories can also be plotted and these inventories are shown in the graph plotted in Fig. 10.

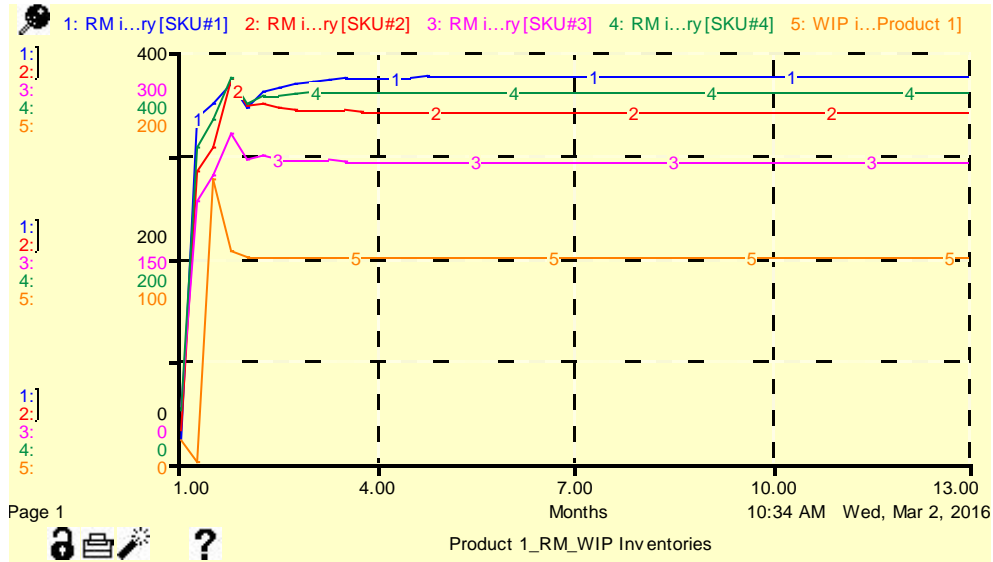


Fig. 10. Inventories for Product 1 – Raw materials, Work-in-process and Finished goods

The order fulfillment ratio was obtained by considering the ratio of actual shipment to the customer orders. This ratio depends on the maximum shipment that is possible for each product. When we define the maximum shipment for each product in excess of the total customer orders, then naturally, we get the order fulfillment ratio as 100% as shown in Table 5.

**Table 5. Shipment of products and Order fulfillment rate**

Months	Shipment[Product1]	Shipment[Product2]	Shipment[Product3]	Order Fulfillment Ratio
Initial				77.76
1	360	180	260	91.82
2	500	180	400	91.82
3	500	180	400	91.82
4	500	180	400	91.82
5	500	180	400	91.82
6	500	180	400	91.82
7	500	180	400	91.82
8	500	180	400	91.82
9	500	180	400	91.82
10	500	180	400	91.82
11	500	180	400	91.82
12	500	180	400	91.82

When we define the maximum shipment to be below the total customer orders, then the order fulfillment ratio falls below 100% as shown in Table.

## 5. CONCLUSIONS

Maintaining and accounting for inventory of raw materials, work-in-process and finished goods is a day-to-day fire-fighting for production managers. ‘How much to buy?’ and ‘when to buy?’ are questions is the basis for the

deterministic and probabilistic models that are in vogue. Real-time difficulties in predicting demand and maintaining production at expected levels has encouraged the development of many quantitative and qualitative models. Through Simulation of the developed model in this pull production system using system dynamics, we can see that the level of the various inventories can be forecast by knowing the customer orders or the forecast orders. There can be further enhancements to the model with the following additions. Firstly, the customer orders can be varied over each month also. To do this, we need to define an array as 'Month' dimension with 12 elements. When we consider changes in the order quantity for each month for each customer, the effect of safety stock will affect the system. Secondly, the cost of stock outs can be modeled into the system. Using this model, companies can estimate the amount of inventories on-hand and thus have a better control over the inventory. This facilitates them in fulfilling

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**Raghuram P.** currently serves as Assistant Professor at Department of Mechanical Engineering, School of Engineering, Coimbatore Campus. His areas of research include Responsive Supply Chain Management, Lean Manufacturing, Agile Manufacturing and Tool Design.

**Dr. Mridula Sahay** obtained her Ph.D. degree in Management from U.P. Technical University, Lucknow, Uttar Pradesh, India and Post Doctorate in Management from Bond University Australia with an Endeavour Research Fellowship of the Australian Government in 2008. She also has a PG Diploma in Computer Science & Application from Indian Institute of Computer Management, Ahmedabad, India. She has taught at Institute of Public Enterprise, Hyderabad before joining Amrita School of business, Amrita Vishwa Vidyapeetham, Coimbatore, Tamil Nadu, India as Associate Professor.

Dr. Mridula has awarded with Glory of India Award, 2017, Bharat Jyoti Award along with Certificate of Excellence in 2012 and also conferred with the Best Citizens of India Award 2012.

She has published more than 90 research papers in the international/ national refereed journals/ conference proceedings and edited and compiled 8 books. She has completed many consultancy assignments for universities, banks, LIC and other public sectors organizations. She has also conducted MDPs and FDP. Her current research interests are in the area of corporate governance, higher education, business modeling, and strategic planning. She has supervised many master students and guiding Ph.D. students. She is associated with a number of professional bodies, both national and international. She is on the Editorial Board of few international journals.

**Dr. Saleeshya P. G.** received both her M. Tech. and Ph. D. in Industrial Engineering and Operations Research from IIT Bombay. Her dissertation was titled, "Agile Manufacturing Systems --- An Investigative Study." She has numerous publications at national and international levels, and a total of 20 years' experience in industry and academia. Her research is mainly focused on the area of operations strategy: agile manufacturing (especially agility in automotive industries), lean manufacturing in continuous manufacturing systems, responsive supply chains and lean 6-sigma.