Drought and Production Capacity of Meat; A System Dynamics Approach

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Abstract

The persisting drought in Iran, where the livestock are mostly fed by natural pastor-lands, has caused a higher rate of sheep slaughter, thus an increase in the supply of meat and a reduction of the price in the Summer 2008. On the other hand, the higher slaughter diminished the available level of the cattle which in turn reduced the production capacity of the following year. This is inherent and unique to this production sector that the production capacity depends on the inventory. This study, based on a modified supply chain dynamic model, indicates that the short term effect of drought is a lower meat price; however, in the coming season a sudden increase in the price should be expected. It can be concluded that using right policies, such as importing provender, could save the hardly recoverable production capacity of the country.

Key Words: Meat Supply Chain, Drought, System Dynamics

1- Introduction

The supply chains have been the subject of many researches so far. Food supply chains are no exceptions though they have special characteristics stemming from the perishability of the food. This perishability may create uncertainty with respect to product quality, safety and reliability, for the buyer on one hand, and in locating a buyer for the seller on the other hand. Moreover, the necessity of efficient storage facilities to further ensuring the quality of food, along with the dynamically evolving legislative framework further hinder the task of managing efficiently food supply chains [1]. The food supply chain however assumes a stable supply and demand whose dynamics is subject to seasonal changes due to festivals and so on.

Drought, even its periods and frequencies, is not unknown to the inhabitants of a semiarid country like Iran. Dry weather has formed the food regime in such regions; the main meat is the lamb since the sheep can survive a dry year by less provender compared to the cows. While most industrial farms which keep cows now are dependent on the imported provender, the sheep cattle are fed in the natural pasture lands, which are highly vulnerable in drought years.

After China, India and Australia, Iran has the highest number of sheep in the world. The meat price depends very much on the supply per capita. Due to drought the dry pasture lands could not feed the sheep anymore. The slaughter rate increased, so did the supply per capita. The result was twenty percent reduction in the price. In the supply side the capacity is reduced now and in the demand side, the demand has increased due to lower prices. Sharp increase in the price could be expected. This happened before this paper was ready for presentation. The second dry year will even further destabilize the market.

Using system dynamics, this paper models the supply chain and investigates alternatives which could save the capacity of production. Production and distribution model introduced by Forrster [2] has been extended to investigate the effect of initial material supply.

2- Literature review

Case studies in system dynamics simulation of food supply chains have been performed by many researchers. Minegishi and Thiel used system dynamics to show how it could contribute to improving the knowledge of the complex logistic behavior of an integrated food industry. They simulated a generic model and used its result in poultry industry. The bullwhip effect was observed in their simulation [3].

Georgiadis *et al.* used the same approach to tackle the strategic modeling of single and multi echelon supply chains. The long-term capacity planning policies for a food supply chain with transient flows due to market parameters is analyzed. They demonstrate the applicability of the developed methodology on a multi echelon network of a major Greek fast food chain [1].

Sachan and *et al.* modeled the total supply chain cost (TSCC) of an Indian grain chain in order to understand and predict the future outcome of each supply chain model in different situation and to devise policies, accordingly, to reduce TSCC [4].

Villegas and Smith studies how safety stock policies could induce variation in production and distribution order quantities along the supply chains. The effect is illustrated using a system dynamics model of the supply chain of a Mexican branch of multinational food and beverage companies [5].

In all of these studies, the production capacity is not under question as it is rarely endangered by natural disasters like drought. However, this is the focus of the current study. The study considers the long term effects of a sudden change in the structure of the supply chain, not in policies; thus it could be extended to similar changes.

3- Model description

The meat supply chain modeled in this article contains three levels: the retailer, the distributor and the farm- slaughterhouse which is called here the factory. Forrester's production and distribution model has been used and extended to investigate the role of supply capacity. In Forrester's model, the production is not limited to the availability of the labor and material since in that model the inner structure of the factory is not the purpose of the study. Instead, the production rate is determined by the production capacity of the factory and manufacturing rate decided [2]. A slightly modified model is presented in figure 1, in which factory relies on the supply of animals by the farms. This allows the study of the behavior of the chain in response to changes in the level of the supply.

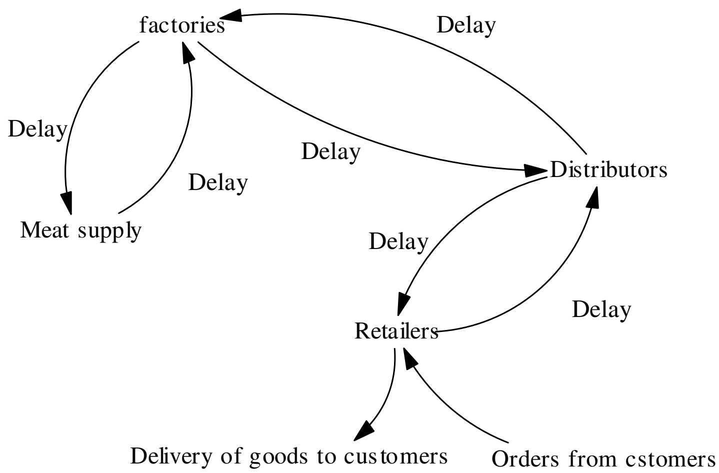

Figure 1 Structure of the model.

Stock and flow diagrams are given in Appendix 1. All variables and system equations also have been defined in Appendices 2 and 3.
One level is used to show the meat inventory as:

$$Inventory.K = Inventory.J + (DT)\ (Slaughter.JK - Birth.JK) \quad (1)$$

Each birth and slaughter rates is a fraction of the total cattle inventory and is defined as:

$$Birth.KL = (Fractional\ birth\ rate)\ (Inventory.K) \quad (2)$$
$$Slaughter.KL = (Fractional\ slaughter\ rate)\ (Inventory.K) \quad (3)$$

A variable defines the minimum of the manufacturing rate desired at factory (MWF) and the supply (slaughter). Therefore, the equation for manufacturing rate decision at the factory (MDF) is defined as:

$$MDF.KL = IF\ (ALF \geq Limit.K)\ THEN\ (Limit.K)\ ELSE\ (ALF) \quad (4)$$
$$Limit.K = IF\ (MWF.K \geq Slaughter.K) THEN\ (Slaughter.K)\ ELSE\ (MWF.K) \quad (5)$$

By defining these variables, manufacturing rate decision at factory (MDF) is the minimum of the supply, factory's capacity and manufacturing rate desired at the factory

(MWF). Figure 2 shows stock and flow diagram of this section. The other variables and relations between them are as given in Forrester's model [2].

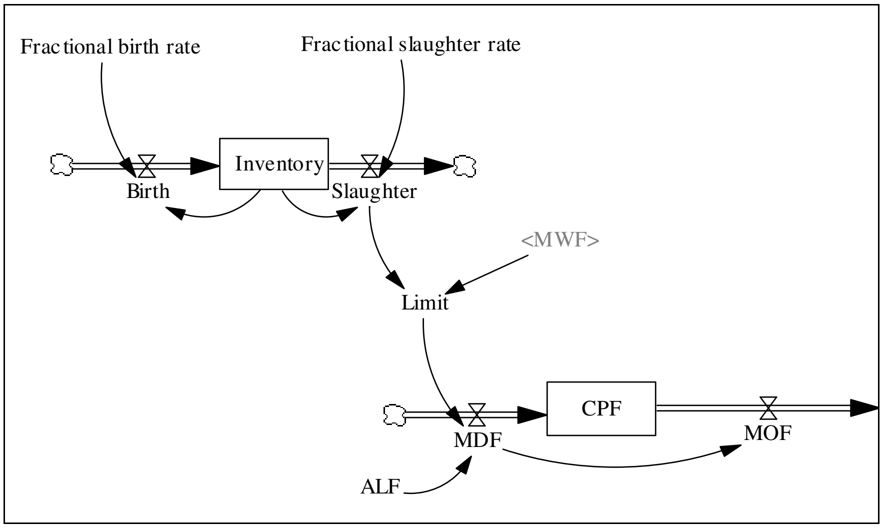

Figure 2 stock and flow diagram of the supply section.

4- Case study

Monthly slaughter data in Isfahan, one of the provinces of the country hit by drought as an example, from April 2007 to September 2008 (18 month), is provided by Isfahan slaughterhouse. The meat supply is shown in figure 3; please note that the time period of the model in VENSIM is "week", thus the supply has been calculated as Kg/week.
As figure 3 shows, the supply from May to September 2008 has increased significantly. As a result of drought in recent years, many of premature cattle have been slaughtered. Farm keepers are not able to maintain their cattle because of high provender price and so the slaughter rate has increased. Our surveys show that provender price in these 18 months has had increasing trend that caused early slaughter of the sheep before reaching proper weight.

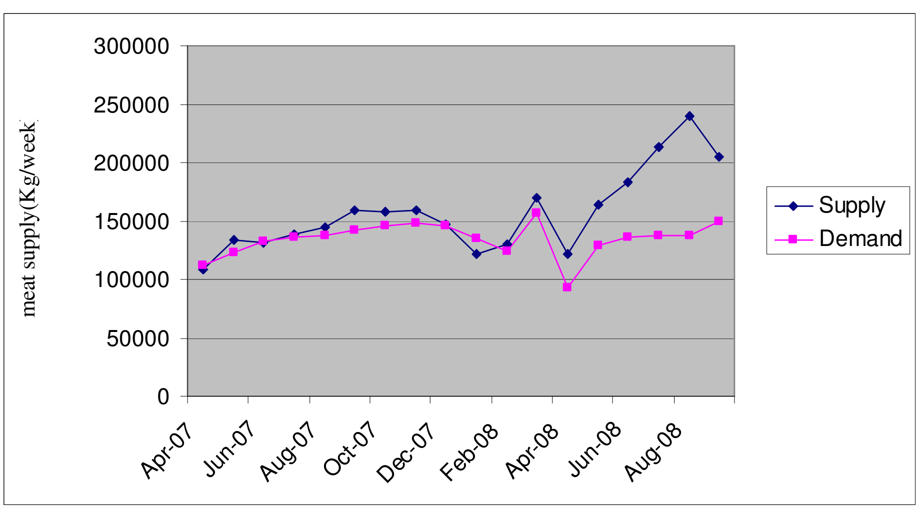

Figure 3 Meat supply and demand in Isfahan from April 2007 to September 2008.

To start the simulation, there must be initial values for level variables and system must be in steady-state condition. Three independent variables in the model, RRR (Requisitions Received at Retail), Fractional slaughter rate, and Fractional birth rate have been defined in start so that the demand, the supply and the production are all set to 140,000 kg/week.

Then the fractional slaughter rate is entered to the model so that slaughter variable equals actual supply in the period under study. Fractional birth rate, i.e. production, remains constant. Demand is assumed to be 140,000 Kg per week on average. However, in real life, demand will increase when the price is low due to the higher supply. Furthermore, demand in some specific times is higher than average; as the consumption increases in some national or religious festivals. Fluctuations in demand are taken into consideration and entered by RRR into the model section. The simulation is carried out for 100 weeks. Figure 4 shows the result for slaughter (supply) and RSR (demand).

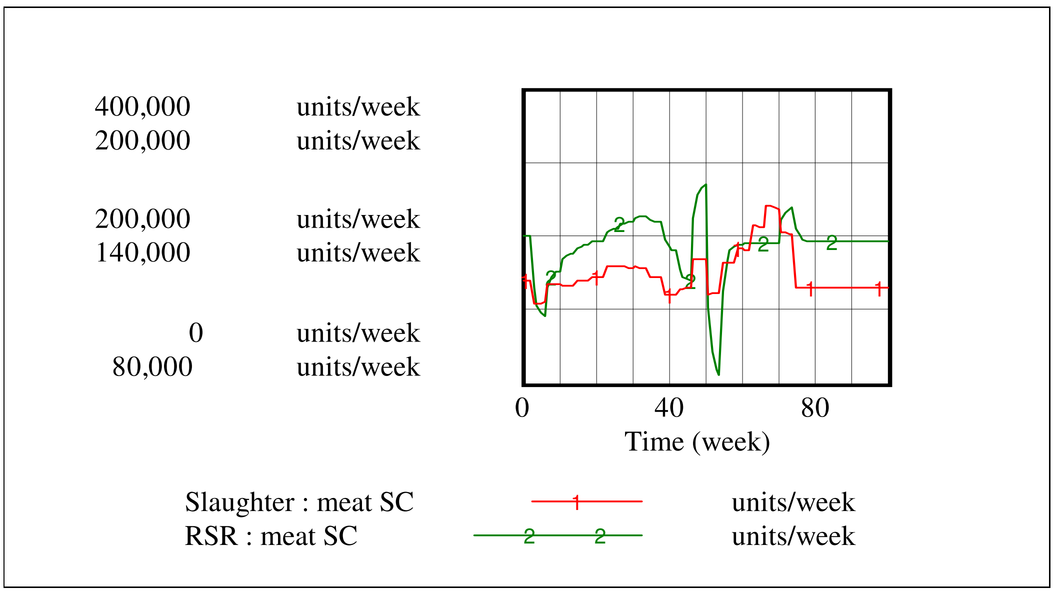

Figure 4 Supply and demand in stable conditions based on the provided data before the drought has its effects. Sharp changes are only due to some festivals.

Table 1 shows the changes in the supply, demand and price during 18 months. Supply and price are real data and demand is provided by the model.

Price is a function of the supply and demand. It plays the key role in defining the decision functions of the model. Lower prices promote people to buy and it would promote farms to reduce the supply if they did not face the drought. The price here is to be forecasted for the coming months based on simulation results. Multi variables regression coefficients estimation is used for estimating the price as a function of supply, S, and demand, D:

$$Price = 6090181.8 \times S^{-0.005} + 5.67679e^{-9} \times D^{2.42} - 5687794.342 \quad (6)$$

Table 1: Supply, demand and price fluctuations in 18 months.

Month	Average meat supply (Kg/week)	Average meat demand (Kg/week)	Price per Kg (Rial)
April 2007	108473	111685	55000
May	134178	123386	55000
June	130933	132130	55000
July	139038	135754	54000
August	144495	137907	54000
September	158798	142484	54500
October	158288	145331	54000
November	158875	147838	54500
December	147018	146048	55000
January 2008	121405	135495	55000
February	129675	123534	56000
March	169643	156151	68000
April	121553	93074	62000
May	164055	129193	59500
June	182670	136662	58700
July	213293	136797	55000
August	240303	136799	56400
September	204473	149669	59000

The effect of inflation (20% in this case), is taken into consideration by changing the real life data to have a base price. Out of trend changes in price around festivals are not considered in calculating equation (6).

Figure 5 shows estimated and real prices. The figure confirms that the price model is justified enough to be used for the coming months.

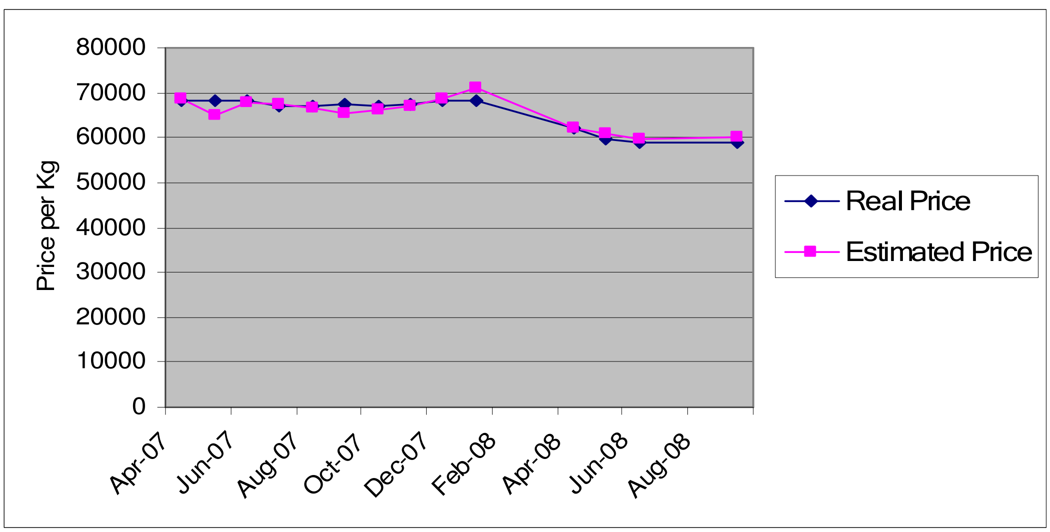

Figure 5 Real and estimated prices. The effect of the inflation is taken into account.

By the increase of supply, the cattle inventory diminishes and the supply cannot meet the demand. Therefore, the price will increase, especially when demand is higher than the average.

For October 2008 to March 2009, RRR assumes the values of the last year. Fractional slaughter rate is high by January 2009 and in February decrease to initial value. Figure 6 shows the behavior of the inventory as a level variable. Cattle inventory falls, so does the slaughter and the supply.

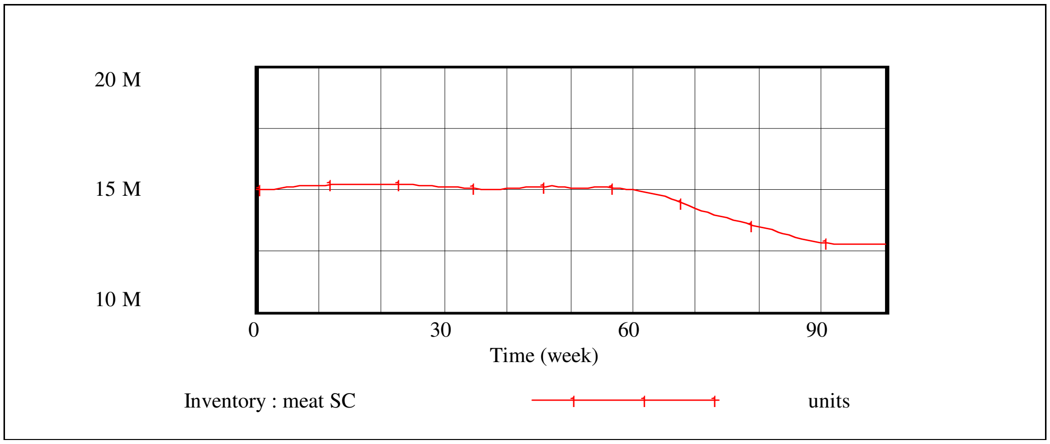

Figure 6 Cattle inventory is reduced due to high slaughter rate.

Table 2 shows supply and demand quantities and also forecasted prices based on equation (6).

Table 2 Forecasted supply, demand and price.

Month	Average supply (Kg/week)	Average demand (Kg/week)	Estimated price for each Kg(Rial)
October 2008	199728	140821	58218.8
November	195599	138832	58263.56
December	191556	147380	61321.56
January 2009	187596	140194	59838.58
February	120950	138825	72050.55
March	120892	168745	81607.79

As results show, the fractional slaughter rate in February and March 2009 are similar to initial fractional slaughter rate (in equilibrium condition), but initial supply was about 140,000 kg/week and in these two months has decreased to about 121000 kg/ week. The only reason for this shortage in supply is the decrease in cattle inventory, figure 6. The decrease in inventory has a long term effect on the supply capacity in the future. Figure 7 shows the birth level or meat production capacity.

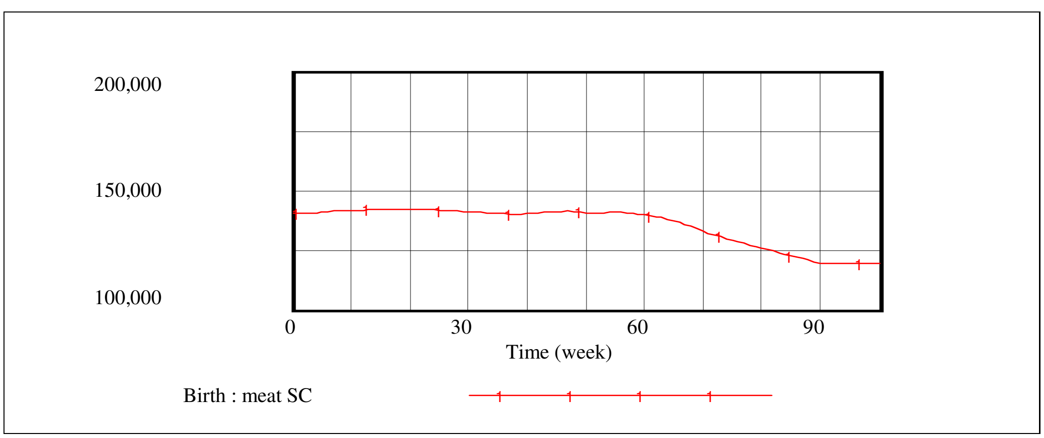

Figure 7 Production, or birth, decreases by reduced inventory.

5- Conclusions

The meat supply chain has a unique aspect in which the production capacity depends on the inventory. Recent dry years caused a higher slaughter rate in Iran. The price, in short time, and the inventory of the female sheep, with a long term effect, decreased. The lower production capacity will cause a higher price in the coming year. This sharp increase (30% in four months) happened while this paper has been prepared. A policy which might stop high rate of slaughter would be to provide imported provender with affordable price to the sheep farms. This simply would stop the crisis to pass to years ahead.

References

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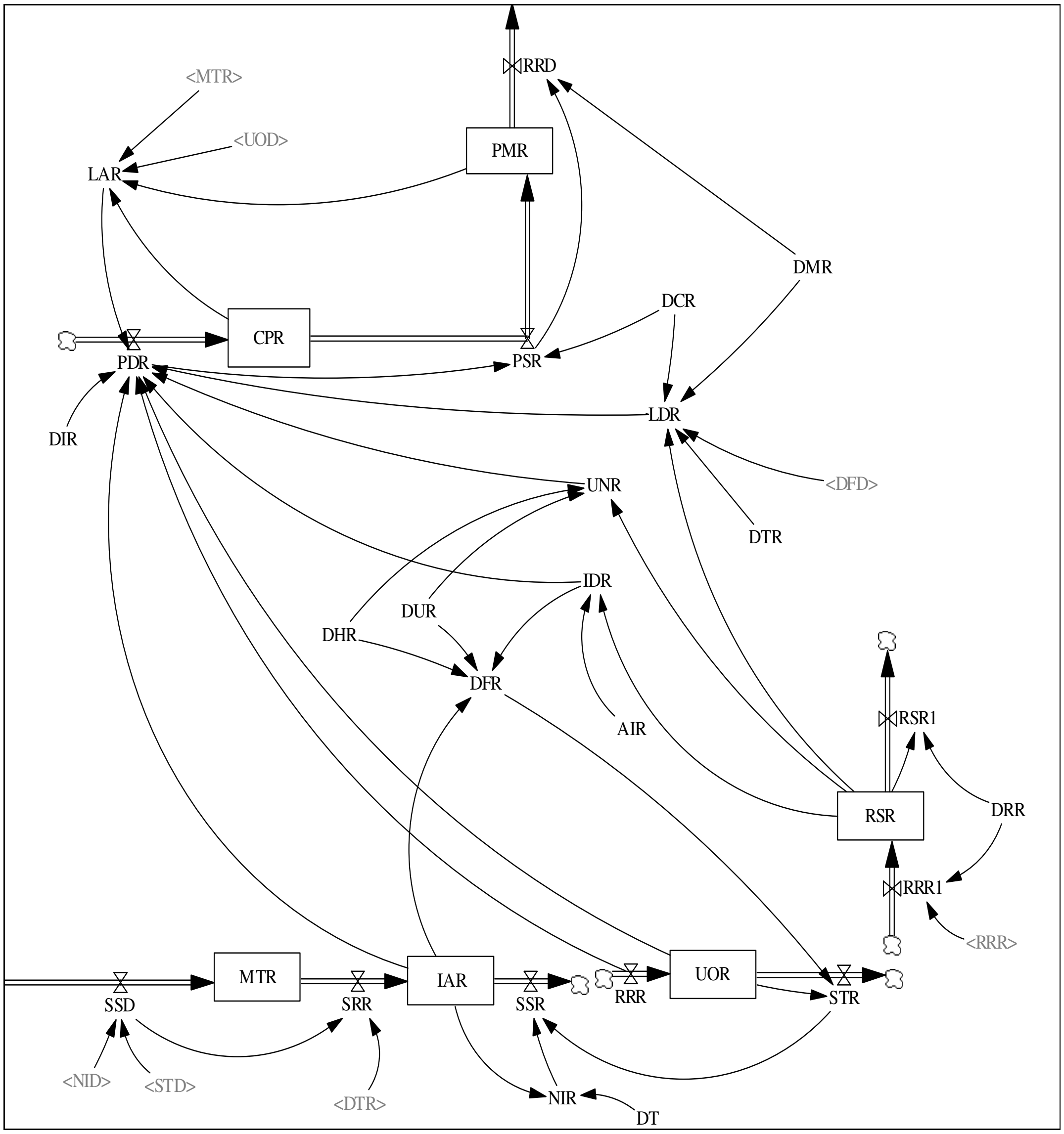
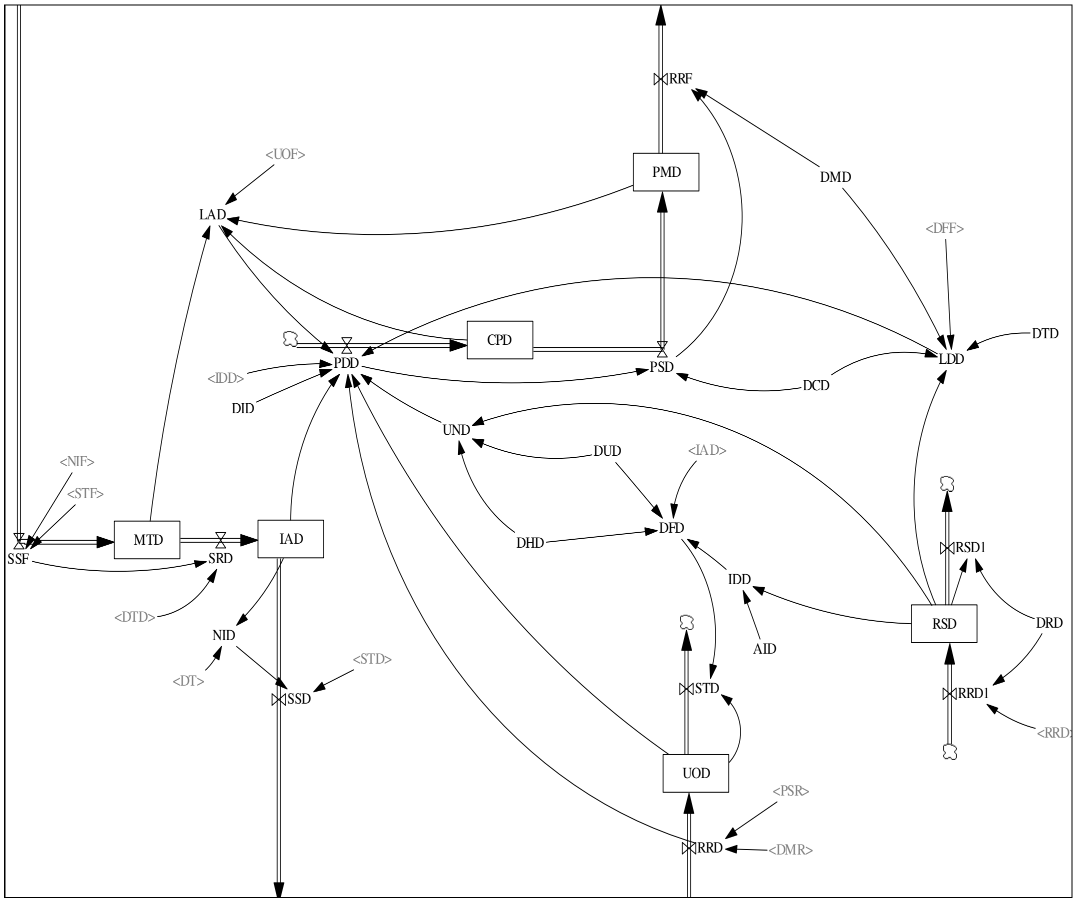
Appendix 1: Stock and flow diagrams

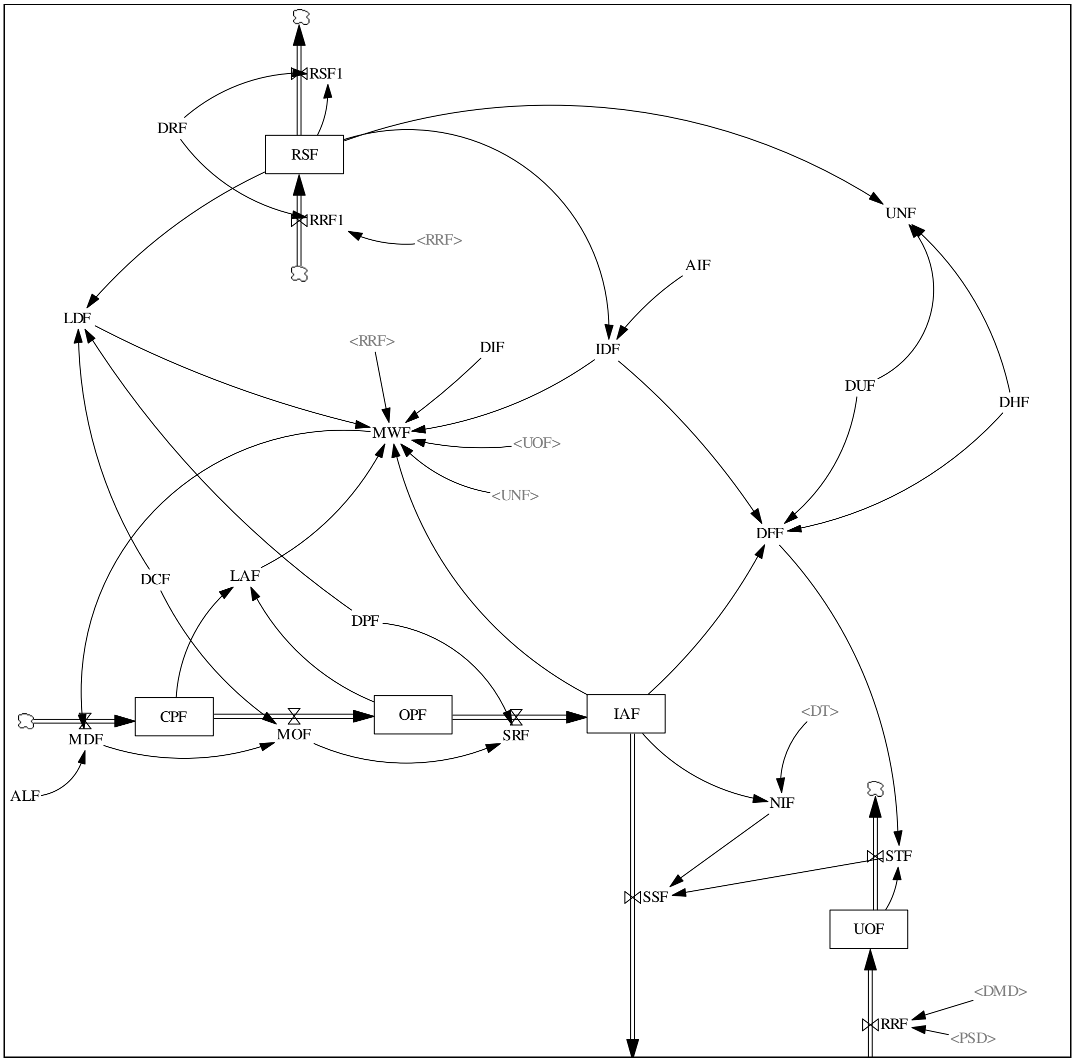
Retailer sector:



Distributor sector:



Factory sector:



Appendix 2: System variables of Forrester's production and distribution model

Level variables in retailer sector:

Variable	Description
UOR	Unfilled Orders at Retail(units)
IAR	Inventory Actual at Retail(units)
RSR	Requisitions Smoothed at Retail(units/week)
CPR	Clerical in-Progress orders at Retail(units)
PMR	Purchase orders in Mail from Retail(units)
MTR	Material in Transit to Retail(units)

Rate variables in retailer sector:

Variable	Description
SSR	Shipments Sent from Retail(units/week)
RRR	Requisitions Received at Retail(units/week)
SRR	Shipment Received at Retail(units/week)
PDR	Purchasing rate Decision at Retail(units/week)
PSR	Purchase orders Sent from Retail(units/week)
STR	Shipping rate to be Tried at Retail(units/week)

Auxiliary variables in retailer sector:

Variable	Description
NIR	Negative Inventory limit rate at Retail(units/week)
DFR	Delay (variable) in Filling orders at Retail(weeks)
IDR	Inventory Desired at Retail(units)
LDR	pipeLine orders Desired (necessary) in transit to supply Retail(units)
LAR	pipeLine orders Actual from Retail(units)
UNR	Unfilled orders, Normal, at Retail(units)

Parameters (constants) in retailer sector:

Parameter	Description
DT	Delta time(weeks), the time interval between solutions of the equations
DHR	Delay due to minimum Handling time required at Retail(weeks)
DUR	average Delay in Unfilled orders at Retail caused by out-of-stock items when inventory is “normal” (weeks)
AIR	Proportionality constAnt between Inventory and average sales at Retail(weeks)
DRR	Delay in smoothing Requisitions at Retail, the smoothing time constant(weeks)
DIR	Delay in Inventory (and pipeline) adjustment at Retail(weeks)
DCR	Delay in Clerical order processing at Retail(weeks)
DMR	Delay in order Mailing from Retail(weeks)
DTR	Delay in Transportation of goods to Retail(weeks)

With changing the third letter-R- to D and F, Distributor and factory variables are the same as retailer. For factory there are some additional variables:

Factory’s additional variables:

Variable	Description
MWF	Manufacturing rate Wanted at Factory(units/week)
MDF	Manufacturing rate Decision at Factory(units/week)
MOF	Manufacturing Orders into Factory(units/week)
OPF	Orders in Production at Factory(units)

Factory’s additional parameter:

Parameter	Description
DPF	Delay in Production lead time at Factory(weeks)

Appendix 3: System equations of Forrester's production and distribution model

Retailer's equations:

UOR.K = UOR.J + (DT) (RRR.JK-SSR.JK)
IAR.K = IAR.J + (DT) (SRR.JK-SSR.JK)
SSR.KL = IF (NIR.K ≥ STR.K) THEN (STR.K) ELSE (NIR.K)
STR.K = UOR.K/DFR.K
NIR.K = IAR.K/DT
DFR.K = DHR + DUR (IDR.K/IAR.K)
IDR.K = (AIR)(RSR.K)
RSR.K = RSR.J + (DT) (1/DRR) (RRR.JK-RSR.J)
PDR.KL = RRR.JK + (1/DIR) [(IDR.K – IAR.K) + (LDR.K – LAR.K) + (UOR.K – UNR.K)]
LDR.K = (RSR.K) (DCR + DMR + DFD.K + DTR)
LAR.K = CPR.K + PMR.K + UOD.K + MTR.K
UNR.K = (RSR.K)(DHR + DUR)
CPR.K = CPR.J + (DT)(PDR.JK – PSR.JK)
PSR.KL = DELAY3(PDR.JK, DCR)
PMR.K = PMR.J + (DT) (PSR.JK – RRD.JK)
RRD.KL = DELAY3(PSR.JK, DMR)
MTR.K = MTR.J + (DT) (SSD.JK – SRR.JK)
SRR.KL = DELAY3(SSD.JK, DTR)

Distributor's equations:

UOD.K = UOD.J + (DT) (RRD.JK-SSD.JK)
IAD.K = IAD.J + (DT) (SRD.JK-SSD.JK)
SSD.KL = IF (NID.K ≥ STD.K) THEN (STD.K) ELSE (NID.K)
STD.K = UOD.K/DFD.K
NID.K = IAD.K/DT
DFD.K = DHD + DUD (IDD.K/IAD.K)
IDD.K = (AID)(RSD.K)
RSD.K = RSD.J + (DT) (1/DRD) (RRD.JK-RSD.J)
PDD.KL = RRD.JK + (1/DID) [(IDD.K – IAD.K) + (LDD.K – LAD.K) + (UOD.K – UND.K)]
LDD.K = (RSD.K) (DCD + DMD + DFF.K + DTD)
LAD.K = CPD.K + PMD.K + UOF.K + MTD.K
UND.K = (RSD.K)(DHD + DUD)
CPD.K = CPD.J + (DT)(PDD.JK – PSD.JK)
PSD.KL = DELAY3(PDD.JK, DCD)
PMD.K = PMD.J + (DT) (PSD.JK – RRF.JK)
RRF.KL = DELAY3(PSD.JK, DMD)
MTD.K = MTD.J + (DT) (SSF.JK – SRD.JK)
SRD.KL = DELAY3(SSF.JK, DTD)

Factory's equations:

(Variables that are similar to retailer and distributor, have the same equations, so have been eliminated here)

MWF.K = RRF.JK + (1/DIF) [(IDF.K – IAF.JK) + (LDF.K – LAF.K) + (UOF.K – UNF.K)]
MDF.KL = IF (ALF ≥ MWF.K) THEN (MWF.K) ELSE (ALF)
LDF.K = (RSF.K) (DCF + DPF)
LAF.K = (CPF.K + OPF.K)
UNF.K = (RSF.K) (DHF + DUF)
CPF.K = CPF.J + (DT) (MDF.JK – MOF.JK)
MOF.KL = DELAY3(MDF.JK, DCF)
OPF.K = OPF.J + (DT) (MOF.JK – SRF.JK)
SRF.JK = DELAY3(MOF.JK, DPF)