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A System Dynamics Model of Demand Chain Management in the Context of Manufacturing Industries

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Abstract **– Customer demand is characterized by uncertainty because of its relation to a large number of factors which affect it. As in any other real life situation these also have closed loop feedback relationships. The DCM system consists of many closed loop feedback relations and thus reinforces the need for a dynamic modeling. A System Dynamics model for DCM is developed with the help of expert opinion for DCM feedback relationships, in consistence with the standard procedure of System Dynamics modeling.**

Keywords – System Dynamics (SD), Demand Chain Management (DCM), Closed Loop Feedback Relationships.

I. Introduction

Demand Chain Management (DCM) is a new tool in the hands of the management that deals with all assets, information, and processes to define demand followed by synchronization of various activities to fulfill demand on a real-time basis by managing flow of information and products efficiently and effectively (Agrawal, 2012). Close integration of operations between manufacturers, suppliers, and customers in DCM relies to some degree on business process reengineering (Frohlich and Westbrook, 2001). Thus, research in DCM includes Just-in-Time (JIT) manufacturing, mass customization, and use of third-party logistics (Lee *et al*., 2005). Demand Chain Management (DCM) organizations empower R&D staff to work closely with customers to develop products and processes cooperatively (Walters, 2006). Given a precise under--standing of customer needs (and market trends); it is possible for the procurement process to work with design and development to develop optimal solutions to product and process development options. Thus implementation of DCM results in overall improvement in the organization.

In DCM system the close integration of operations between manufacturers, suppliers, and customers by synchronization of various activities and flow of information, to fulfill customers demand on a real-time basis increases complexity and adds dynamics. In such complex systems perturbations in one factor impacts other factor which in turn may impact some other factor until they form a structure of closed loops to influence the factor which started the perturbation. Therefore, the efforts directed at resolving one problem is not separated from other issues that form part of system or influence it. In many cases, adjustments made in one factor through some decision is not limited to the factors within the system but outside it as well, such as is seen in the changes in demand due to some decision by Government or because of change in geographic location or entry of a new competitor. It is these impacts that need to be assessed and incorporated in to the modeling framework for more realistic assessment of demand. Closed loop interactions constrain the outcome of any decision, which may not be obvious to the decision maker or manager and may not be directly subjected to manipulation by them. Therefore, to have a realistic assessment of demand it is essential that interrelatedness between various factors and their closed loop interactions is understood and clearly represented.

This work presents a System Dynamic (SD) model of Demand Chain Management (DCM) through literature review, expert's opinion through NGT and the framework of SD methodology.

II. Literature Review

The increased customers focus requires the prioritization of activities and variables facilitating the fulfillment of demand and creation of demand. Many researchers (Selen, 2001; Chase, 2001; Rainbird, 2004; Canever, 2008, Agrawal, 2012c) have indicated to the presence of feedback loops within the DCM system responsible for dynamics within it. Selen, 2001: It was suggested to address the issues of aligning education with emerging needs of market place along the dimensions of DCM with dynamic performance measurement. Chase (2001): Dema--nd chain is a dynamic network of a company's customers; customers' customers; and direct and indirect marketing, sales, and service providers who facilitate the firm with the capability to get, keep, and nurture profitable lifetime relationships in better and faster ways. Rainbird, 2004: The demand chain is not something to be added at the end of a super supply chain, it is dynamic in its own right. Canever *et al.*, 2008: The consideration of the dynamics within and between chains requires the holistic approach of DCM. Agrawal, 2012c: Demand Chain Management is a ''sense-and respond'' philosophy that focuses on acquiring new capabilities to offer maximum customer value in the dynamic market condition.

Literature review for System Dynamics methodology reveals a wide range of application of SD method in dynamic and complex situations. The use of SD modeling in supply chain was mostly limited to the work in demand amplification; some important contributions are Forrester, 1958; Burbidge, 1961; Saporito, 1994; Lee *et al.*, 1997; McGuffog, 1997; Taylor, 2000; Holweg *et al.*, 2005. Recently, it has gained popularity due to the complexity

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involved in supply chain. The dynamic nature of supply chain systems and their behavior depends on the uncertainties of customers' demand, suppliers, logistics routes, and alternative inventory methods. In fact uncertainty rules the supply chain therefore it is natural to apply SD simulation (Ashayeri and Lemmes, 2006).

System dynamics presupposes that the behavior of any system is essentially dependent upon its structure and interrelationship between the system components (Richard -son and Pugh, 1989). It is particularly well suited for problems whose behavior is governed by feedback relationships (Vennix, 1996). DCM is one such system, which is dynamic, multi-loop, and has non-linear character of feedback system along with flows and stocks of the inventories and time delays associated with fulfillment of demand and its impact. For effectiveness of DCM a clear understanding of structure is required. The process of creating simulation model helps to clarify the system structures and makes modelers assumptions of how system works explicit. Once the model is built it can be used to simulate the effect of proposed actions on the problem and the system as a whole (Stave, 2003). The following features of system dynamics make it a desirable methodology to analyze DCM. These are its ability (Mahapatra *et al.*, 1994) to:

a. Dynamically model complex, nonlinear relationships of large number of variables. This enables one to consider many related aspects of a problem, resulting in holistic approach.
b. Explicitly model qualitative factors.
c. Experiment with alternatives.
d. Generate alternative scenarios.
e. Incorporate time delays in decision-making and implementation.
f. Test the efficacy of alternatives in a simulated environment before being implemented.

III. Methodology

SD Simulation Model for DCM Involves following Steps (Mahapatra et al., 1994)

1. Define the problem
2. Define the model boundary and build model aggregate
3. Build the detailed model
4. Test and validate the model
5. Analyze the model and evaluate the policy alternatives
6. Recommend the most viable policy

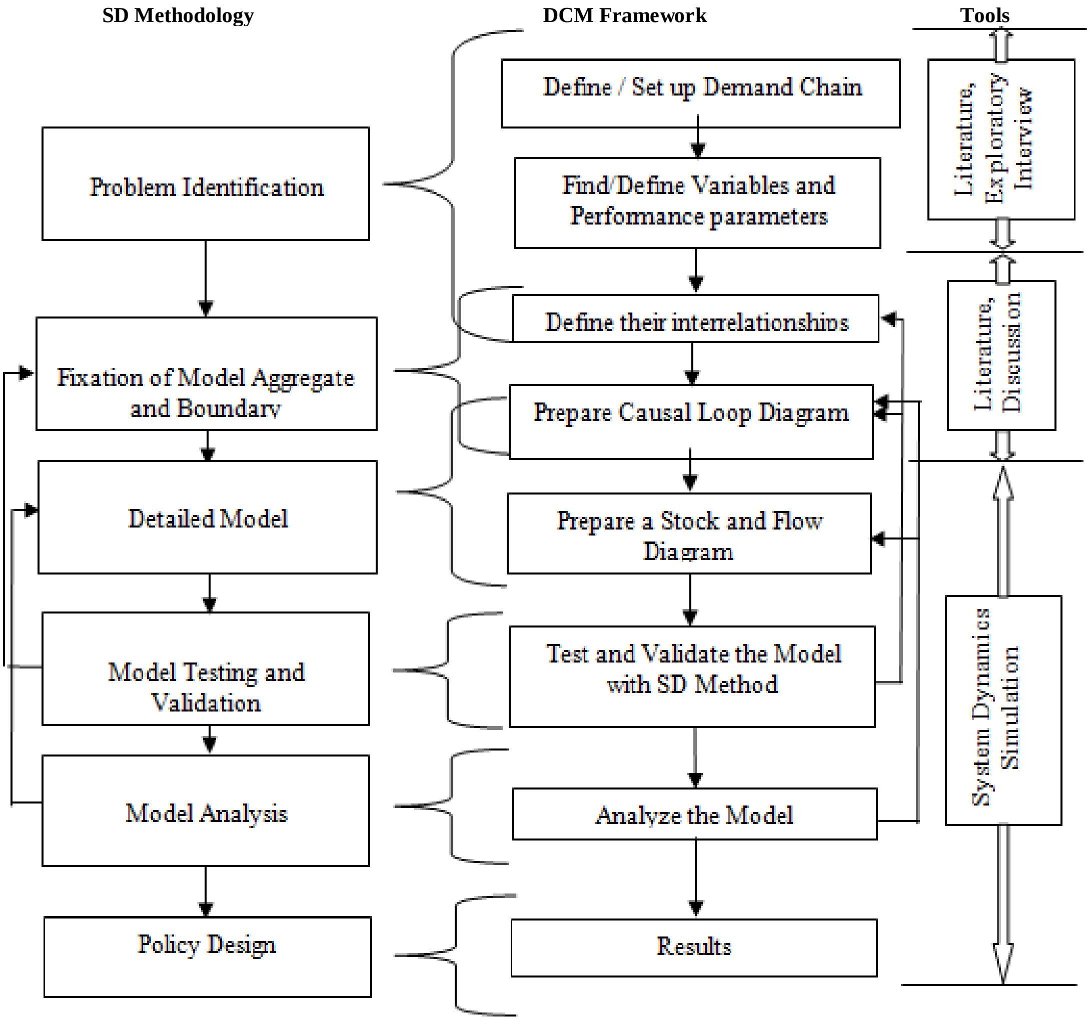

Fig. 3.1. System Dynamics-DCM Framework.

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System Dynamics model is developed using simulation software, ‘Powersim Constructor’ version 10. The build--ing blocks of the Powersim Constructor are shown in Table-3.1.

Application of SD methodology for DCM is shown by a diagram in Fig 3.1. The framework shows the integration of SD methodology and DCM along with the correspond--ing tools used. Literature review, exploratory interviews and NGT have helped in problem identification, defining model boundaries and developing interrelationships with model variables. A causal loop diagram is developed based on the interrelationships taken from literature and validated by experts through NGT (Fig 3.2), which depicts the feedback relationships in DCM.

Causal Loop Diagram

Causal loop diagram (Fig 3.2) is visual representation of cause-effect relationship among the elements of a system, forming a structure of feedback loops.

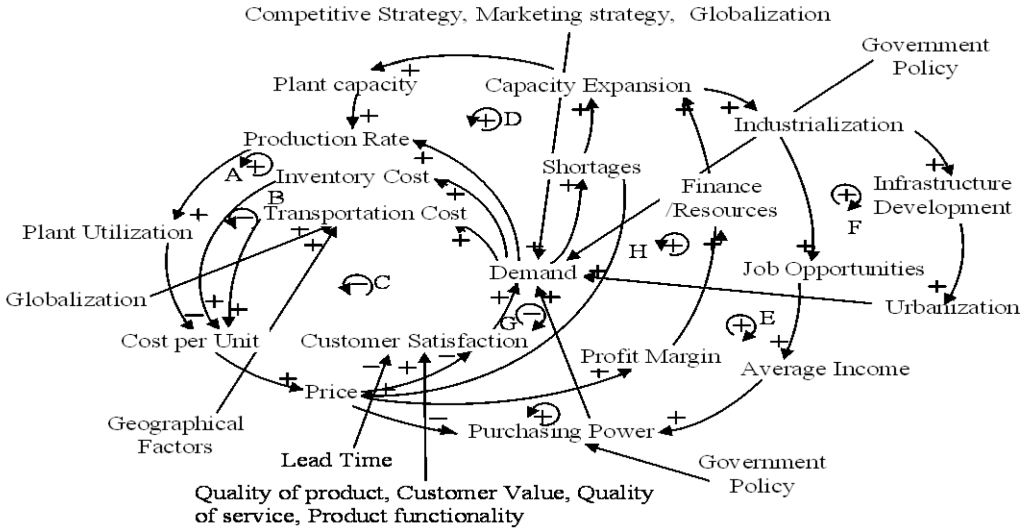

Fig. 3.2. Causal loop diagram for DCM.

The causal relationships represent the possible cause-effect relationship among the variables established with the consideration of conservation, direct observation and accepted theories. DCM’s holistic view requires conside--ration of internal as well as environmental variables, thus the system consists of a large number of variables. While developing System Dynamics model of DCM these variables are suitably converted in appropriate stock, flow and information variables, to facilitate formulation of mathematical relationships among them. (System dynami--cs model (Stock and flow diagram)

In the next stage with the help of causal loop diagram a System dynamics model is developed. A Model (represen--ted through Stocks and flows) consists of a set of interrelated components, called variables.

Table 3.1. Description of important system dynamics building blocks Source (Powersim, 2010) 4.

S. No.	Variable Name	Symbol	Description
1.	Level	Level	It accumulates changes and is influenced by flows
2.	Auxiliary	Auxiliary	A variable type, which contains calculations based on other variables
3.	Constant	Constant	Contains fixed values that are used in calculations of auxiliary variables or flows
4.	Flow with rate		It influences levels. The flow is controlled by the connected rate variable, normally an auxiliary variable
5.	Information link	Level → Auxiliary	Gives information to auxiliary variables about the value of other variables
6.	Delayed info-link	Level → Auxiliary	Used only when the auxiliary variable contains special delay functions
7.	Initializa--tion link	Level ← Auxiliary	Gives start-up information to level variables about the value of other variables
8.	Cloud		Undefined source or outlet for a flow to, or from a Level.
9.	Dynamic Data Exchange Link	DDE Link	It is used to exchange data with an Excel spreadsheet, where it can be manipulated further.

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It is constructed by defining these variables and the relationships between them. A brief description of the symbols used for defining system dynamics variables is given. These variables are connected using links and flows. Each link represents a relationship between the variables connected by the link. The exact definition of the relationship is defined as an equation in the System Dynamics language. The use of stock (level) and flow in system dynamics model presents the power of mathemati--cal integration in an intuitive and straightforward ways, which even a non-mathematician, can understand.

Validation and Testing of SD Model

The System dynamics model thus developed with the help of constructors presented in Table 3.1 is tested and validated. Validation of system dynamics model is necessitated to establish sufficient confidence in the model (Sahay *et al.*, 1996). Forrester and Senge, (1980) state that validity is fundamentally determined by the extent to which the model fulfils the purpose for which it is built. A systematic validation process first tries to establish the structural validity of the model with respect to the modeling purpose. This is crucial because the purpose of a system dynamics model is to evaluate its behaviour to alternative structures (strategies, policies) (Saysel

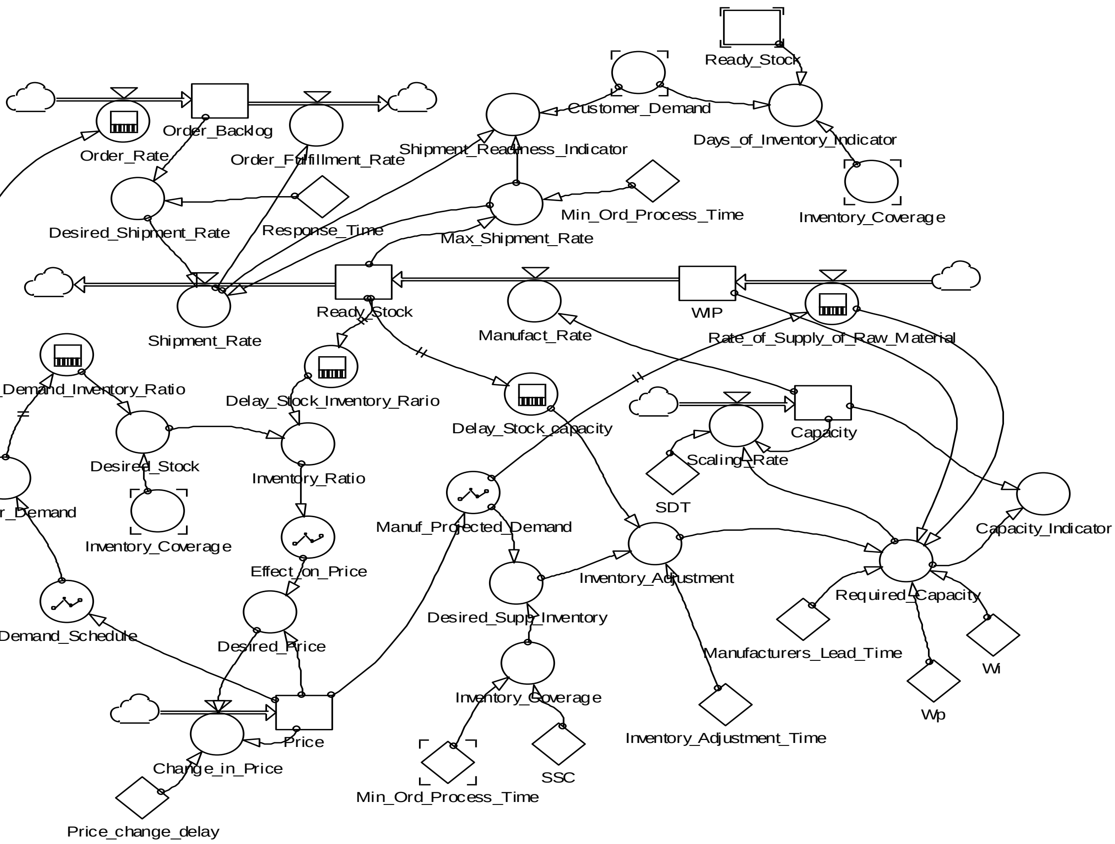

Fig. 3.3. Stock and Flow diagram for DCM.

et al., 2002). The next step involves accessing the accuracy of model behaviour, which is meaningful only if there is sufficient confidence in the model structure. As a consequence tests for model behaviour are typically performed after structural validation. A typical set of model structure validation tests may involve the use of parameter verification, extreme conditions tests, boundary adequacy test and dimensional consistency test. In behavior validity tests, emphasis is mainly on pattern prediction rather than on point prediction (Barlas, 1996). These tests involve behaviour reproduction tests, dimensional consistency test, boundary adequacy test, behaviour sensitivity tests and extreme condition tests. The validation scheme for the proposed model follows the steps suggested by Mohapatra *et al.*, (1994). It is interesting to note that there is a broad agreement amongst those who have dealt with the issue of validation of system dynamics mode1, that there is nothing like absolute validity, only a degree of confidence can be established, which becomes greater as more and more tests are passed.

Sensitivity Analysis of Model

After the validation of model through different tests the model is analyzed with the help of sensitivity analysis. The purpose of the analysis is to develop more insight into the functioning of the system, and knowledge acquired through these analyses helps in redesigning the model and designing meaningful policies for further exploration. Expert opinion is also sought in designing tentative policies. Causal loop diagram Fig 3.2 gives the details of relations of variables on one another. Impact of demand on various variables like price, production rate, inventory cost, and plant capacity can be understood. Similarly impact of many variables like price, urbanization, marketing, globalization, infrastructural development etc on demand can also be understood.

IV. Conclusion

The model of DCM (Stock and flow diagram) is developed and tested for its robustness according to System Dynamics procedure. It can be subjected to experiments to find out the impact of DCM on performa--nce of manufacturing industries. The set of experiments can be designed to include the most important DCM drivers/activities and then its impact for finding out the performance in terms of effectiveness/responsiveness of DCM.

Appendix A

Basic Model Nomenclature:
C = Capacity level at time t.
B = Backlog level at time t.
I = Inventory level at time t.
WIP = WIP level at time t.
PR = Production rate at time t.
PSR = Production start rate at time t.
AD = Average demand.
SD = Standard deviation for the normal demand distribution.
DT = Time step.
OR = Order rate at time t.
ShR = Shipment rate at time t. 18
OFR = Order fulfillment rate at time t.
TRT = Target responsiveness time.
DSR = Desired shipment rate at time t.
MSR = Maximum shipment rate at time t.
MOPT = Minimum order processing time.
SSC = Safety stock coverage time.
DIC = Desired inventory coverage time.
IAT = Inventory adjustment time.
I = Desired inventory level at time t.
AI = Adjustment for inventory rate at time t.
U = Utilization level of the available capacity.
RC = Required capacity at time t.
SDT = Scalability delay time.
SR = Scalability rate at time t.
MLT = Manufacturing lead time.
MUT = Manufacturing unit time.
Wi = The relative weight of inventory consideration in capacity scalability decision.
Wp = The relative weight of demand consideration in capacity scalability decision.

```
init   Capacity = 20
flow   Capacity = +dt*Scaling_Rate
init   Order_Backlog = 0
flow   Order_Backlog = -dt*Order_Fulfillment_Rate
       +dt*Order_Rate
init   Price = 10
flow   Price = +dt*Change_in_Price
init   Ready_Stock = 100
flow   Ready_Stock = +dt*Manufact_Rate
       -dt*Shipment_Rate
init   WIP = 50
flow   WIP = +dt*Rate_of_Supply_of_Raw_Material
       -dt*Manufact_Rate
aux    Change_in_Price = (Desired_Price-Price)/Price_
       change_delay
aux    Manufact_Rate = Capacity
aux    Order_Fulfillment_Rate = Shipment_Rate
aux    Order_Rate = DELAYPPL(Customer_Demand,
       0, 0)
aux    Rate_of_Supply_of_Raw_Material = DELAY
       PPL(Manuf_Projected_Demand, 0, 0)
aux    Scaling_Rate = (Required_Capacity-Capacity)/
       SDT
aux    Shipment_Rate = MIN(Desired_Shipment_Rate,
       Max_Shipment_Rate)
aux    Capacity_Indicator = IF(Required_Capacity/
       Capacity>1, 2-(Required_Capacity/Capacity),
       Required_ Capacity/Capacity)*10
aux    Customer_Demand = Demand_Schedule
aux    Days_of_Inventory_Indicator = (Ready_Stock*
       10/Customer_Demand)/Inventory_Coverage
aux    Delay_Demand_Inventory_Ratio = DELAYINF
       (Customer_Demand, 0, 0, 20)
aux    Delay_Stock_capacity = DELAYINF(Ready_
       Stock, 0, 0, 50)
aux    Delay_Stock_Inventory_Rario = DELAYINF
       (Ready_Stock, 0, 0, 50)
aux    Demand_Schedule = GRAPH(Price,5,5,[100,73,
       57,45,35,28,22,18,14,10"Min:5;Max:100"])
aux    Desired_Price = Effect_on_Price*Price
aux    Desired_Shipment_Rate =
       Order_Backlog/Response_Time
aux    Desired_Stock = Delay_Demand_Inventory_
       Ratio*Inventory_Coverage
aux    Desired_Supp_Inventory_Coverage = Manuf_
       Projected_Demand*Inventory_Coverage
aux    Effect_on_Price = GRAPH(Inventory_Ratio, 0.5,
       0.1,[2,1.8,1.55,1.35,1.15,1.0,0.875,0.75,
       0.65,0.55,0.5"Min:0.5;Max:2"])
aux    Inventory_Adjustment =  (Desired_Supp_
       Inventory_Coverage-Delay_Stock_capacity)/
       Inventory_Adjustment_Time
aux    Inventory_Coverage = Min_Ord_Process_Time+
       SSC
aux    Inventory_Ratio = Delay_Stock_Inventory_Rario
       /Desired_Stock
aux    Manuf_Projected_Demand = GRAPH(Price, 0,
       5,[0,0,40,57,68,77,84,89,94,97,100"
       Min:0; Max:100"])
aux    Max_Shipment_Rate = Ready_Stock/Min_Ord_
       Process_Time
aux    Required_Capacity = (Wp*Rate_of_Supply_
       of_Raw_ Material+Wi*Inventory_Adjustment+
       (1-Wp-Wi)*WIP/Manufacturers_Lead_Time)
aux    Shipment_Readiness_Indicator = (Max_
       Shipment_Rate-Shipment_Rate)/Customer_
       Demand
const  Inventory_Adjustment_Time = 1
const  Manufacturers_Lead_Time = 1
const  Min_Ord_Process_Time = 1
const  Price_change_delay = 14
const  Response_Time = 1
const  SDT = 1.5
```

const SSC = 2
const Wi = 0.3
const Wp = 0.5

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