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SYSTEMS DYNAMICS MODELLING OF A MANUFACTURING SYSTEM

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Abstract

In today's highly competitive global economy, the demand for high-quality products manufactured at low costs with shorter cycle times has forced a number of manufacturing industries to consider various new product design, manufacturing, and management strategies. Recently, due to the rapid advances in Information Technology (IT), new paradigms have successively emerged such as CIM, JIT, lean manufacturing, concurrent engineering, business process engineering and more enterprise engineering (EE). System dynamics modelling is currently in use either as a technique to represent and understand the structure and behaviour of the enterprise, or as a technique to analyze business processes. The developed model was built using a systems dynamics approach. Insights gained from exercising the SD models are used to establish a new managerial conceptual framework. This structure guides managers through the continuous improvement process relative to addressing a physical, policy, or paradigm constraint in their production system.

Index Terms: *System dynamics, Performance, Manufacturing.*

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1. INTRODUCTION

The manufacturing sector has become increasingly competitive as markets have become more globalized. Producers of goods are under intense pressure to improve their operations by enhancing productivity, quality, customer responsiveness, and reducing manufacturing costs. Consequently, there have been major shifts in the design of manufacturing systems using innovative concepts. A manufacturing system exhibits the attributes and characteristics of a system. It can be viewed as the conversion of resources of materials into finished Products. Such a view focuses on the flows inside the manufacturing system, which is close to the terminology used in SD. Thus a manufacturing system may be seen to comprise inputs, processes and outputs. Yet this simple system structure can represent a manufacturing system at any level of details, e.g. On Organisation as whole, or part of it. Therefore, a manufacturing system thus can be modelled as one or more of such converting activities and queues (WIP) connected together in series or parallel manner. Each individual converting activity takes materials, labours and information as inputs and generates products as outputs. The manufacturing word is in permanent change. Many companies around the word saying business means (9).

- Meeting customer requirements
- Reducing the time to market of their products
- Manufacturing products at low cost with in increased quality.

The different functions within a company, focus on different goals and in the pursuit to fulfil them, they do not consider their implications to other departments. At the same time, decisions made by particular functions about the product or process could have an effect on the goals of other functions even if they have no direct interest in or control over the process or goal. In most supply chains, an increase in customer service could result in higher inventory levels and lowering the inventory levels could consequently result in lower customer service. If inventory and customer service are the responsibility of different functions then they would compete each other to achieve their goals.

1.1 System Dynamics

System Dynamics (SD) was originally developed during the 1950s at MIT (4) as a set of tools for relating the structure of complex managerial systems to their performance over time, via the use of simulation. Diagrammatic representations of systems dynamics models are based on cause and effect diagrams (known as causal loop or influence diagrams) and pipe diagrams. The purpose of these diagrams is to allow mental models about system structure and strategies to be made explicit. The word 'structure' is taken to imply the information feedback structure of the system, and hence system dynamics models are often described as taking a feedback perspective of a situation, the underlying premise being that the feedback structure of a system is a direct determinant of its behaviour. Level and Rate Variables are to represent the activity within a feedback loop requires two and only two distinctly different kinds of variables - the levels and the rates. The levels represent the system condition at any point in time. In engineering, the level variables are often referred to as the system state variables. In economics, the system levels are often spoken of as stocks. The levels are the accumulations within the system. Mathematically they are integrations. The rate variables represent the system activity. The rate equations are the policy statements in, the system which defines how the existing conditions of the system produce a decision stream controlling action. The clear separation of system concepts into the two classes of variables - levels and rates - has interesting and useful consequences. The level variables are the integrations of those rates of flow which cause the particular level to change. It follows that a level variable depends only on the associated rates and never depends on any other level variable. Furthermore, in any system, be it mechanical, physical, or social, rates of flow are not instantaneously observable. No rate of flow can depend on the simultaneous value of any other rate. Rates depend only on the values of the level variables. If levels depend only on rates and rates depend only on levels, it follows that any path through the structure of a system will encounter alternating level and rate variables

1.2 Role of System Dynamics in Manufacturing Systems Analysis

The study of the information feedback characteristic of industrial activity to show how organisation structure, amplification and time delays interact to influence the success of the enterprises. This creation was in response to recognition that management sciences were not providing insight and understanding into strategic problems in complex systems. Forrester argued that mathematical analysis is "not powerful enough" to solve the problems of the complex system as a whole, therefore a simulation approach is needed. The process of the SD approach has subsequently been considered by many authors [1, 3, 5, 6]. Inherent to SD is the concept that any natural or management system can be viewed from a distance and can be simply treated on the basis of continuous, fluid-like process. A system can be modelled as converting resources between states and thus can be alternatively represented by "levels interconnected by controlled flows" using a flow diagram. Ten years after conception the emphasis of SD application shifted away from the industrial dynamics origins to business problems. A survey of SD applications conducted by Scholl [8] shows that business policy is the most active area of SD application. However, some researchers have been active in the manufacturing systems field. The basis for research in manufacturing applications of System Dynamics is usually the production-distribution supply chain model proposed by Forrester [4] and the conceptualised model of a manufacturing system outlined by Parnaby [7]. Both break down the manufacturing activity into inter-linked blocks. Towill has long been an advocate of the value of Forrester's work, and much of Edghill and Towill's [2] research activity has been involved with developing the Forrester supply chain models. Edghill and Towill have, for example, developed a generic library of control theory based models of manufacturing systems. They have based their work around three fundamental components of a manufacturing system: orders, materials and information. They argue that these models fulfil the criteria of being meaningful and comprehensible, since these three components give the holistic view that a manufacturing manager requires.

2. SYSTEM DYNAMICS MODEL DEVELOPMENT

2.1 Causal loop Diagram

The primary purpose of the causal loop diagram is to depict causal hypothesis during model development .so as to make the presentation of the structure in an aggregate form. The causal loop diagram helps the modeller to communicate the feedback structure and underlying assumptions. The variables in the system are connected by causal linkages. The direction of the arrow shows the direction of cause effect relationship. The effect of one variable on the other can be positive or negative and this is shown by a +ve or –ve sign on the head of the arrow of the causal linkages. On joining the causal linkages, if one starts tracing the causal path from a particular variable and ends up with the same variable causal path a cause effect feedback loop. As the rule of thumb if the number of –ve links in a feedback loop are either zero or even the feedback loop considered to have a positive polarity and if the number of negative links are odd in feedback loop that loop has negative polarity.

There are two distinct loops in Fig. 1, one controlling the inventory and the second one controlling the backlog of orders. The first loop shows that customer order rate increases backlog of orders will increases ,if the backlog of orders increases the delivery delay will increases, if the delivery delay increases obviously customer orders will decreases

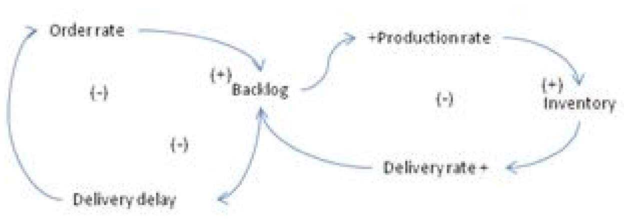

Fig-1: Casual loop diagram

The first loop shows that the delivery has a counteractive effect on the order rate. Therefore, when inventory is low the order rate will be high. The order rate in turn has a positive influence on the delivery rate as, when the order rate increases so does the delivery rate. The loop is negative as it controls the inventory level to a predetermined policy. The second loop represents the desired shipment rate and backlog, which are influenced by the order rate. As Fig. 1 suggests, the backlogged inventory influences the desired shipment rate in the same direction (+). Therefore, as the number of backlogged orders increases the desired production rate will also be increased. Finally, the delivery rate has a counteractive (negative) effect on the backlogs. The above loop is negative as it involves a counteractive influence. The overall influence of the loop can be also be checked by multiplying the individual influences (_)(+)(+) = (_). As the loop is negative it will always try to reduce the backlog to zero.

2.2 Flow Diagram

The next stage in the modelling process is to convert the influence diagrams to rate and level diagrams by utilising the systems dynamics program used in the context of this work. The flow diagram is to represent the detailed flow structure in terms of the fine policy structures so as to facilitate the development of mathematical model. Fig 2 shows that various variables which are presented in different forms to identify them as levels (accumulations), rates (decisions), auxiliaries (algebraic sub division of rates).

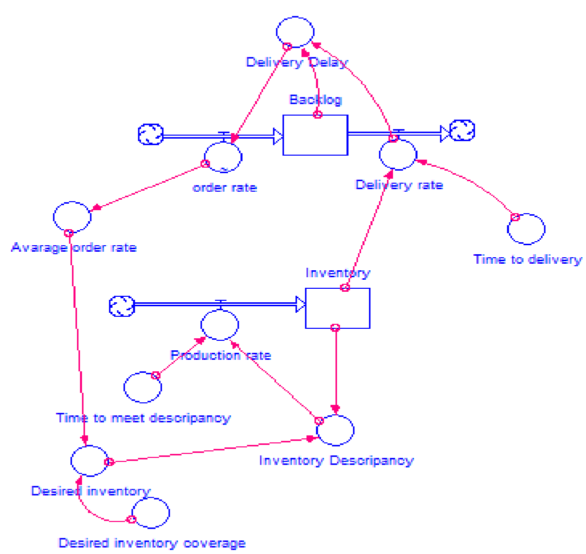

Fig-2: Flow diagram

According to the logic of the model the order policy controls the order rate to fill the deficit between the inventory level and the desired inventory stock. The delivery delay of a product is given approximately by the ratio of backlog to delivery rate. In other words, the time

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to fill an order is indicated by how long the present delivery rate will require to work its way through the present order backlog. Orders booked increase the order backlog which increases the delivery delay which makes the product less attractive and reduces the order rate. A negative feedback loop, as in Loop is goal seeking. Here the loop tends to adjust the rate of order booking to equal the delivery rate. If order booking is too high, the backlog rises and decreases the rate of order booking and vice versa. The policy statement makes a comparison of the goal and apparent condition to detect a discrepancy. The discrepancy may be in the form of a difference, a ratio On the basis of the discrepancy, the policy describes the action to be taken.

3. RESULTS & CONCLUSION

The concept of the technique of SD has been outlined and the role of SD in manufacturing system analysis has been discussed. Modelling ability is concerned with the ability of SD generic approach to truly represent real system under study. An efficient modelling of the associations and interrelationships is vital as a thorough understanding of the system's dynamics and behaviour is the key step towards the optimisation of its performance. A benchmark model was initially created to represent the operation of the system under normal conditions. The performance of the system was analysed with respect to a number of key performance metrics. Initially the delivery delay very high due to the difference between the inventory and the backlog of orders because of time to meet the discrepancy is 6 weeks. The late deliveries counteracts on the orders, obviously the backlogs will pile-up which directly impacts on the performance of the enterprise. So, the time to meet the discrepancy reduced 4 weeks either to enhance the productivity or to increase the manufacturing capacity the system will be stable at 12^{th} week. The SD generic approach provides a mean of easy modelling at a suitably aggregate level, which results in efficient and effective modelling and time saving.

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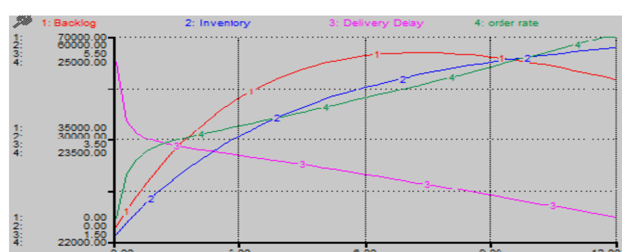
Annexure-1: Mathematical equations

Backlog(t) = Backlog(t - dt) + (order_rate - Delivery_rate) * dt
INIT Backlog = 5000
INFLOWS:
order_rate = GRAPH(Delivery_Delay)
(2.00, 25000), (3.80, 23000), (5.60, 22000), (7.40, 22000), (9.20, 21000), (11.0, 20500), (12.8, 18000), (14.6, 15000), (16.4, 12000), (18.2, 9000), (20.0, 8000)
OUTFLOWS:
Delivery_rate = Inventory/Time_to_delivery
Inventory(t) = Inventory(t - dt) + (Production_rate) * dt
INIT Inventory = 2000
INFLOWS:
Production_rate = Inventory_Descripancy/Time_to_meet_descripancy
Avarage_order_rate = SMTH3(order_rate,5)
Delivery_Delay = Backlog/Delivery_rate
Desired_inventory = Avarage_order_rate*Desired_inventory_coverage
Desired_inventory_coverage = 2.5
Inventory_Descripancy = Desired_inventory-Inventory
Time_to_delivery = 2
Time_to_meet_descripancy = 4

Annexure-2: Graph shows Backlog, Inventory, Delivery Delay and Order rate



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