Inbound, Internal Supply chain management of an Iron Foundry through Simulation and System Dynamics Model

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Abstract— Supply chain management plays a vital role in the growth of the industry, improving the production rate and the dynamic interaction among the internal suppliersand customers.The objective of this paper is to show how the system dynamic could contribute to improving the complicated production process, internal supply chain of an Iron Foundry. It presents the internal supply chain model of a medium size foundry which will produce cast iron components, and also the dynamic interaction between the variables using the system dynamic approach. The simulated model results have been discussed and validated based on actual results of a foundry. This paper addresses the important relations related to demand procurements of materials, inventory, producton rates, and shipments of the foundry.

Index Terms—An Iron foundry, core shop, fettling, moulding, melting, simulation, supply chain management (SCM), system dynamics (SD)

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1 INTRODUCTION

The production of gray iron casting requires the following steps. (1)Preparation of molds by high pressure molding machine (hpmm),(2)Preparation of cores (by cold box process),(3)Preparation of molten metal according to the acceptable grade,(4)Fettling operations, i.e. knockout, removing gates and risers, removal of sand attached to castings (shot blasting),(5)Painting & Quality Control (6)Dispatch.

For preparing the good molds, the quality parameters are to be maintained, concentrated for the molding sand as per the Indian standards (IS1918:1966). For preparing the good cores, by cold box process (with automatic core shooters), good washed sand having AFS GFN 45-55(American Foundry Society-Grain Fineness Number) required. 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). Steel scrap and additives are added according to the requirement of the casting properties. The high pressure molding line can produce one mould per every two minutes and core shooters of cold box process can produce one core per every four minutes.

This foundry produces different types of castings. Transmission case is one of the casting is taken for study. The present inbound, internal supply chain management model is developed by integrating purchase department, stores, molding shop, core shop, melting shop and fettling.

2 .LITERATURE SURVEY

There is limited research study on SCM of an Iron foundry (Automobile industry) through simulation and system dynamic approach. Lorenzo Tiacci and Stefano Saetta [1] have taken past demand data for forecasting on the basis of which stock is controlled. For global operation of SCM on foundries, the total cost is taken; they compared the historical data with simulation results. R Raimo Keloharju [2] explained the hard, soft and semi hard Systems thinking, and also explained system dynamics optimization as a methodology which is well suited for the tasks to combine all the systems. Kung-Jeng Wang et.al. [3] Considered highly and fast deteriorating rates of the products, and there by inventory causes loss. For multi level sc, with multiple products of this nature, it is difficult to control the inventory. Firms develop strategic partnerships and alliance to optimize the inventory. Joint policies are developed through the simulation and system dynamic approaches. Mohapatra and Mandal [4] explained about policy modeling and developments of SD in India and how they are used for different inventory situations. Chester K.M. et.al. [5] Considered each step, starting from raw materials (suppliers) to finished products (manufacturers), to distribution to market, to warehouses, to retailers and then to customers. At every stage the value of product is increased, he simulated to find the process performance. G. Perrone et.al. [6], discuss project management approach in automotive industry. Developing a product mainly depends upon price, reducing time for new product, and engineering design aspects. In this, multi-attribute mechanisms are simulated using system dynamics.

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Guoyin Jiang et.al. [7], and Jing Li et.al. [8] discussed the multi objective simulation study. They say negotiations, bargaining, coordinating and collaboration mechanism are needed for the higher profits. They discussed multi-agent simulation (MAS) study approach. MAS tool understands, analyses the behavior, and defines the relations between purchasing and selling prices. Dynamic relationships between agents can be found. Sanjay Kumar Shukla et.al. [9] developed the hybrid SCM model involving collaboration in (i) information sharing, (ii) capacity planning, and (iii) reliability among the players. In this hybrid model, Simulation, Taguchi method, and robust multiple non-linear regression analysis are used..

Simulation and system dynamic approach is mostly done on the food and Electronic industries. Most of the studies such as YoussefBoulaksil and Jan C.Fransco [10], Chao-Kuei Huang. [11], Felix T.S. Chan and T. Zhang [12],], Pratap K.Mohapatra and Purnendu Mandal [13],and K.Vizayakumar and PKJ Mohapatra[14] are studied on simulation of vendor managed inventory, project design, product development, supply chain risk, vendor selection, order release strategy to control outsource operations in SCM, agent based simulations, and transportation management in SCM. Extensive research is needed in the area of inbound, internal supply chain management of an iron foundry by simulation and system dynamic approach. Sufficient research has not been done in the area of the of iron foundry, which is a very much complicated process of production of castings. It integrates purchase, stores, core shop, molding, melting, fettling, .

3. PROBLEM AND DESCRIPTION

3.0 Manufacturing process:

3.1 Core preparation (sector-1):

Core sand is procured from sand suppliers, and then stored. Cores are produced by Cold box process.In this process, sand is mixed with Part - A phenol formal dehyde 0.8-1.8 percentage, Part - B 0.7% to 1.1%, Part - C catalyst is added 0.15% to 0.2% and mixed in the mixture about 3 minutes. This mixed sand must be used before 40 minutes (shelf life of sand) only. Through conveyer belts, the mixed sand transported to bunkers, then to core shooters and core boxes. By passing amine gas into core box which contains mixed sand, the cores are made. In this System dynamic simulation model, core shop, is shown in the sector-1.The core sand procurement rate, core production rate, core utilization rate, shipping to molding etc..are shown as flow variables, core sand, number of cores stock, unfinished cores (before painting), cores for assembly line, expected shipping of cores to molding line are shown as level variables.

3.2 Mould preparation (sector-2)

Molding Sand is procured from the suppliers and then stored. Used sand 90%,new sand 3.4%,bentonite 1.2%,lustron 0.4% is mixed for 2 minutes in the mixture by adding 4% moisture. The mixed sand is transferred through the conveyer belt to the high pressure molding line. The mixed sand is stored in the bunker. This mixed sand is utilized for making mold by automatic high pressure molding line. The total weight of molding sand is (cope and drag) 1.8 tones. Mold sand procurement rate, new sand utilization rate, mold production rate, mold utilization rate, molds shipping rate liquid metal pouring, etc...are shown as flow variables, new molding sand, old molding or used sand, number of molds stock, finished molds, molds for assembly (core setting),expected shipping of molds to melting shop for pouring etc..are shown as level variables.

3.3 Melting (sector-3)

Steel scrap is procured from the scrap suppliers and then stored. The medium frequency Induction furnaces used for melting the steel scrap. The weighted steel scrap is dumped into the furnace and heated up to 1400-1500^{0}c temperature, by supplying power. By adding additives like ferro-silicon, graphite powder, copper etc., the required composition and grades are achieved which satisfies the customers. Before taping liquid metal from the furnace into the ladle, the composition of liquid metal is checked by spectrum equipment. Through the ladle, liquid metal is poured in to different moulds according to the weight of the casting tree (Contains actual product weight, in-gate weight, runner weight, spruce weight, spruce basined weight.

3.4 Fettling (sector-4)

After solidification, castings are knocked out from molding boxes by knockout machine. The castings are transferred to the fettling section to break or to cut, the runners, gates and risers. These castings are transferred to shot blasting machine through the chain conveyer to remove attached sand. After inspection,, if it is found OK these are painted and then supplied to the respective customers.

4. MODEL DEVELOPMENT
4.1 Models

The model is developed for one of the product "Transmission case" by applying system dynamic approach , using Stella software. Modeling is done on the basis of feedback system. Icons and Symbols used for drawing the simulation diagram. Level variables expressed as states. Flow is expressed by actions. It uses the continuous integration which represents the simulation process. Stella software is used to for this research work. This model contains different symbols for ease representation..STOCK-FLOW model diagram is shown in the figures. In fig.1 the core production process is shown in sector-1, mould production process in sector-2, in,

fig.2.melting, sector-3 and fettling process in sector-4 .Model equations are given in the tables 1,2,3,4 about the process of sectors-1, 2, 3 and 4.
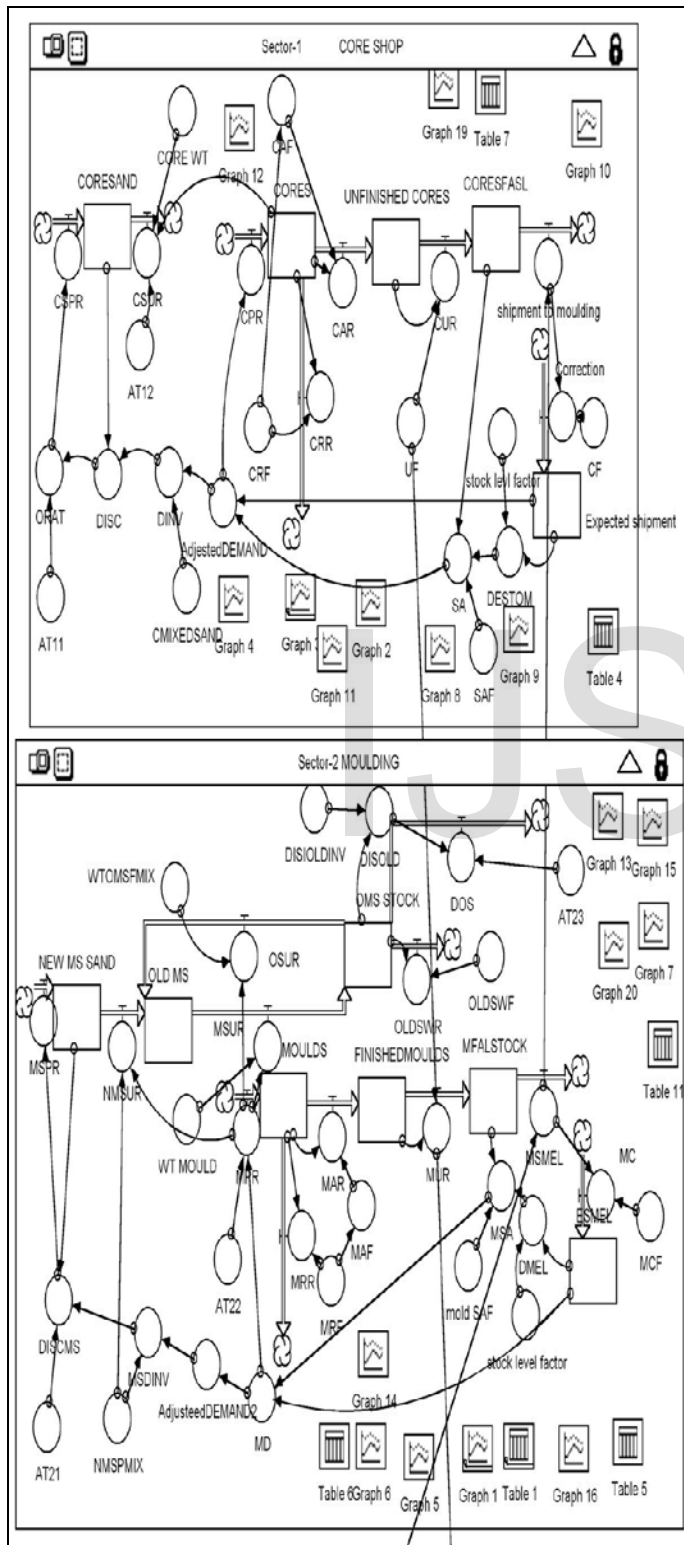

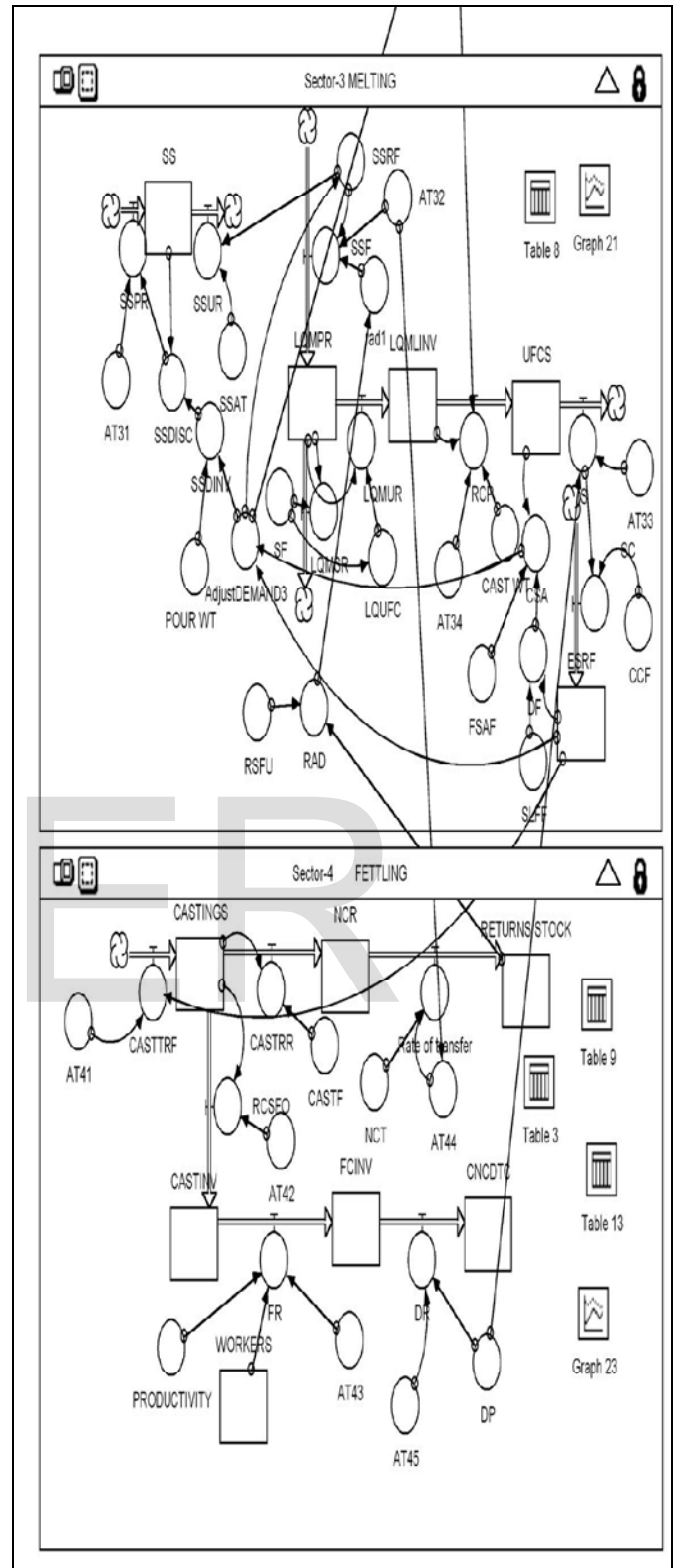Fig.1 Core shop (sector-1) and Molding (sector-2)

Fig.2 melting (sector-3) and Fettling (sector-4)

Inbound, internal supply chain model is prepared by taking internal suppliers and internal customers (internal departments-core shop ,molding ,melting and fettling).Material transaction and information transfer from one department to another department (called as internal suppliers and customers) is shown in the models ,then analyzed and found its impact on objective function (OF). Validation is done through using the actual foundry data.

4.2 Information sharing

The information is shared with the transactional documents to the suppliers (outside)-sand suppliers, steel scrap supplier, additive suppliers etc. Invoices, dispatch notices, for internal information is shared by the production plans, inventory reports generated by production and planning department. .Sharing, coordinating, was planning the activities enables the reduction of inventory. The service improvement can be done by coordination,vendor managed inventory, and by collaborative planning.

4.3. Delay

It is the transformation process in SC. Outflow and Inflow rates differed according to supply and demand, under the dynamic interactions where the procurement, preparation and production changes. The Information delay, procurement delay, production delay, delay due to rejections are s important delays associate with the SC system. Reducing the delays, managing the delays is to strengthen the SC. SC delay model is analyzed in different situations.. This model is checked for different parameters of SC.

4.4. Assumptions

These assumptions are pertaining to the foundry industry, sand suppliers, scrap suppliers, departments –pattern shop, core shop, molding, melting, fettling etc. considered as different partners (inbound supply chain) within the organization. The organizations should know

> ➢ Within and outside must know about SCM for implementation.
> ➢ the gap between SC opportunities and challenges, which will increase inventories
> ➢ that SCM contributed to develop business

5 EQUATIONS

Table.1 stock-flow eaquations of core shop


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Sector-1        CORE SHOP
☐  CORES(t) = CORES(t - dt) + (CPR - CAR - CRR) * dt
   INIT CORES = 0
   INFLOWS:
      ⇌ CPR = AdjestedDEMAND
   OUTFLOWS:
      ⇌ CAR = CORES*CAF
      ⇌ CRR = CORES*CRF
☐  CORESAND(t) = CORESAND(t - dt) + (CSPR - CSUR) * dt
   INIT CORESAND = 1000
   INFLOWS:
      ⇌ CSPR = ORAT
   OUTFLOWS:
      ⇌ CSUR = CORES*CORE_WT/AT12
☐  CORESFASL(t) = CORESFASL(t - dt) + (CUR - shipment_to_moulding) * dt
   INIT CORESFASL = 0
   INFLOWS:
      ⇌ CUR = UNFINISHED_CORES*UF
   OUTFLOWS:
      ⇌ shipment_to_moulding = MSMEL
☐  Expected_shipment(t) = Expected_shipment(t - dt) + (Correction) * dt
   INIT Expected_shipment = 2250
   INFLOWS:
      ⇌ Correction = shipment_to_moulding*CF
☐  UNFINISHED_CORES(t) = UNFINISHED_CORES(t - dt) + (CAR - CUR) * dt
   INIT UNFINISHED_CORES = 0
   INFLOWS:
      ⇌ CAR = CORES*CAF
   OUTFLOWS:
      ⇌ CUR = UNFINISHED_CORES*UF
○  AdjestedDEMAND = Expected_shipment+SA
○  AT11 = 2
○  AT12 = 1
○  CAF = 1-CRF
○  CF = 1.2
○  CMIXEDSAND = 110
○  CORE_WT = 100
○  CRF = 0.007
○  DESTOM = Expected_shipment*stock_levl_factor
○  DINV = CMIXEDSAND*AdjestedDEMAND
○  DISC = DINV-CORESAND
○  ORAT = DISC/AT11
○  SA = (DESTOM-CORESFASL)*SAF
○  SAF = 1
○  stock_levl_factor = 2
○  UF = 1
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Table.2 stock-flow equations of moulding

Sector-2 MOULDING

☐ ESMEL(t) = ESMEL(t - dt) + (MC) * dt
INIT ESMEL = 2250
INFLOWS:
⚓ MC = MSMEL*MCF

☐ FINISHEDMOULDS(t) = FINISHEDMOULDS(t - dt) + (MAR - MUR) * dt
INIT FINISHEDMOULDS = 0
INFLOWS:
⚓ MAR = MOULDS*MAF
OUTFLOWS:
⚓ MUR = FINISHEDMOULDS*UF

☐ MFALSTOCK(t) = MFALSTOCK(t - dt) + (MUR - MSMEL) * dt
INIT MFALSTOCK = 0
INFLOWS:
⚓ MUR = FINISHEDMOULDS*UF
OUTFLOWS:
⚓ MSMEL = AdjustDEMAND3

☐ MOULDS(t) = MOULDS(t - dt) + (MPR - MRR - MAR) * dt
INIT MOULDS = 0
INFLOWS:
⚓ MPR = MD/AT22
OUTFLOWS:
⚓ MRR = MOULDS*MRF
⚓ MAR = MOULDS*MAF

☐ NEW_MS_SAND(t) = NEW_MS_SAND(t - dt) + (MSPR - NMSUR) * dt
INIT NEW_MS_SAND = 1
INFLOWS:
⚓ MSPR = DISCMS
OUTFLOWS:
⚓ NMSUR = NMSPMIX*MPR

☐ OLD_MS(t) = OLD_MS(t - dt) + (NMSUR + OSUR - MSUR) * dt
INIT OLD_MS = 1800
INFLOWS:
⚓ NMSUR = NMSPMIX*MPR
⚓ OSUR = MPR*WTOMSFMIX
OUTFLOWS:
⚓ MSUR = MPR*WT_MOULD

☐ OMS_STOCK(t) = OMS_STOCK(t - dt) + (MSUR - OSUR - OLDSWR - D(
INIT OMS_STOCK = 50000
INFLOWS:
⚓ MSUR = MPR*WT_MOULD
OUTFLOWS:
⚓ OSUR = MPR*WTOMSFMIX
⚓ OLDSWR = OMS_STOCK*OLDSWF
⚓ DOS = DISOLD/AT23

○ AdjusteedDEMAND2 = MD
○ AT21 = 4

○ AT22 = 1
○ AT23 = 2
○ DISCMS = (MSDINV-NEW_MS_SAND)/AT21
○ DMEL = stock_level_factor*ESMEL
○ MAF = 1-MRF
○ MCF = 1.15
○ MD = MSA+ESMEL
○ mold_SAF = 1
○ MRF = 0.07
○ MSA = (DMEL-MFALSTOCK)*mold_SAF
○ MSDINV = AdjusteedDEMAND2*NMSPMIX
○ NMSPMIX = 200
○ OLDSWF = 0.01
○ stock_level_factor = 1
○ WTOMSFMIX = 1620
○ WT_MOULD = 1800

Sector-3 MELTING

☐ ESRF(t) = ESRF(t - dt) + (SC) * dt
INIT ESRF = 2250
INFLOWS:
⚓ SC = S*CCF

☐ LQMLINV(t) = LQMLINV(t - dt) + (LQMUR - RCP) * dt
INIT LQMLINV = 0
INFLOWS:
⚓ LQMUR = LQMPR*LQUFC
OUTFLOWS:
⚓ RCP = LQMLINV/CAST_WT*MUR*AT34

☐ LQMPR(t) = LQMPR(t - dt) + (SSF - LQMUR - LQMSR) * dt
INIT LQMPR = 2000
INFLOWS:
⚓ SSF = (SSRF+rad1)/AT32
OUTFLOWS:
⚓ LQMUR = LQMPR*LQUFC
⚓ LQMSR = LQMPR*SF

☐ SS(t) = SS(t - dt) + (SSPR - SSUR) * dt
INIT SS = 10000
INFLOWS:
⚓ SSPR = SSDISC/AT31
OUTFLOWS:
⚓ SSUR = SSAT*SSRF

☐ UFCS(t) = UFCS(t - dt) + (RCP - S) * dt
INIT UFCS = 0
INFLOWS:
⚓ RCP = LQMLINV/CAST_WT*MUR*AT34
OUTFLOWS:
⚓ S = DP*AT33

○ AdjustDEMAND3 = ESRF+CSA

Table 3 stock-flow equations of melting

Table 4 stock-flow equations of fettling

○ AT31 = 1
○ AT32 = 1
○ AT33 = 1
○ AT34 = 3
○ CAST_WT = 100
○ CCF = 1
○ CSA = (DF-UFCS)/FSAF
○ DF = ESRF*SLFF
○ FSAF = 3
○ LQUFC = 1-SF
○ POUR_WT = 100
○ RAD = RETURNS_STOCK*RSFU
○ rad1 = RAD
○ RSFU = 0.01
○ SF = 0.001
○ SLFF = 1
○ SSAT = 100
○ SSDINV = POUR_WT*AdjustDEMAND3
○ SSDISC = SSDINV-SS
○ SSRF = AdjustDEMAND3

Sector-4   FETTLING

☐ CASTINGS(t) = CASTINGS(t - dt) + (CASTTRF - CASTRR - RCSFO) * dt
INIT CASTINGS = 2000
   INFLOWS:
      ⇌ CASTTRF = ESRF/AT41
   OUTFLOWS:
      ⇌ CASTRR = CASTINGS*CASTF
      ⇌ RCSFO = CASTINGS/AT42
☐ CASTINV(t) = CASTINV(t - dt) + (RCSFO - FR) * dt
INIT CASTINV = 0
   INFLOWS:
      ⇌ RCSFO = CASTINGS/AT42
   OUTFLOWS:
      ⇌ FR = PRODUCTIVITY*WORKERS/AT43
☐ CNCDTC(t) = CNCDTC(t - dt) + (DR) * dt
INIT CNCDTC = 0
   INFLOWS:
      ⇌ DR = DP/AT45
☐ FCINV(t) = FCINV(t - dt) + (FR - DR) * dt
INIT FCINV = 0
   INFLOWS:
      ⇌ FR = PRODUCTIVITY*WORKERS/AT43
   OUTFLOWS:
      ⇌ DR = DP/AT45
☐ NCR(t) = NCR(t - dt) + (CASTRR - Rate_of_transfer) * dt
INIT NCR = 0
   INFLOWS:

      ⇌ CASTRR = CASTINGS*CASTF
   OUTFLOWS:
      ⇌ Rate_of_transfer = NCT/AT44
☐ RETURNS_STOCK(t) = RETURNS_STOCK(t - dt) + (Rate_of_transfer) * dt
INIT RETURNS_STOCK = 0
   INFLOWS:
      ⇌ Rate_of_transfer = NCT/AT44
☐ WORKERS(t) = WORKERS(t - dt)
INIT WORKERS = 20
○ AT41 = 1
○ AT42 = 1
○ AT43 = 1/30
○ AT44 = AT32
○ AT45 = 1
○ CASTF = 0.01
○ DP = 2250
○ NCT = 200
○ PRODUCTIVITY = 1

Not in a sector
○ DISIOLDINV = 5000
○ DISOLD = OMS_STOCK-DISIOLDINV

5. RESULTS

The simulated results of the Gray Iron foundry, using the Stella software are analyzed. The base year 2009, is taken for one of the product of the firm (Transmission case), about which the variable behaviors are analyzed for a simulation time period of one year/two years/30months/60 months. The model is run for varying the delay/adjustable times. The conceptual model is compared with the simulation models. The behavior of the model is similar to the conceptual models. The simulated results are shown in the Fig: 3 to 6.The procurement strategy of core shop sand, molding sand, steel scrap and shipment of castings for one year is shown in the Fig.3.In the Fig.4 Inventory of core sand, desired inventory of core sand and core sand utilization is given, Fig.5 explains the supply chain of molding sand, procurement strategy, ,new molding sand inventory are shown. In Fig. 6 explains melting section-expected shipments of castings to fettling, un fettled castings inventory, and ,steel scrap required for furnace to melt. The simulated results which are validated by the actual data taken from the industry.These simulated and system dynamics results can be used for the strategic management of inbound, internal supply chain of the foundry.
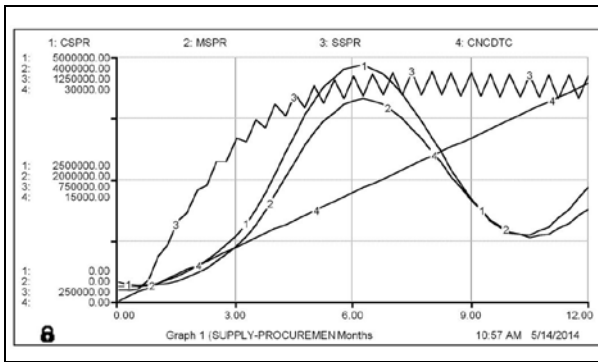
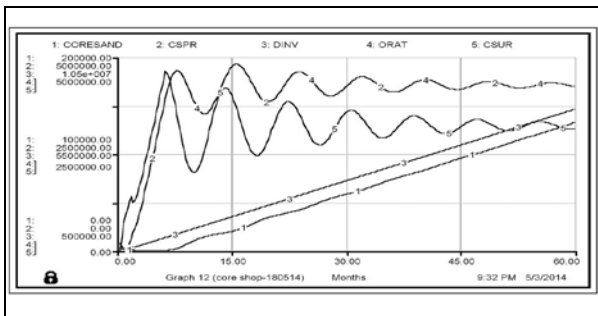Figure.3.Procurement rate of core sand, molding sand, steel scrap

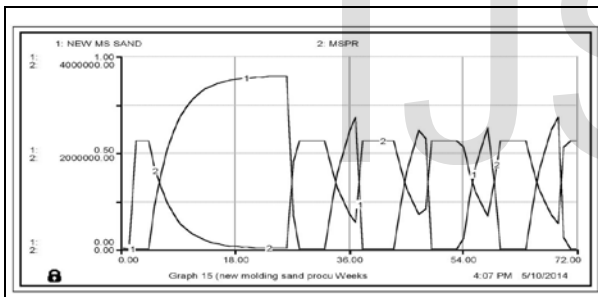Figure 4 Inventory desired inventory, utilization of coresand

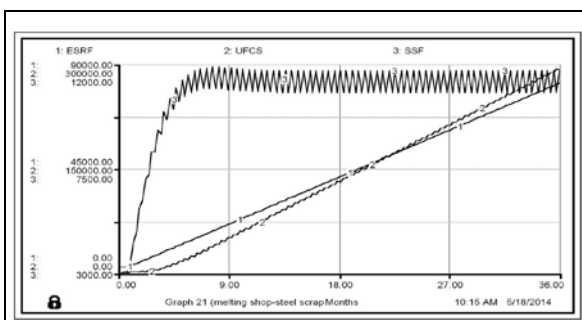Figure 5 New molding sand, sand procurement rate

Figure 6Melting shop-expected shipments, unfinished castings

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