SUPPLY CHAIN MANAGEMENT, SIMULATION & SYSTEM DYNAMICS OF AN IRON FOUNDRY

S. Shyam Sunder Rao¹, K. Vizaya kumar²

¹ Department of Mechanical Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, India,
sshyamsunderrao@yahoo.com

²Professor, Ahlia University. O. Box 10878, MANAM, Kingdom of Bahrain,
vizaya@gmail.com

Abstract: Supply chain management plays a vital role in the growth of the industry, survival in the market, the production rate and the dynamic interaction among the suppliers and the customers. Strategic decision makers need comprehensive models to guide them in efficient decision making that increases the profitability of the entire chain. System dynamics is a methodology whereby complex, dynamic and nonlinear interactions can be understood and analyzed. The objective of the paper is to show the system dynamics and simulation model for iron foundry to control inventory, and also to make the inventory policies. This paper presents a simulation of supply chain model of a medium size industrial iron foundry which will produce gray cast iron and Spheroidal graphite cast iron, and also the dynamic interaction between the variables using system dynamic approach. Under different delay conditions, rejection rates, conditions, the policy experimentations carried out considering various factors of the foundry and their degree of development. The model results have been discussed and validated based on the actual results of a foundry. This paper has addressed many important issues related to demand, inventory, production rates of a foundry

Keywords: supply chain management, simulation, system dynamics, foundry

1. Introduction

Supply chain management (SCM) plays a vital role in the growth of the industry, survival in the market, the production rate and the dynamic interaction among the suppliers and the customers. SCM has been met with increased recognition during the last decade both by academicians as well as practitioners. SCM of medium size iron foundry is taken and its system dynamic & simulation model is studied. System Dynamics (SD) is a methodology whereby complex, dynamic and nonlinear interactions in the systems can be analyzed and new structures and policies can be designed to improve the system behavior. SD modeling requires two types of flows, one is the physical flows, and another is the information flow. In today’s highly competitive marketplace a successful winner is one who has the ability to satisfy the end customer requirement. Foundry, which is studied for this purpose is a medium size, is established in 1970, located at Hyderabad, in Andhra Pradesh. It manufactures Spheroid graphite cast iron (Ductile Iron) and Gray cast iron castings (GI). It produces hubs, housings, axle parts to cater to commercial vehicle, tractor. Ductron Castings commitment to quality was recognized when the company was awarded ISO9002 and QS 9000 certification.

The concept of system dynamics and its application to industrial problems are not new. This paper presents a simulation of supply chain model of a medium size industrial iron foundry which will produce gray cast iron and Spheroidal graphite cast iron, and also the dynamic interaction between the variables using system dynamic approach. Under different delay
conditions, rejection rates, conditions, the policy experimentations carried out considering various factors of the foundry and their degree of development. The model results have been discussed and validated based on the actual results of a foundry. Great attention has to be paid to reduce the information and material delay associate with the supply chain, to reduce the inventory between the members and maximize the supply chain efficiency. Broad objective of the study has been developing system dynamics model representing the behavior of foundry in India for policy analysis. The specific objectives are to develop a frame work on supply demand scenario casting foundry in India, to build a simulation model for castings and to generate future scenario against various policy options, to discuss policy options in terms of castings. This paper has addressed many important issues related to demand, inventory, production rates of a foundry. In this paper SC of medium size foundry is taken, production of gray iron castings is considered and system dynamic model is developed and discussed for the iron foundry. The remainder of the paper is organized as follows. Section 2 gives the information regarding the literature review, Section 3 introduces the development of the model on gray & SG iron foundry, Section 4 explains the system dynamic and simulation model, and model validation, and in Section 5 about results and discussion and, finally it wrapped up with the conclusions in the last section.

2. Literature Review

Forrester [1] developed industrial dynamics, which later extended and called system dynamics. Intact, he already developed a model for simple supply chain which has four links, namely retailer, wholesaler, distributor, and factory. He examined how these links react to deviations between actual and target inventories. M.M.Naim [2] in his, articles and books, developed a real world dynamic system. He developed a “real world dynamic analysis” of any business is extremely difficult to perform Supply chain management, i.e. the process of planning, implementing, and controlling operations of the supply chain while satisfying customer requirements as efficiently as possible. The process includes all internal functions, logistics, distribution, sourcing, customer service, sales, manufacturing, and finance departments of an organization. By involves external suppliers that provide finished products, components, parts and assemblies, and their delivery. This definition is given by David Simchi-Levi [3]. A cooperative, two-stage supply chain consisting of two members: a retailer/manufacturer and a supplier, is discussed by Yossi Aviv [4]. He studied the interaction between inventory and forecasting in a two-stage supply chain of a single product that faces stochastic demand. Tae Cheol Kwak [5] explained in his paper supplier –buyer models for the bargaining process over a long-term replenishment contract. In his paper he has given two different models one for supplier i.e. supplier –leading models and another for buyer, i.e. buyer –driven model. There are many models are developed for either the supplier or manufacturer or buyer. Terry[6] has developed supply chain relation and contracts the impact of repeated interaction on capacity investment and procurement. Chi-Leung[7] has presented in his literature on scalable methodology for supply chain inventory coordination with private information. He considered the problems of coordinating serial and assembly systems with private information where end item demands are known a finite horizon. On inventory there are several models like Economic order quantity(EOQ) models, Economic Production Quantity (EPQ) models are discussed in the Operation Research book written by Dr.S.D.Sharma[8] in this book he has not explained supplier –buyer models which should benefited to both the supplier and buyer, which the total cost of the system is minimum. Other papers like single supplier/multiple supply co-ordination models which are written by Seljuk[9] studied, in this paper the supplier to coordinate the supply chain by offering quantity discounts to obtain their complete cost information, in this paper supplier has the information of buyer’s holding cost and also set up cost structures. Fangruo Chen[10] presented a literature on coordination mechanisms for the distribution system with one supplier and
multiple retailers. Here he explained the holding cost rates depend on the whole prices of the items. Studying the different system dynamic papers and also books, Benita M. Beamon[11] explained in his research paper, supply chain design and analysis: Models and methods, reviewed literature in multi stage supply chain modeling and also defined a research agenda for future research in this areas, Shotaro Minegishi[12]. In system dynamics modeling and simulation of a particular food supply chain, showed dynamics could contribute to improve the knowledge of the complex logistic behavior of an integrated food industry. He presented practical simulations results are presented. Patroklos [13] he adopted system dynamic methodology as a modeling and analysis tool for the strategic supply chain management.

3. Development of model

Modeling is done on the basis of feedback system with symbols of level and flow variables. The “Level” variables describe the state of the systems by continuous integration of actions resulting from these systems. The flow variables express actions. The level exist permanently even if any activity were to cease, where as the flow would disappear. This mode of representation makes it possible there after to represent the variations of these states through differential equations and to study their dynamic behavior. This progressive step of modeling leads us to continuous simulations, which allow us to visualize stabilized behaviors and to analyze characteristic phenomena of stability within certain real systems. Stella software is used to for this research work. This e model contains different symbols for ease representation

STOCK: The basic building block is the stock, which is used to represent anything that accumulates. Examples of stock include population, water in a stream or reservoir, and mass. We can also represent non physical accumulations, like skills, knowledge, and fear.

FLOW: The flow is used to represent activities. Examples to flow include births, water flowing and migration. These activities will change the magnitude of stock in a system. With non physical stocks it can be more difficult to name associated flows. Examples of non physical flows are learning, forgetting and building up.

CONNECTORS: connectors look like wires and are used to transmit information and inputs that are used to regulate flows. Connectors can connect into flows or converters but never in to stocks. As an Example, a connector could take the amount of water in reservoir and transmit that to the discharging flow affecting rate at which water is released. This in turn changes the level of water in reservoir.

CONVERTERS: converters contain equations that generate an output value for each time period. Converters often take in information and transform it for use by another variable in the model. In the above water example, one converter could store the desired water level. Another converter uses that information.

The production of gray iron casting and spheroid graphite cast iron is complicated process which requires the following steps.

- Preparation of molds by high pressure moulding machine (hpml),
- Preparation of cores (by cold box process),
- Preparation of molten metal according to the acceptable grade,
- Fettling operations, i.e. removing, castings from moulds (knockout), removing gates and risers, removal of sand attached to castings (shot blasting),
- Painting & Quality Control
- Dispatch.

For preparing the good molds, the following properties are required for the molding sand (IS1918:1966 Physical testing of foundry sands)[14] by High pressure molding machine

- Fineness number (grain size/AFS Number) of the base sand
- Moisture content in the mixture (ranges from 2-7% depending on the casting method)
• Permeability (ability of compacted mould to pass air through it)
• Total clay content (dust content)
• Active clay content (presence of active bentonite/clay which can readily bond)
• Compressive strength

For preparing the good cores, by cold box process (with automatic core shooters) very good washed sand having AFS GFN 45-55(American Foundry Society-Grain Fineness Number) required, this process is based on formation of poly urethane under the catalytic effect of a tertiary amine. These two components, a gas curing resin and the activator, contain both additives and considerable amounts of solvents are mixed with sand (washed and then dried sand, to remove the acids and also alkalis), this mixed sand is used to make cores.

Molten metal is prepared in Induction furnace by melting - Steel scrap, Foundry returns (rejected castings, risers, runners, gates etc.) and additives (Ferro silicon, Ferro manganese, Carbon etc.) to get the required grade (composition).

The medium size foundry is having two 8 ton furnaces, two 3.5 furnaces and two 2.5 furnaces for melting steel scrap and additives are added according to the requirement of the casting properties. This foundry contains one high pressure molding line which can produce one mould box per two minutes. It has cold box process to produce cores, one core per every four minutes. This foundry produces different types of castings like transmission case, axle housings, center housings, differential carriers, hubs, trumpets, etc... For making different grades and types castings. To produce these castings it requires various types of cores, moulds, patterns, and also different liquid metal composition is required.

The co-ordination between purchases, stores, core shop, molding and melting is very much required. The model is developed, considering purchase department, stores, molding shop, core shop and melting shop, and its process parameters, rate of rejections at various places, and also considering capacity constraints of melting shop, core shop and molding shops. At present the model is developed for one of the product of the company, by using Stella software.

**Table-1:** Short abbreviations are written

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Acronyms/ abbreviation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TIDC</td>
<td>Time to meet the inventory discrepancy of core chop sand</td>
</tr>
<tr>
<td>2</td>
<td>TIDM</td>
<td>Time to meet the inventory discrepancy of molding sand</td>
</tr>
<tr>
<td>3</td>
<td>MMRC</td>
<td>Material requirement for core shop</td>
</tr>
<tr>
<td>4</td>
<td>CSPR</td>
<td>Core sand procurement rate</td>
</tr>
<tr>
<td>5</td>
<td>CSUR</td>
<td>Core sand utilization rate</td>
</tr>
<tr>
<td>6</td>
<td>CSUF</td>
<td>Core sand utilization factor</td>
</tr>
<tr>
<td>7</td>
<td>CPR</td>
<td>Cores production rate</td>
</tr>
<tr>
<td>8</td>
<td>CRR</td>
<td>Cores rejection rate</td>
</tr>
<tr>
<td>9</td>
<td>CAR</td>
<td>Cores acceptance rate</td>
</tr>
<tr>
<td>10</td>
<td>CUR</td>
<td>Cores utilization rate</td>
</tr>
<tr>
<td>11</td>
<td>CRF</td>
<td>Core rejection factor</td>
</tr>
<tr>
<td>12</td>
<td>MSPR</td>
<td>Molding sand procurement rate</td>
</tr>
<tr>
<td>13</td>
<td>MSUR</td>
<td>Molding sand utilization rate</td>
</tr>
<tr>
<td>14</td>
<td>MSPR</td>
<td>Molding sand procurement rate</td>
</tr>
<tr>
<td>15</td>
<td>MSUF</td>
<td>Molding sand utilization factor</td>
</tr>
<tr>
<td>16</td>
<td>MPR</td>
<td>Mold production rate</td>
</tr>
<tr>
<td>17</td>
<td>MRR</td>
<td>Mold rejection rate</td>
</tr>
<tr>
<td>18</td>
<td>MUR</td>
<td>Mold utilization rate</td>
</tr>
<tr>
<td>19</td>
<td>MAR</td>
<td>Mold acceptance rate</td>
</tr>
<tr>
<td>20</td>
<td>SSPR</td>
<td>Steel scrap procurement rate</td>
</tr>
<tr>
<td>21</td>
<td>SSUR</td>
<td>Steel scrap utilization rate</td>
</tr>
<tr>
<td>22</td>
<td>LQMPR</td>
<td>Liquid metal production rate</td>
</tr>
<tr>
<td>23</td>
<td>LQMUR</td>
<td>Liquid metal utilization rate</td>
</tr>
<tr>
<td>24</td>
<td>CR</td>
<td>Casting rejection rate</td>
</tr>
<tr>
<td>25</td>
<td>FR</td>
<td>Fettle ling rate</td>
</tr>
</tbody>
</table>

The Stella equations to produce the castings

\[
\text{CASTINGStpy25} \ (t) = \text{CASTINGStpy25} \ (t - dt) + (\text{casting_production_rate} - \text{CRR_25}) \ast \ dt
\]
INIT CASTINGStpy25 = 0

INFLOWS: casting_production_rate = (FINISHED_MOUSLDS*LQM_20)/1000

OUTFLOWS: CRR_25 = CASTINGStpy25*0.1

CORES (t) = CORES (t - dt) + (CPR - CAR - CRR) * dt

INIT CORES = 0

INFLOWS: CPR = demand

OUTFLOWS: CAR = CORES*CAF

CRR = CORES*CRF

CORESAND(t) = CORESAND(t - dt) + (CSPR - CSUR) * dt

INIT CORESAND = 0

INFLOWS: CSPR = 250

OUTFLOWS: CSUR = CORES*CSUF*CORESAND

FETTLED_CASTINGS (t) = FETTLED_CASTINGS (t - dt) + (FR_25 - DESPATCH_RATE) * dt

INIT FETTLED_CASTINGS = 10

INFLOWS: FR_25 = CASTINGStpy25 - FETTLED_CASTINGS*CF_25

OUTFLOWS: DESPATCH_RATE = AT_DESPATCH + FETTLED_CASTINGS - BACKLOG_ORDERS

FINISHED_CORES (t) = FINISHED_CORES (t - dt) + (CAR - CUR) * dt

INIT FINISHED_CORES = 0

INFLOWS: CAR = CORES*CAF

OUTFLOWS: CUR = CFPC

FINISHED_MOUSLDS (t) = FINISHED_MOUSLDS (t - dt) + (MAR_16 - MUR17) * dt

INIT FINISHED_MOUSLDS = 0

INFLOWS: MAR_16 = MOULDS_13*MAF

OUTFLOWS: MUR17 = MFPC_27

LQM_20(t) = LQM_20(t - dt) + (SSUR + LQMPR_25 - LQMUR22 - LQMSR) * dt

INIT LQM_20 = 0

INFLOWS: SSUR = SS*SSAT_25factor

LQMPR_25 = SSUR*SSCF

OUTFLOWS: LQMUR22 = LQM_20*LQFC

LQMSR = LQM_20*0.1

MOULDS_13 (t) = MOULDS_13 (t - dt) + (MPR_15 - MAR_16 - MRR_25) * dt

INIT MOULDS_13 = 0

INFLOWS: MPR_15 = demand

OUTFLOWS: MAR_16 = MOULDS_13*MAF

MRR_25 = MOULDS_13*MRF*CRF

MS_10 (t) = MS_10 (t - dt) + (MSPR_Tpmonth - MSUR_TpY_12) * dt

INIT MS_10 = 0

INFLOWS: MSPR_Tpmonth = 500

OUTFLOWS: MSUR_TpY_12 = MOULDS_13*MSUF_TpMOULD_25*MS_10

SS(t) = SS(t - dt) + (SSPR - SSUR) * dt

INIT SS = 0

INFLOWS: SSPR = 275*SSRPLQpt_of_lq

OUTFLOWS: SSUR = SS*SSAT_25factor
AT_DESPATCH = 0.1  
BACKLOG_ORDERS = 0.05  
CAF = 1-CRF  
CFPC = 0.1  
CF_25 = 300  
CRF = 0.07  
CSUF = 0.9  
demand = 2250  
LQFC = 0.1  
MAF = 1-MRF  
MFPC_27 = 0.05  
MRF = 0.07  
MSUF_TpMOULD_25 = 0.95  
SSAT_25factor = 0.1  
SSCF = 0.1  
SSRPLQtpt_of_lq = 0.05  

mines, it is mixed with the resins, passed to cold box core shooters, then to core box, after passing the amine gas, the core will be produced. The molding sand is prepared by mixing new sand with the additives-like old sand (used sand), bentonite, lustron (carbon powder) and water. This passed through the converyor to the High Pressure Molding Line (hpml), which prepares moulds. The transmission cores are assembled in the drag mould box, and then closed with cope box, after that it is passed to the melting shop, where molten metal is poured into the assembled moulds. After solidification of liquid metal, castings are knocked out from the mould boxes, and then send to fettling shop, after the quality checking is over, and then the castings are dispatched. Purchasing materials like- steel scrap, carbon powder, sand for making the moulds and cores is called inbound supply chain. The different stages of production i.e. core making, mould making, melting, fettling; quality checking is called in process supply chain. Dispatch to, warehouse and to customers is called as outbound supply chain management.

4. Model validation

The simulated model results are compared with the actual results. To develop confidence in the model, the structure of the model is validated through the employers and experts. The initial values of model parameters were compiled and computed from secondary sources. The data is collected from the production reports, rejection reports of the company. Some data is collected by direct observations. This system model is developed for casting requirement. An overview diagram developed with influential parameters in finished castings. One product, i.e. Transmission case is taken for the purpose of study. The model is studied starting from the purchase department- (purchase of raw material and indirect materials) Production departments (core shop, molding shop, melting shop, and fettling shop) then to sales department. The processing time, customer orders, rejections rates are taken. The data is collected for 25 days and simulated. Graphs are plotted for purchase of core sand, molding sand, steel scrap, and inventory of steel scrap, assembling of

Figure1: Stock flow diagram for the variables supplies chain of iron foundry.

Fig 1 is the simulation model diagram; it gives the information flow, process flow and feedback mechanism. The supply chain model is developed for the production of transmission case iron castings. Core shop sand i.e. washed and dried sand is procured from the M/S southern silica
moulds etc. Model validation is done on the basis of statistical tests. The validity of the test is done by heuristic method, judged by its usefulness. In this case previous year procurements of sands are taken and compared with the simulated results and also the castings produced, in this cases strike periods, abnormal cases are eliminated. Fettling stock, finished castings and also the delivery rate of the castings to the customers.

5. Results and discussions

In this paper it has considered simple deterministic model. The demand of the product (transmission case) is taken. The simulated graphs, shows that how much sand should be procured according to the time(month), it also gives very good validated results to procurement of scrap, plan for dispatch.Fig.3,4,5,6, are the simulated graphs. In this graphs one can generate the policies also, i.e. when to procure, how much to procure, inventory planning’s can also done by this simulation results.

6. Conclusions

This work has made it possible to understand and explain the complex behavior of molding sand, core sand effect to the production of iron castings and its rejections. This paper we considered a
simple system dynamic model developed based on the supply chain, relationships for identified various parameters. The simulation has been carried out for one year. The model is tested by using secondary data. System dynamic model presented hear helps the organization to understand it supply chain variables-procurement of steel scrap, sand and other materials, process planning and also maintaining inventory, thereby reducing cost of inventory. By maintaining vendor relations, it also helpful to reduce the lead time, and improvement in its quality of services, customer satisfaction and improving the supply chain efficiency. It is useful to take the decisions by studying the graphs such that, when to purchase the raw material, when to start production and also one can know the situation of the products. It is useful to make inventory policies such that how much to produce, how much to keep the core stock, castings stock, one can able to know the requirements of core production taking care of core rejection, mold rejections. By taking the yearly demand he one can able to estimate the rejections castings, required sand level, core stock level and also rate production.

7. References

5. Tae Cheol Kwak,Jong Soo Kim,Chiung Moon(2006), Supplier –buyer models for the bargaining process over a long – term replenishment contract, Computers and

Industrial Engineering 51 (2006),pp219-228

Biography

SHYAM SUNDER RAO SIRIVOLU is an Associate Professor in Mechanical Engineering Department, Faculty of Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, India. He did his M.Tech. in Industrial Engineering from JNTUH, Hyderabad, MBA (P&OM) from IGNOU, New Delhi, and currently pursuing Ph.D. in Mechanical Engineering from JNTUH. His research areas include Supply chain management, Material Science, Production and Operation Management, Composite Materials, He has few papers published in conference proceedings and journals.

VIZAYAKUMAR KARUMANCHI is a Professor of Industrial Management at AHLIA UNIVERSITY, Bahrain. He did his M.Tech. (Industrial Engineering) and PhD from IIT, Kharagpur. He worked as professor and Head, Industrial Engineering and Management ,IIT, Kharagpur, U.P.