Journal of Quality and Technology Management
Volume XIV, Issue II, December 2017, Page 01 - 19

A SYMBIOSIS MODELING APPROACH OF GLOBAL SUPPLY CHAIN OF AN SME USING MIXED INTEGER PROGRAMMING (MIP) AND SYSTEM DYNAMICS (SD)

***S. Mehmood*[1], *A. Sultan*[2], *W. Anwar*[3], *Z. Butt*[4], *K. Javed*[5], *R.A. Rehman*[6]**
[1,2,4,5,6]University of Engineering and Technology, Taxila, Pakistan
[3]Institute of Space Technology, Islamabad, Pakistan

ABSTRACT

A cost effective supply chain (SC) involves selection of proper suppliers for each component, low manufacturing cost and selling its final product at good cost. Inventory level of raw material and of the manufactured product depends on manufacturing cycle time (MCT) and order processing time (OPT). In this research work, a global SC of an SME is modelled using synergy of two modelling techniques: 1) Mixed Integer program (MIP): for the selection of proper suppliers and customers based on the rates offered and lead time, and 2) System Dynamics (SD): to decide the production start rate, production rate, work in process (WIP) inventory, and total inventory of the finished product so that the processing cost of the product attains its optimum value. This research work will be obliging to eradicate abnormalities in the SCs comprised of various interacting variables by complex feedback loops.

Keywords: *Global Manufacturing supply chain, Mixed integer programming, System dynamics*

1) INTRODUCTION

One of the most important qualitative transformations of modern business management is that individual companies no longer compete just as independent entities, but rather as supply chains (SCs) (Bowersox, 1997). In this developing economic environment, the ultimate success of the single business will depend in integrating the company's complex network of trade relations. There is a requirement for establishing theory and developing more robust tools and methods for successful SC (Lambert and Cooper, 2000, Seuring, 2013). There has been a growing interest in design, performance, and analysis of SC. The concept of SC arose from some practical changes. These changes involve rising costs of manufacturing, shrinking of resources, and globalization of economical market etc.(Beamon, 1998). The concept of system dynamics (SD) was developed by Professor Jay Forrester of the Massachusetts Institute of Technology during the mid-1950s (Forrester, 1971). The field of SD was used to understand complex social systems at that time. In its full development, SD has become a discipline with the scope of science, education, law, engineering, or medicine (Forrester, 2009). The application of SD modelling to supply chain (SC) management has its origins in industrial dynamics.

In 1961, a model for production-distribution system was developed. This model was consisted of six interacting flow systems, namely materials, flows of information, manpower, money, orders, and capital equipment. Based on the development and use of a SD simulation model, Forrester described, analysed, and explained few issues such as inventory swings, demand amplification and the effect of advertising policies on production variations. The research work on SD Modelling of SC highlights policy and development inventory decision (Angerhofer and Angelides, 2000). These days, at global level the management of SC is very complex. But good management is responsible of profitable business. Therefore multinational companies come to know that the non-integration in procurement, production and distribution results in the form of hurdles in their success (Smew et al., 2013).

Since 1990s, supply chain had been considered very important for different organizations in the global perspective and to fulfil the customer's demand. To compete at global level, companies started to outsource their activities and focused on strategies of supplier selection (Nair et al., 2015).The holding and ordering cost depend on the service level of the company and inventory level is based on service level (Zafiriou, 2006). Kaya et al. (Kaya and Urek, 2016) presented a mixed integer model in which facility location and inventory control are optimized to increase the total profit of the SC.

SD modelling clearly captures transient behaviour of different variables by taking all feedbacks and delays in the SC. More research is required to explore this modelling technique (Tang and Vijay, 2001). Virginia et al. (Spiegler et al., 2016) suggested a simplification method to reduce complexity in the model by taking insight into the SD solution. By this method more accurate and simplified representation of the non-linear SC is possible.

The development of a SC never remained an easy task in past although there were limited options for SC partners. As technology progressed information systems and transportation systems become rapid. Different nations come to the conclusion to reduce their trade barriers to get maximum benefit by the cost effective services offered from different countries. Therefore, manufacturing industry of this era has to compete at global level. Companies are struggling to improve performance of their product at reduced cost and are converging to the special product which is most profitable.

The performance of the supply chain is based on the selection of proper suppliers and distributors (customers) all over the world (GÜLEN, 2007). These selections are influenced by variety of factors such as currency exchange rate, strategic alliance, government incentives, and cultural variations. After manufacturing, the product is delivered to the distributors in different countries that are also selected on the basis of above mentioned factors (Prasad and Sounderpandian, 2003, Pontrandolfo, 1999). Instead of manufacturing all parts and subassemblies by a single company, focus is converged to some particular part or sub assembly using endowment benefits of that place. One company manufactures one part of the product and delivers its product to the next company and so on. By this way at lesser cost and the quality of ultimate product is multiple of that product that is produced by a single manufacturer (Garcia and You, 2015).

The purpose of this research work is to optimize the global supply chain by selecting more appropriate suppliers and distributers using MIP and adjusting the production rate and inventory levels to keep the overall cost of the product in acceptable range.

2) MIXED INTEGER PROGRAMMING (MIP)

The MIP was defined by Wolsey (Wolsey, 2007), "*an optimization problem in which a non-empty subset of integer variables (unknowns) and a subset of real-valued (continuous) variables exist, the constraints are all linear equations or inequalities, and the objective is a linear function to be minimized or maximized*". It is a form of linear programming model in which some or all of the variables are required to be nonnegative integers It is said to be a mixed integer program when some, but not all, variables are restricted to be integer, and is called a pure integer program when all decision variables must be integers. The purpose of our MIP model is to select suppliers and customers in such a way that the total revenue of the company could be maximized. The costs of components incorporated include transportation cost, taxes and tariffs, currency exchange cost, and labour cost.

2.1) Generic Model Formulation in Mixed Integer Programming of GSCs

Let us define;

$C_{i,j,t} =$ Cost in country i of component j in time period t.
$S_{i,j,k} =$ Supply in country i of component j in time period t.
$R_{i,j,t} =$ Revenue from country i of component j in time period t.
$W_{i,j,t} =$ Wholesaler requirement from country i of component j in time period t.

$D_j =$ Demand of component j
$SA_j =$ Sub $-$ assembly of component j
$n_j =$ Number of components j required
$P_{i,j,t} =$ Production in country i of component j in time period t
$A_{i.j.t} =$ Availability in country I of component j in time period t
$Y_i =$ binary variable (1 if selected, and, 0 otherwise)

The objective of MIP formulation is to formulate a global SC; i.e. to determine from which country to purchase the raw material components and, to which country to deliver the finished product. The objective of the MIP model is to maximize the revenue, which incorporates the influencing factors of different countries such as transportation cost, taxes and tariffs, currency exchange cost, and labour costs. All these costs and sales prices are supposed to be in same units. Generic MIP formulation is;

Objective function,→ Maximize $Z=\sum_{i=1}^{n}\sum_{j=1}^{N}\sum_{t=1}^{T} (R_{i,j,t}W_{i,j,t} - C_{i,j,t}S_{i,j,t})$

Subject to,

$$\sum_{i=1}^{n}\sum_{j=1}^{N}\sum_{t=1}^{T} S_{i,j,t}Y_i \geq D_j$$ (A least-Cost supplier selection to meet demand at Production Source)

$$\sum_{i=1}^{n}\sum_{j=1}^{N}\sum_{t=1}^{T} W_{i,j,t} \geq P_{i,j,t}$$ (Wholesalers demand is met by Production)

$$S_{i,j,t} \leq A_{i,j,t}$$ (Supply meets availability at source)

$$\frac{D_j}{n_j} \geq P_{i,j,t}$$ (Components/Sub-Assemblies for Production Balancing)

$$Y_i = [0,1]$$ (Supplier Selection Binary Variable)

$$i\forall N_c, j\forall N, t\forall T$$ (For all countries, for all items, for all time periods)

Where

N_c = No of countries in GSC,
N = No of types of items,
T = Planning Horizon

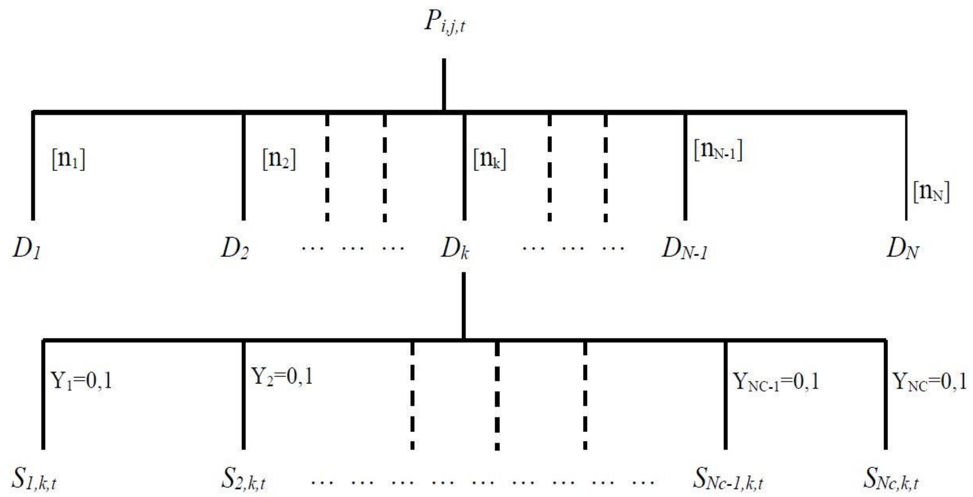


Figure 1: Component/Sub-Assemblies' requirement for Balancing Production

The requirements to produce $P_{i,j,t}$ units of end item is decided from Product structure shown in Figure 1. n_j is the number of components/sub-assemblies required to produce one unit of $P_{i,j,t}$. With D_j quantities available of j types of components/sub-assemblies, the amount of $P_{i,j,t}$ will be;

$$P_{i,j,t} = \text{minimum} \left\{ \frac{D_1}{n_1}, \frac{D_2}{n_2}, \ldots \frac{D_j}{n_j} \ldots, \frac{D_N}{n_N} \right\}$$

The set of constraints satisfying above equation will be;

$$\frac{D_j}{n_j} \geq P_{i,j,t}$$

3) SUPPLIER'S SELECTION

The electric water heating element (HE) is one of the SME's products primarily manufactured for international markets, where this element is installed in industrial and commercial geezers. The HE has a thermostat and heating element subassembly which are made up of sub components. The detail of both subassemblies are provided below,

1. Thermostat
   a. Brass Pipe
   b. Reset Lever
   c. Sensor Rod
   d. Base
   e. Contact [2 no.]
   f. Fasteners [6 no.]
   g. Ceramic piece
2. Heating Assembly
   a. Filling Tube
   b. Sensor Tube
   c. MgO
   d. Nicrome

Data regarding distributors of heating elements and suppliers of components in other countries is shown in Table 1 and Table 2, respectively.

Table 1: Distributor's data of Heating Element

Country Name	Lead Time (Month)	Sale's Price (Rs)	Requirement by month		
			January (HE)	February (HE)	March (HE)
UK	3	1800	15000	20000	10000
Ireland	4	1850	5000	5000	5000
Dubai	1	1950	2000	2000	2000
Australia	2	1900	3000	3000	3000

Table 2: Supplier's Data for all Components

Country	Price (Rs.)	Lead Time (month)	Country	Price (Rs.)	Lead Time (month)
Filling Tube			Base		
Italy	400	3	India	30	2
Malaysia	350	2	Germany	40	3
China	400	2	Malaysia	20	2
Sensor Tube			Contacts		
Malaysia	210	2	Turkey	10	2
China	250	2	Italy	15	3
MgO			Ceramics		
USA	100	3	Italy	14	3
UK	150	3	Taiwan	6	3
China	120	2	Pakistan	7	15 days
Nicrome			Reset Lever		
UK	30	3	Germany	20	3
China	50	2	India	30	2
India	40	2	Malaysia	25	2
Brass Pipe			Fasteners		
Malaysia	150	2	Pakistan	4	15 days
China	170	2	China	5	2
USA	250	3	India	6	2
Italy	200	3			
Sensor Rod					
Italy	300	3			
China	250	2			
UK	225	3			

3.1) Optimal Solution

The optimal solution regarding supplier selection and production quantities at producer's source in the month of January, February and March are given in Table 3 and Table 4 respectively.

Table 3: Optimal suppliers selected by MIP Model.

Component	**Filling Tube**	**Sensor Tube**	**MgO**	**Nicrome**	**Brass Pipe**	**Sensor Rod**
Country	Malaysia	Malaysia	USA	UK	Malaysia	Italy
Component	Base	Contacts	Ceramics	Reset Lever	Fasteners	
Country	Malaysia	Turkey	Taiwan	Germany	Pakistan	

Table 4: Distributor's requirement of Heating Element

Wholesaler/Distributors	**Quantity Requirements(HE)**		
	January	**February**	**March**
UK	15000	20000	10000
Ireland	5000	5000	5000
Dubai	2000	2000	2000
Australia	3000	3000	3000
Total	25000	30000	20000

4) SYSTEM DYNAMICS (SD) MODEL

The discipline of SD modelling was developed by J.W. Forrester at MIT. In the start, this technique was used in control engineering, social sciences and management. System dynamics has been used also in corporate planning, energy planning, biological systems and to view economy behaviours. Forrester introduced SD as industrial dynamics and defined it as "*The study of the information feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decision and actions) interact to influence the success of the enterprise. It treats the interactions between the flows of information, money, orders, materials, personnel, and capital equipment in a company, an industry, or national economy*". *(Bowersox, 1997)*

As there are feedback loops and nonlinear relationships in management and social systems that could not be solved by analytical means. Therefore SD modelling had been introduced to deal with large number of feedback loops and nonlinear relationships. System dynamics contains three basic elements 1) stock and 2) flow rate and 3) feedback loops through which information is transferred. This methodology uses these three elements to build-up a complete model structure to determine the behaviour of different variables keeping in view lot of time days associated with variable and feedback loops. A block diagram of SD model comprising customer order, production scheduling, Inventory and shipping is shown in Figure 2.

The SME maintains a certain level of finished inventory of HE and tries to fulfil the routine customer orders but any change in customer order results some delays. It is assumed that customers are delivery sensitive. Those orders which the company cannot fulfil immediately are lost as customers seek other sources of supply. When orders arrive, production starts and WIP inventory starts to increase. As manufacturing processes of HE complete, the WIP inventory will decrease.

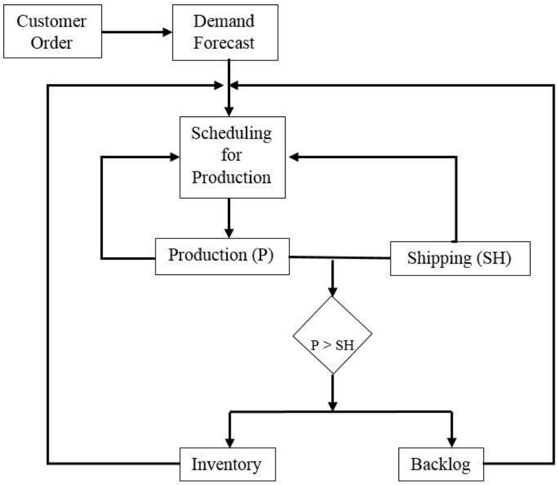


Figure 2: Block diagram for complete cycle from customer order to shipping (Sterman, 2000).

According to Sterman (Sterman, 2000), order fulfilment determines the ability of a firm to fulfil the customer orders by the on-hand inventory of finished product. The SD model for the SC for the manufacturing of HE is shown in Figure 3.

After developing the model once, interaction of all variable with each other can be easily visualized. This model provides prediction for any abnormity in the system and necessary decisions can be made to overcome this abnormity without any expected losses.

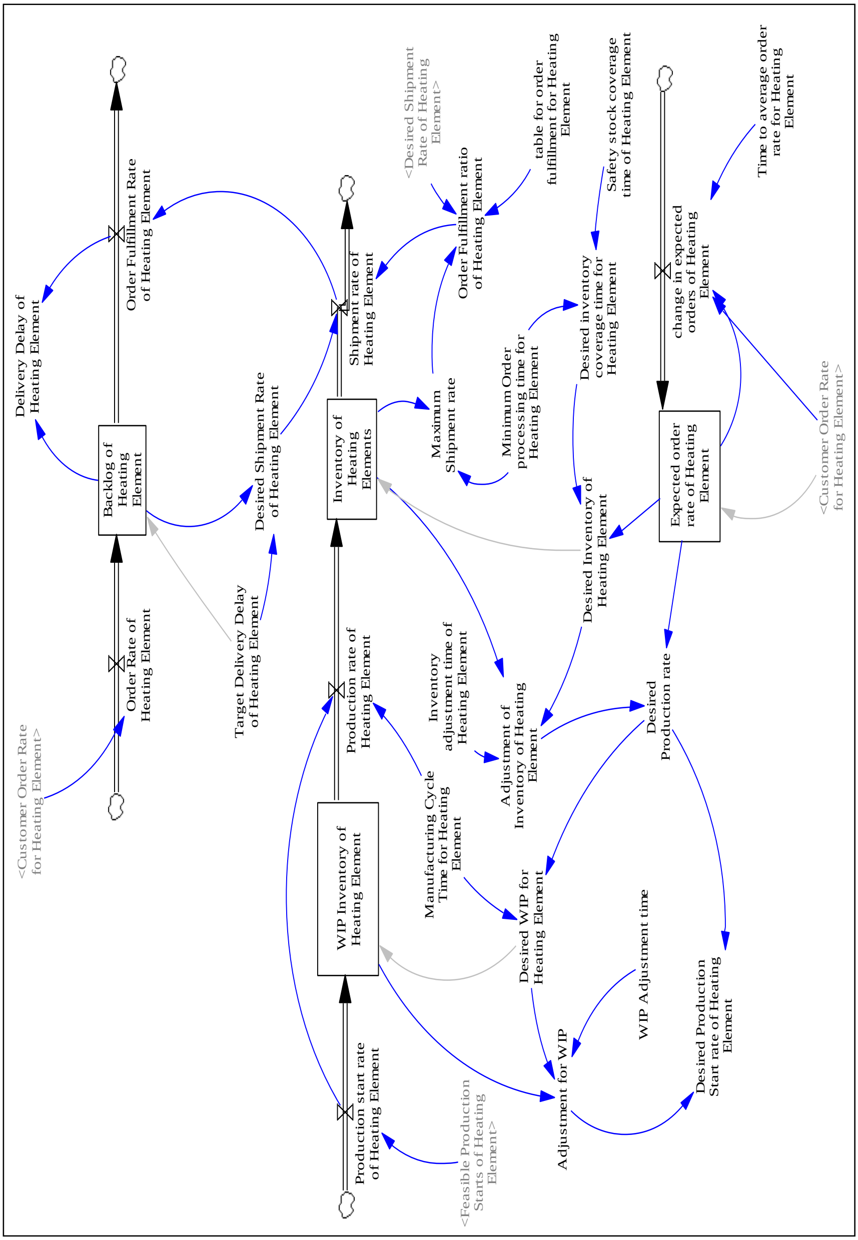


Figure 3: Supply chain SD model of HE at an SME.

4.1) Outcome of SD Model

Delays occur in SC that may depend on different factors. By using SD model most critical factors can be evaluated easily. The behaviour of *Production Rate (PR)* is compared with *Customer Order Rate* as shown in Figure 4. Order rate in first four weeks is 25000 wid./week and this rate increases to 30000 wid./wk after 4th week to 8th wk. Then demand of *HE* is decreased to 20000 widgets/wk.

There is delay of about two weeks in the production rate after which PR trend is increased. At 10th wk, *PR* reaches its maximum value of 27030 wid./wk and after this week *PR* is decreased due to decrease of order rate to a minimum value of 18010 wid./wk in 24th week followed by slow increase in *PR*.

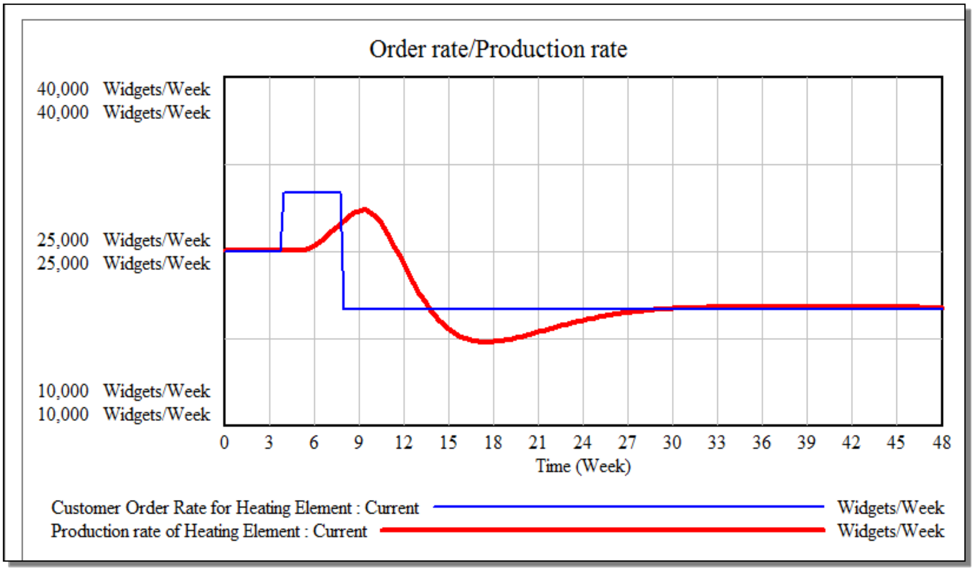
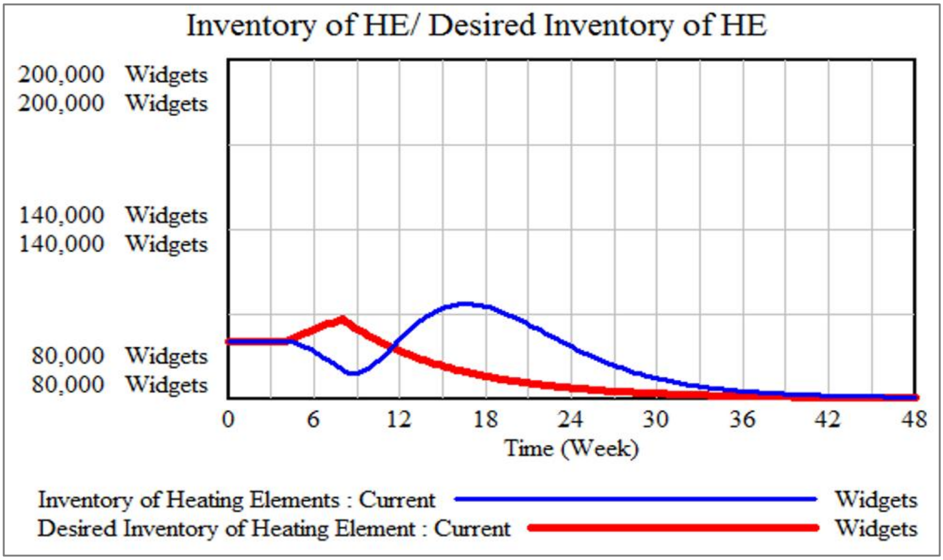
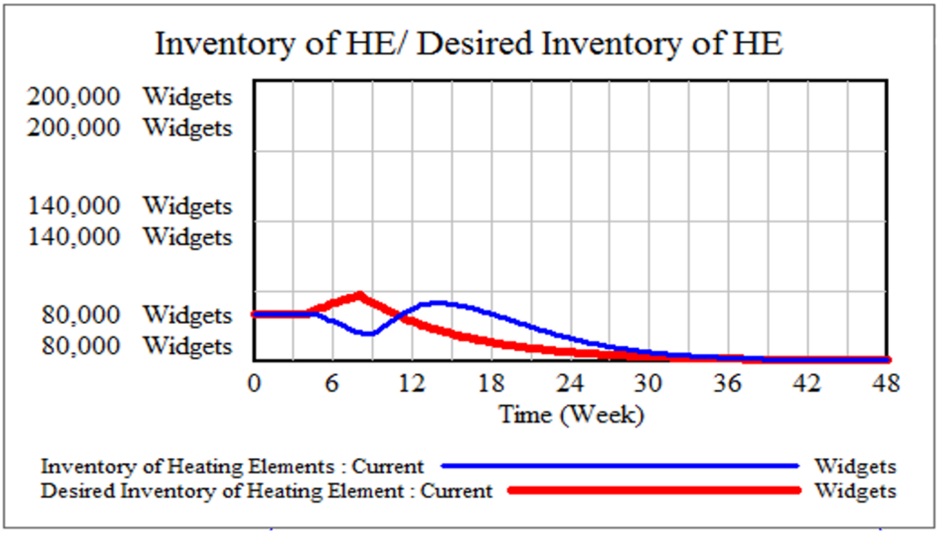


Figure 4: Comparison of Order rate /Production rate

When optimal SC is required to select, the analysis of different parameters is performed one by one for different variables. This way SC can be adjusted as per requirement. First of all inventory of HE and desire inventory are compared in Figure 5. Some questions may arise after sudden changes in the SC due to customer order rate. There is much gap between inventory and desired inventory. By reducing *MCT* from 8 week to 4 week reduces this gap, the system adjusts to equilibrium at 33rd week



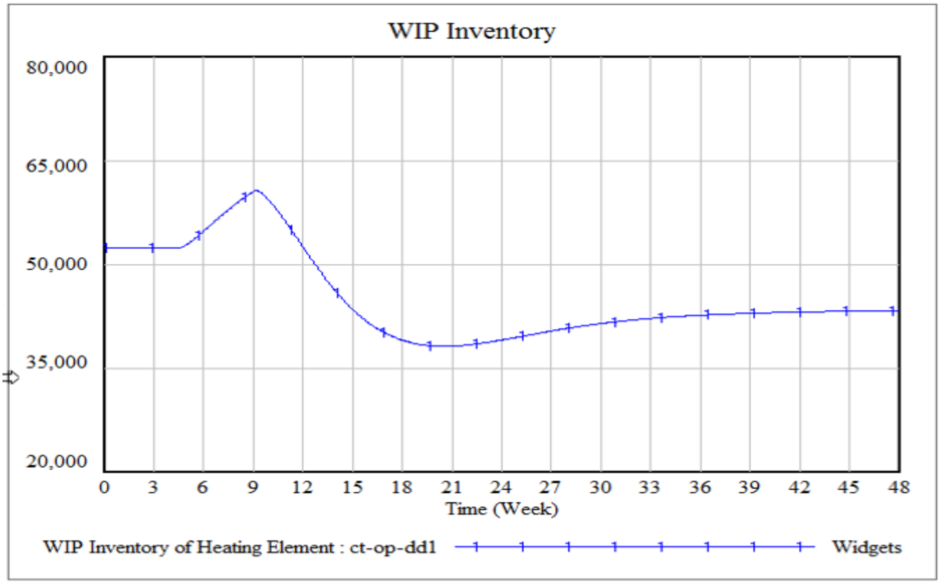
(a)



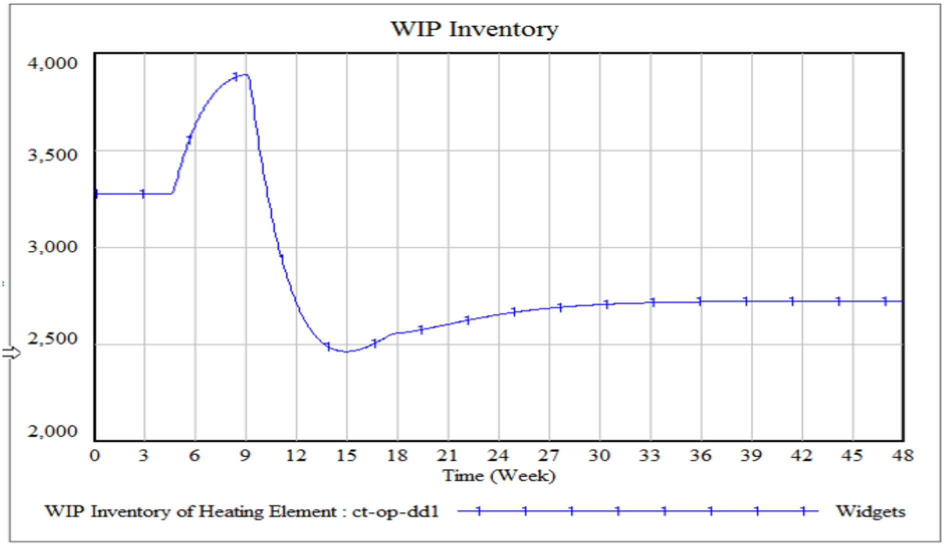
(b)

Figure 5: Response of inventory to desired inventory for (a) MCT=8weaks, (b) 4 weeks

The *WIP* Inventory behaviour with default parameters is shown in Figure 6. This behaviour shows that *WIP* inventory is above 50000 Wid./wk at start of analysis and at the end it will achieve its equilibrium at about 42000 Wid./wk. By changing *MCT* to half week *WIP* inventory decreased to 2700 Wid./wk .



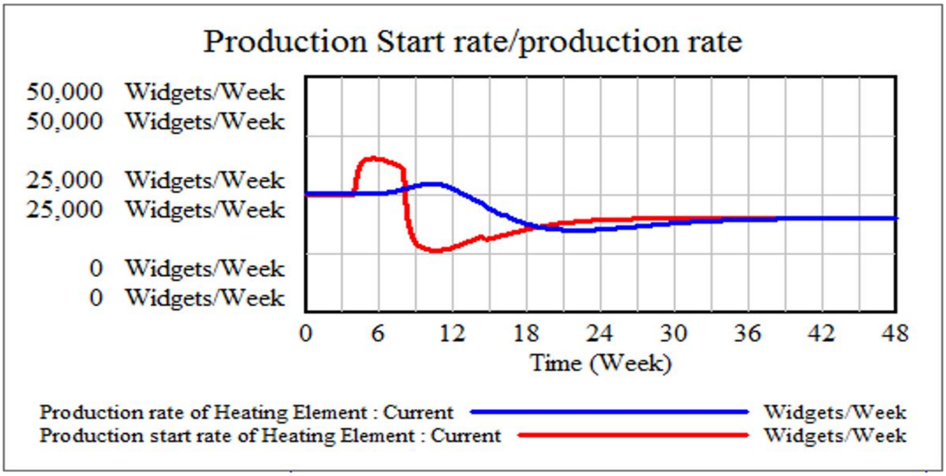
(a)



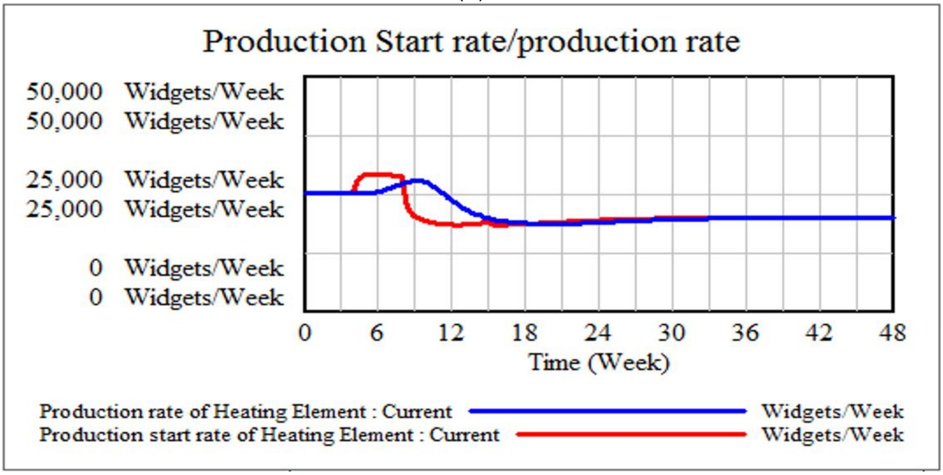
(b)

Figure 6: Behaviour of WIP inventory for (a) MCT= 2 weeks, (b) MCT=0.5 week.

The customer order for the January was 25000 that was increase February to 30000 and in March reduced to 20000. After this month, no change occurred in customer order. In February, after receiving big order, production of the HE was planned. Due to some lead time of different components, delay in production start rate and PR occurred. The behaviour of *production start rate* and *PR* are shown for different *MCT* in Figure 7.



(a)



(b)

Figure 7: Closeness of production start rate to production rate for (a) MCT=8 weeks, (b) 4 weeks

This graph shows that Equilibrium is achieved after 39th week. Let's analyse the model, how production start rate and PR can attain equilibrium in earlier time. Now reducing MCT from 8 week to 4 Week. This graph shows production rate and production start rate come into equilibrium at 18th week. Thus MCT should be reduced.

This analysis concludes that reducing MCT is the best solution to attain production rate closer to the desired PR. Transient period will reduce from 19 Weeks to 6 Weeks under this setting.

4.1.1) Scenario-wise Analysis

The behaviour of inventory level and production rate of HE will be discussed by considering different settings of MCT & Order Processing time (OPT), shown in Table 5.

Table 5: Six scenarios in term of MCT and OPT.

Scenario	Manufacturing Cycle Time	Order Processing Time
01	08 week	02 week
02	08 week	1.5 week
03	08 week	01 week
04	04 week	02 week
05	04 week	1.5 week
06	04 week	01 week

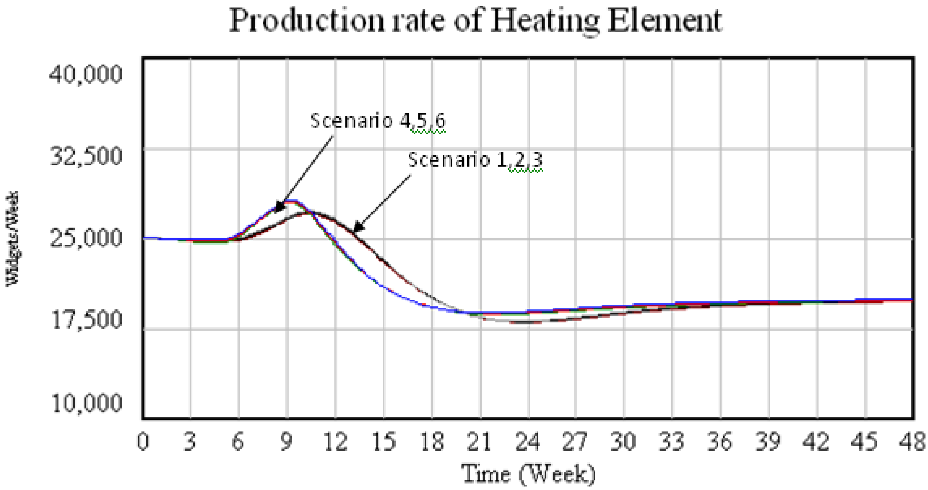


Figure 8: Production rate for different settings of MCT and OPT

After investigating different variables, it has been found that MCT and OPT are very sensitive to inventory stock of HE. As shown in Figure 8, Production rate (PR) is found more sensitive to MCT as compared to OPT.

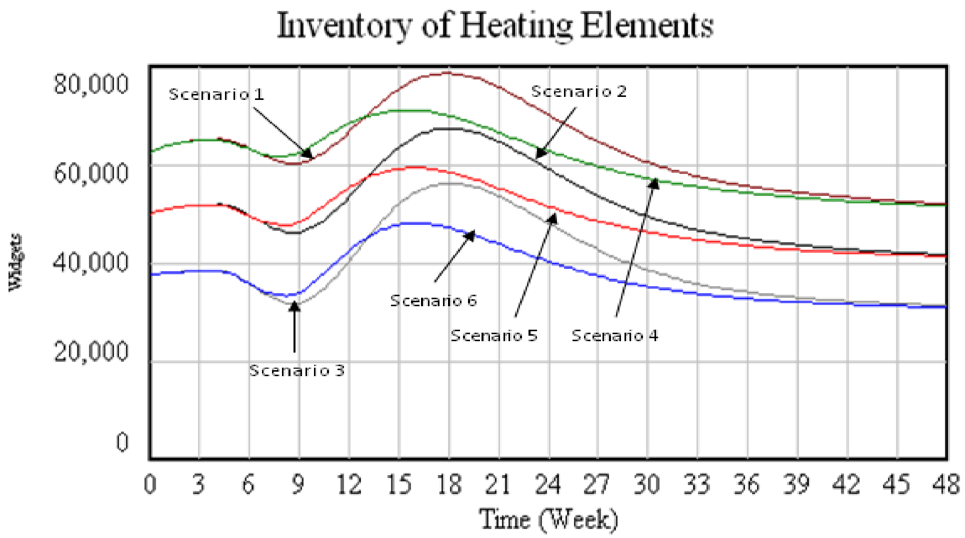


Figure 9: Inventory level for different settings of MCT and OPT

In Figure 9, it is shown that inventory level is directly proportional to OPT and change in inventory is directly proportional to MCT. Above analysis shows that scenario 6 is most suitable to keep inventory level low. But for this purpose MCT and OPT should not be more than 4 weeks and 01 week. Thus clearly, SD modelling is very helpful in adjusting all parameters in dynamic SC comprising complex feedback loops.

5) SUMMARY AND DISCUSSIONS

There are rigorous changes in technology with time and companies are offering their product with improved quality with less price. A successful manufacturing SME gets maximum benefit from intelligent decisions, as multiple factors affect selection of suitable suppliers and distributor. In this research work a basic *MIP* is modelled for selections of most optimal supplier. Different factors that influence GMSC, can change with the passage of time. So the optimal suppliers may change with the passage of time. The SD model provided a transient solution on the time axis of different variable such as inventory level, production rate etc. that have also feedback interactions.

The sensitivity of one variable could be successfully obtained because of these feedback interactions. Thus MIP decides the optimal suppliers and distributors in the SC. The SD model provided the behaviour of all variables throughout the time span, and variation in other dependent variables can be analysed by changing any one parameter in SC. This analysis predicts the influence of each variable in the SC.

6) CONCLUSION

In current research work, supply chain of a local manufacturing industry is modelled using mixed integer programming and system dynamics. The SC of a single product of an SME is focused. Some components of this product are imported from different countries.

MIP is used for the selection of best supplier of each component on the base of its cost and lead time. The SD model is used to analyse the behaviour of production rate and inventory level in response to the customer demand. To fulfil the changing demand of the product, the behaviour of production rate and inventory level for different Manufacturing cycle times and order processing times are observed.

7) ACKNOWLEDGEMENT

I would like to express my special thanks of gratitude to my supervisor who provided me the golden opportunity to do this research.

REFERENCES

Angerhofer, B.J. and Angelides, M.C. (2000), System dynamics modelling in supply chain management: research review. Simulation conference, 2000. proceedings. winter. IEEE, pp. 342-351.

Beamon, B.M. (1998). Supply chain design and analysis:: Models and methods. *International journal of production economics,* 55(3), pp. 281-294.

Bowersox, D. J. (1997), Integrated supply chain management: a strategic imperative. Council of Logistics Management, Annual Conference. pp. 5-8.

Forrester, J.W. (1971). Counterintuitive behavior of social systems. *Technological Forecasting and Social Change,* pp. 31-22.

Forrester, J.W. (2009). Some basic concepts in system dynamics. *Sloan School of Management, Massachusetts Institute of Technology, Cambridge*.

Garcia, D.J. and You, F. (2015). Supply chain design and optimization: Challenges and opportunities. *Computers & Chemical Engineering,* pp. 153-170.

Gülen, K.G. (2007). Supplier selection and outsourcing strategies in supply chain management. *Journal of aeronautics and space technologies,* 3(2), pp. 1-6.

Kaya, O. and Urek, B. (2016). A mixed integer nonlinear programming model and heuristic solutions for location, inventory and pricing decisions in a closed loop supply chain. *Computers & Operations Research,* pp. 93-103.

Lambert, D.M. and Cooper, M.C. (2000). Issues in supply chain management. *Industrial marketing management,* 29(1), pp. 65-83.

Nair, A., Jayaram, J. and Das, A. (2015). Strategic purchasing participation, supplier selection, supplier evaluation and purchasing performance. *International Journal of Production Research,* 53(20), pp. 6263-6278.

Pontrandolfo, P. (1999). Global manufacturing: a review and a framework for planning in a global corporation. *International Journal of Production Research,* 37(1), pp. 1-19.

Prasad, S. and Sounderpandian, J. (2003). Factors influencing global supply chain efficiency: implications for information systems. *Supply Chain Management: An International Journal,* 8(3), pp. 241-250.

Seuring, S. (2013). A review of modeling approaches for sustainable supply chain management. *Decision support systems,* 54(4), pp. 1513-1520.

Smew, W., Young, P. and Geraghty, J. (2013). Supply chain analysis using simulation, Gaussian process modelling and optimisation. *International Journal of Simulation Modelling,* 12(3), pp. 178-189.

Spiegler, V.L., Naim, M.M., Towill, D.R. and Wikner, J. (2016). A technique to develop simplified and linearised models of complex dynamic supply chain systems. *European Journal of Operational Research,* 251(3), pp. 888-903.

Sterman, J.D. J.D. (2000). *Business dynamics: systems thinking and modeling for a complex world*.

Tang, V. and Vijay, S. System Dynamics-Origins, Development, and Future Prospects of a Method. Research Seminar in Engineering Systems, (2001).

Wolsey, L.A. (2007). Mixed Integer Programming. *Wiley Encyclopedia of Computer Science and Engineering.* John Wiley & Sons, Inc.

Zafiriou, K.F. (2006). *Supply chain management for fast-moving products in the electronic industry.* Massachusetts Institute of Technology.