Productivity challenges of food manufacturing: a system dynamics analysis on demand uncertainty and value of time

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Abstract

Managing the supply chains of fast moving consumer goods includes industry specific challenges. For instance food products may have very short life cycle although the routing from factory to distribution centres and finally to wholesale can include several options. Due to competition in the market, there is very much pressure on cost effectiveness. The delivery time is also crucial: the value of the product may disappear in 7 to 14 days. The productivity of food manufacturing may be sensitive to product mix variations too. This paper presents a productivity analysis of a food supply chain, which illustrates some managerial implications. The key elements of the model are the value of the delivery time for the wholesale and the manufacturing costs. There are certain trade-offs between capacity utilisation and lead-time performance. The results of the model suggest the value of sales time to be very important for the retail. By using make-to-order type of production, the total supply chain could create more value for the retail customers.

Keywords: *fast moving consumer goods, supply chains, productivity.*

1 Introduction

Managing the supply chain of fast moving consumer goods, such as food products, is challenged by industry specific challenges. There is a trend of increasing variety of goods that retail business is demanding from the industry. Some authors claim that greater product variety is a necessity to compete in the markets (Kekre & Srnivasan 1990). Food products may have very short life cycle although the routing from factory to distribution centres and finally to wholesale can include several options. Due to competition in the market, there is very much pressure on cost effectiveness. The delivery time is also crucial: the value of the product may disappear in few days. The consumer behaviour is also linked to lead-time. Freshness of food is connected to health, which is increasingly important parameter perceived by consumers in many cultures (see for example Prescott et al 2002).

An example of fast moving consumer goods is food industry supplying foodstuff to retailers. From supply chain point of view, the first operation in food factory is customer order picking. This is done for each retailer and sorted for transportation. Sometimes the batches are transported directly to food markets, sometimes via wholesale terminal, where several supplier batches are combined into single delivery for the retail. Supply chains in food industry operate in very fast phase, counting hours rather than days in many cases. Producing of food is typically made to stock and the order control principles are according to this. The structure of distribution models may vary by channels or countries. The general structure is illustrated in figure 1.

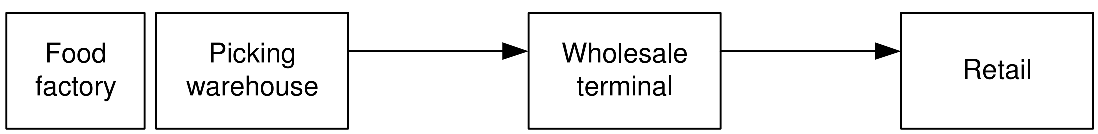

Figure 1. An example of supply chain in food industry.

The challenges of managing fast moving consumer goods are related to economic performance of distribution process. Generally, the customer value fresh products those are economical to purchase (Presscott 2002).

The productivity of food manufacturing and distribution may be sensitive to product mix variations too. This paper presents a productivity analysis of a food supply chain, where the key elements of the model are the value of the delivery time for the wholesale and the manufacturing costs. There are certain trade-offs between capacity utilisation and lead-time performance, which are considered (Steele & Papke-Shields 1993). The reminder of this paper is as follows: Firstly, we will analyse key issues of food supply chains. Order batching and the value of time aspects are discussed. Some lot size modelling is presented for different aspects of make-to-stock production. Thereafter, a system dynamics model is presented.

Finally, conclusions are drawn and managerial implications are suggested to outline improvements in order policies.

2 Productivity issues in supply chains

The key issue in food industry is to maintain the level of logistics that satisfies the requirements of order-fulfilment process both time and cost aspects at the same time. The sales margin level may be very tight and sales volumes are high.

Productivity of food manufacturing may be analysed by using total factor productivity approach (Sumanth 1984, Sumanth 1998). The total productivity may be understood as a ration between outputs generated and the inputs required to produce the outputs. The productivity figures may be collected from balance sheets, which makes the approach very useful. Figure 2 shows and example of input structure of a meat producer. It shows that in order to produce a generic product, 63% of monetary value goes to raw material purchasing, labour takes 17%, machines required take around 3.5%, and about 12% go to other expenses such as overhead costs. The average inventory cycle time for a meat processing company is around 20 days. The value of the inventory is divided into raw materials and finished products as 50-50. This data gives some insight on the sensitivity of cost structure and the time delays involved with the manufacturing stage.

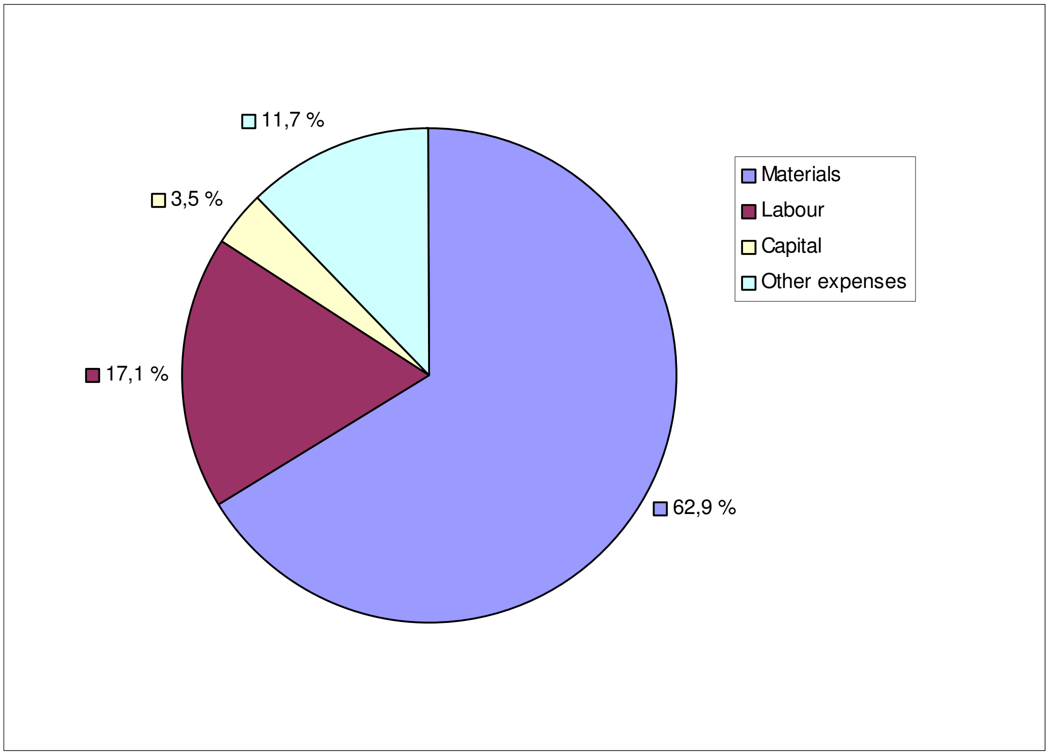

Figure 2. An example of input structure for a meat product manufacturer.

Since the cost margins are tight and the product is vulnerable, it is very essential to manage the flow of goods from production to consumers. Especially in the food industry, the price of product is dynamic and may be defined as function of days from production. The following figure illustrates an example of how the price of a meat food goes during the time. The dynamic structure reminds non-linear pricing problems and as matter of fact is type of this (see Wilson 1992). The output side of the productivity equation shows that the food should be sold before it loses all value. Losing all value is question of few days: dumping near to expire products to retail markets may endanger retailers prices; and destroying old food is very expensive. The key issue is to manage the time from manufacturing to point of sales.

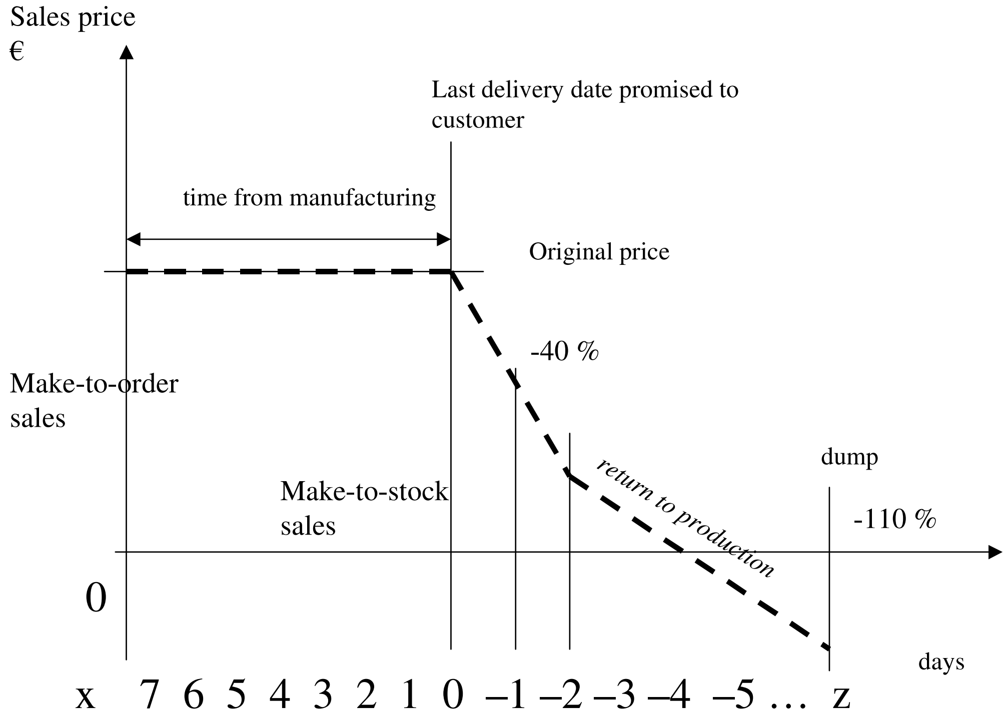

Figure 3. Value of product as function of sales days.

Currently, the production of food is forecast based and thus make-to-stock type of manufacturing. The key element in any forecast based production is to manage uncertainty of demand. One approach is to take stochastic marginal analysis into account. This analysis, sometimes referred as the newsboy problem, is typically used to solve the single order problem with variable demand. The product is assumed to lose its value in the period. The retailing situation may be described as follows: an additional unit in any given inventory level should be added as long as its expected profit added by its expected marginal stockout cost saving is more than the expected marginal loss. An illustrating example of this may be described as follows (Tersine 1986):

(1) $$pMP + pA \geq (1-p)ML$$

or in another form:

(2) $$p \geq \frac{ML}{MP + ML + A},$$

where MP is marginal profit, ML marginal loss, p is the probability of selling one or more additional units, and A the stockout cost per unit. Moreover, we may define expected marginal stockout cost savings as *pA*, expected marginal profit as *p MP* and expected marginal loss as *(1-p) ML*. The following table illustrates a hypothetical demand and probability of sales (histogram) for a food product that loses its sales value in a single period. For example, a probability of demand more than 400 units per day is 60 % according to this table.

Table 1. Demand histogram data.

Demand *D*	Probability $p(M)$	Probability of demand $\geq M^a$
100	0.10	1.00
200	0.10	0.90
300	0.20	0.80
400	0.35	0.60
500	0.15	0.25
600	0.10	0.10
Total	1.00	

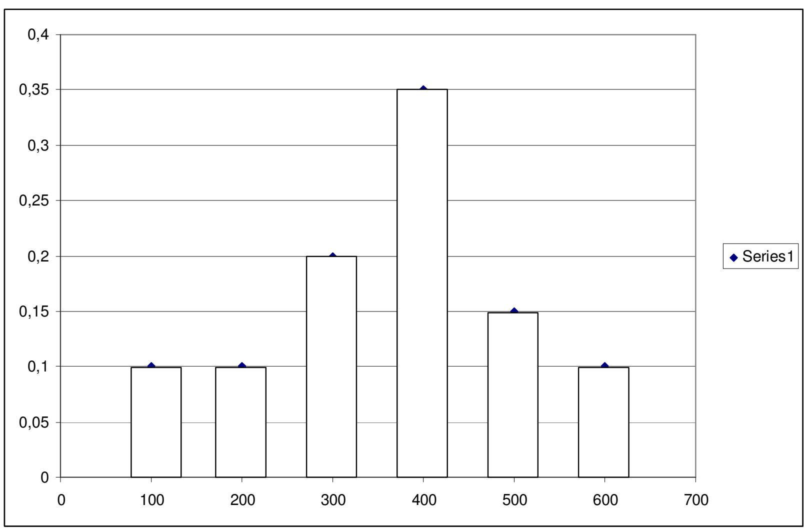

Figure 4. Demand uncertainty of food sales.

In order to demonstrate the approach, consider an example, where a single unit of product costs € 1.00 and the products are sold at unit price of € 5.00. The old product may be dumped into market at price of € 2.00. Assuming the probability given in previous table and no cost for stockout, we may calculate the optimum how may units should be ordered:

(3) $$p \geq \frac{ML}{MP + ML + A} = \frac{1}{4 + 1 + 0} = 0.20$$

This would mean that probability of selling more than 500 is 0.25 and more than 600 is 0.10. For this reason around 500 units should be purchased.

This analysis may be enhanced to cost benefit analysis. Expected cost *EC* may be defined as a sum of order cost, purchase cost, and expected stockout cost minus expected salvage.

(4) $$EC = C + PQ + A\int_{Q}^{\infty}(M - Q) f(M) dM - V\int_{0}^{Q}(Q - M) f(M) dM ,$$

where *C* is the setup cost per order, *P* is unit cost, *Q* the order lot size, A stockout cost per unit, *M* represents demand variable, *M* - *Q* the stockout size, *f(M)* probability density function of demand, and *V* the salvage value per unit. To minimise this function, we may differentiate the set $\frac{dEC}{dQ} = P - A \cdot P(s) - V[1 - P(s)] = 0$. Solving this yields the formula for the economic optimal probability of stockout:

(5) $$P^* = P(s) = \frac{P - V}{A - V} = P(M > Q) .$$

To take an example of this, we may consider a food product, which has normally distributed demand with mean of 100 units per day and standard deviation of 20. Assuming unit cost of € 1.00 and stockout of € 10.00, the ordering lot size according to this would be:

(6) $$P(s) = \frac{P - V}{A - V} = \frac{1 - 0}{10 - 0} = 0.10$$

(7) $$Q^* = M + Z\alpha = 100 + 1.29(20) = 126 \text{ units.}$$

Management of uncertainty is challenging especial in the case of product, which loses its value in relatively short period of time. This risk is the typically taken by the retailers. The newsboy approach provided some example of economic importance of sales days. Synchronising these retail requirements into the rest of the supply chain represents the challenge.

3 Control principles

3.1 Local and global objectives

The manufacturing of food in generally is using make-to-stock type of control and the objective is to keep the fixed costs down by high volume and great manufacturing lot sizes. The problem of this objective is that it may be in some cases controversial to the total supply chain objectives. An example of this kind of performance measure could be kgs per day. Maximum number of this measure could be achieved by minimising the costs by running production as much as possible. This would mean avoiding setups and greater lot sizes. The lot sizing control principle is more or less related with the philosophy of Economic Order Quantity (EOQ). The figure below represents an example of the logic in manufacturing.

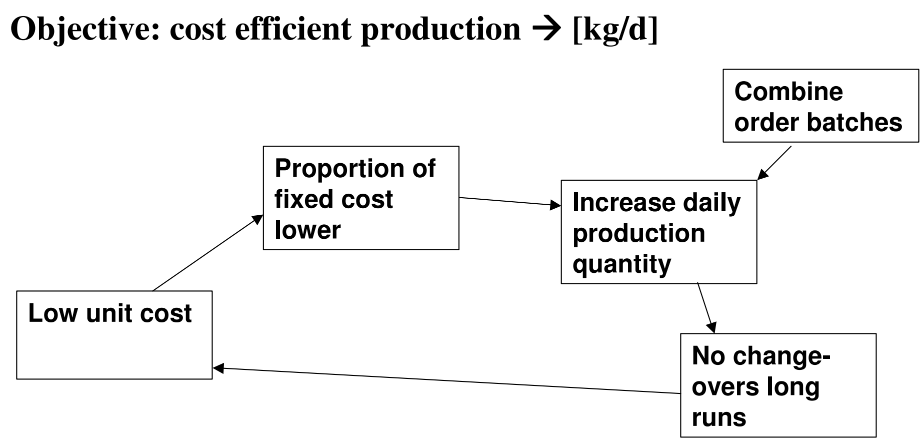

Figure 5. Objectives for manufacturing department.

If we go in the next stage of the chain into the shipping operations, which are performed in the factory warehouse and the following warehouses, the performance measure used is related with delivery compliance. Precise delivery makes customers happy and increases sales of goods. Picking is done from products from inventory and inventory level of each product triggers the production orders from previous stages of the chain. Complying the all the customer orders within long number of sales days for the foodstuff means small ordering batches from the production. Small batches minimise the probability of stockout situation.

Objective: delivery compliance → [%]

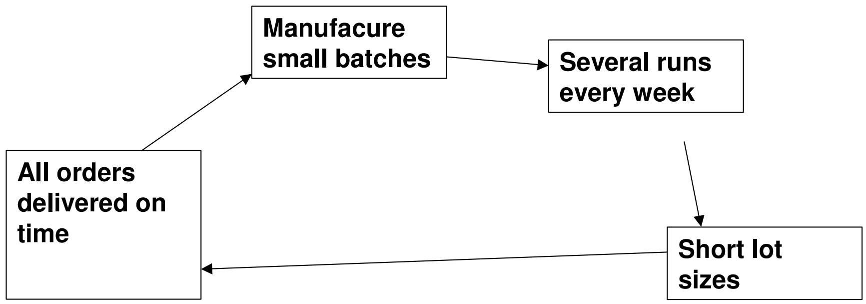

Figure 6. Objectives for sales department.

As seen the following figure, these two objectives are completely against each other. The reason for sub-optimisation is low visibility in the supply chain. Manufacturing sees the production in cost view and distribution the sales days. In case there is no total productivity type of measure that takes account all the aspects of the chain, the result may be completely opposite what was assumed in the beginning. Great batch sizes increased stock. The inventory holding cost becomes extremely expensive when stock is getting old. Sales is forced to dump the product to markets with lower price, and some of the customers may be lost because of short number of sales days.

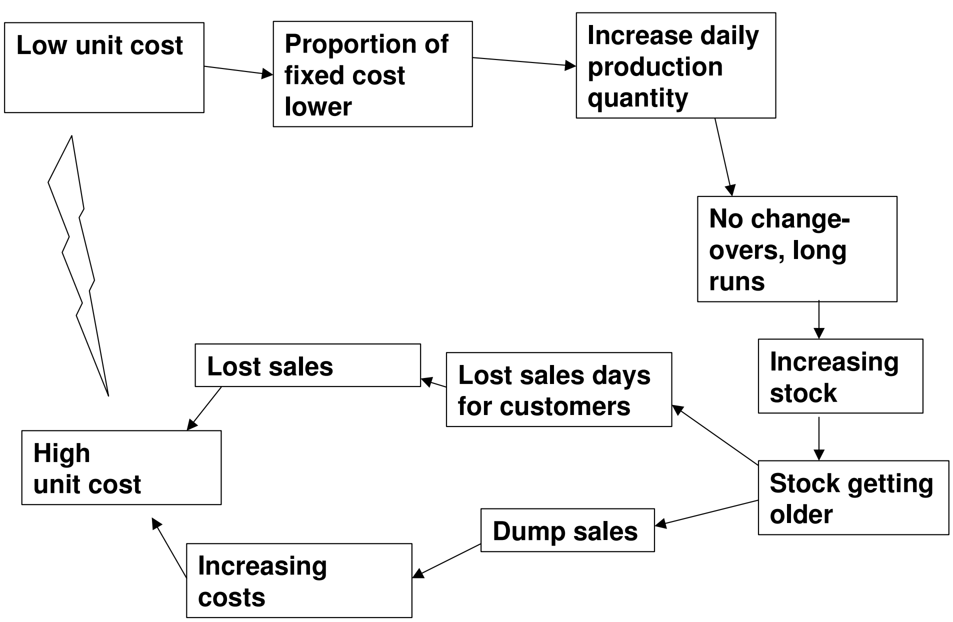

Figure 7. A paradox: objectives were not met because of different measures for production and distribution.

3.2 Lot size discussion

One approach to analyse the lot sizing decisions from expire day point of view could be queue modelling. According to Karmarkar's (1993) approximation, later modified by Suri (1998), the total processing time for an individual order is a function of arrival and service rates, their corresponding variations and batch sizes. These models illustrate the trade-off between capacity utilization (costs) and lead-time (expire dates). The total time of a job in a system is manufacturing time τ added with the queuing time, which is a function of λ arrival rate for orders, and μ service rate for orders (equal to $1/\tau$). The utilisation parameter ρ is λ divided by μ. Assuming a negative exponential distribution for incoming orders yields the following formula:

(8) $$W_q(\rho) = \frac{\tau\rho}{1-\rho}$$

Variations in arrival rate (c_a) and service (c_s) rate may be taken into account.

Karmarkar (1993) used *M/M/1 (M/G/1)* approximation for this kind of situation:

(9) $$W_q(\rho) = \left[\frac{c_a^2 + c_s^2}{2}\right]\left(\frac{\tau\rho}{1-\rho}\right)$$

In order to introduce the lot sizing decision in total order fulfilment time, we can define the waiting time as follows (*M/M/1* system):

(10) $$t(q,\rho) = \frac{1+q\rho}{1-\rho-\left(\frac{1}{q}\right)}$$

Figure below presents the lead time performance of a system with different lot sizes. The utilisation parameters are 0.4, 0.2 and 0.8 for the plots. This analysis shows that lead-time performance is extremely sensitive with lot sizing parameters, especially when the utilisation of the system is very high. For a more complete analysis on lot size decision techniques, refer to Holl & Spearman (2000).

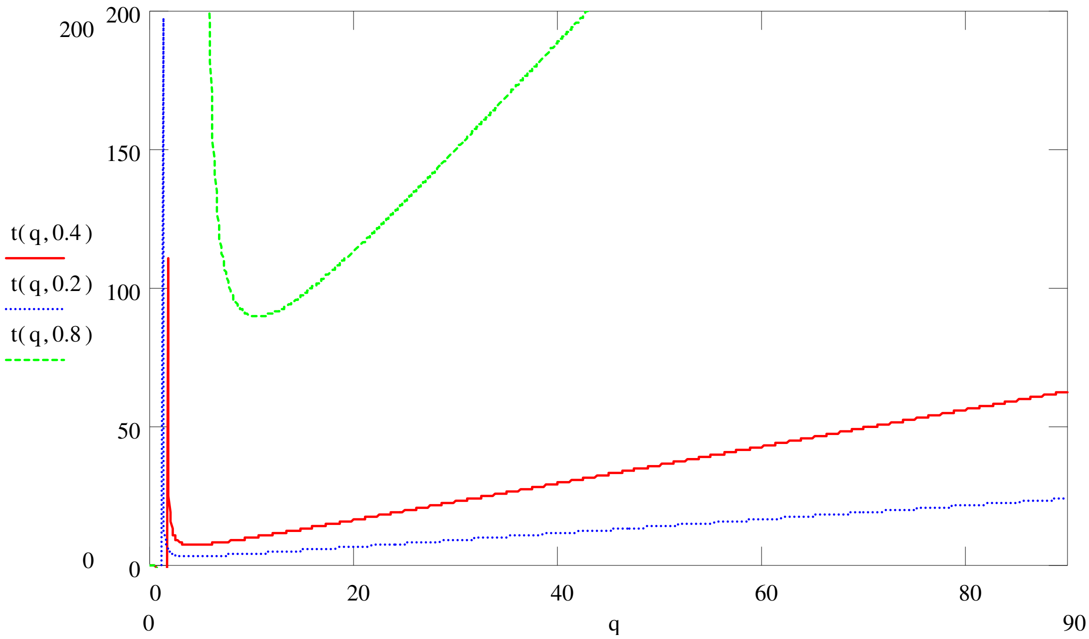

Figure 8. Lead-time as function of lot sizes.

Queuing analysis reveals the time perspective. Order and manufacturing lot sizes have important impacts on the productivity measure of the total chain. Lots of money can be lost if customers sales days are neglected to save money in manufacturing. For more detailed on lot size effects on capacity utilisation, refer to Helo and Hilmola (2003). From the cost accounting perspective, this is a very fresh view. Traditionally, the capacity measurement has been in search of utilisation maximisation (Klammer 1996). Queuing models have shown that idle capacity may be a strategic alternative to lead-time (Steele & Papke-Shields 1993). On the same track, Sopriwala (1998) suggested using practical capacity for determining fixed overhead rate.

4 System dynamics simulation

Managing the value of time is an important issue for maintaining an appropriate level of productivity. In order to analyse the dynamic, i.e. time-dependent, dimension of fast moving consumer goods flow, we will use a system dynamics simulation that consists of the following elements: (1) demand and order backlogging, (2) capacity of manufacturing and order picking, (3) order-fulfilment time depending on ratio between current demand and capacity utilisation, and (4) delayed despatching of ordered goods. This model aims to capture the cost aspect of utilisation as well as the value side of the product freshness. The static approach of newsboy model and the lot-sizing procedures are put together into a larger business dynamics model. For a more comprehensive view on system dynamics simulation and the SD notation, refer to Burgess (1998).

This model is based on order-fulfilment type that is typical for food supply chains. The value of lead-time, i.e. the freshness of food, has a connection to sales price. This is the case when selling food from stock. Expire date labelled in the package has direct pricing effect. Products with few days to expire date have lower price and potentially different sales channels. However, there is no feedback from the sales price to demand. This focuses on short time perspective planning decisions (daily level). Price elasticity of demand has wider connections and is related to longer term decisions and consumer behaviour.

This hypothetical simulation model is run a period of 52 weeks, with following parameters and assumptions: The initial demand is 10 000 units per week and the production ramps up from zero inventories (the demand is an user definable parameter). Around June, the demand starts to increase over the capacity level. The capacity cannot adjust to increasing demand volume and all available capacity is used soon. Because the demand exceeds capacity for a period of time, the shipping orders lags behind for a time after the demand has decreased to the initial standard level. The system measures order-fulfilment time from the customer perspective as a the queue length (the ratio between demand and capacity (Figure 9).

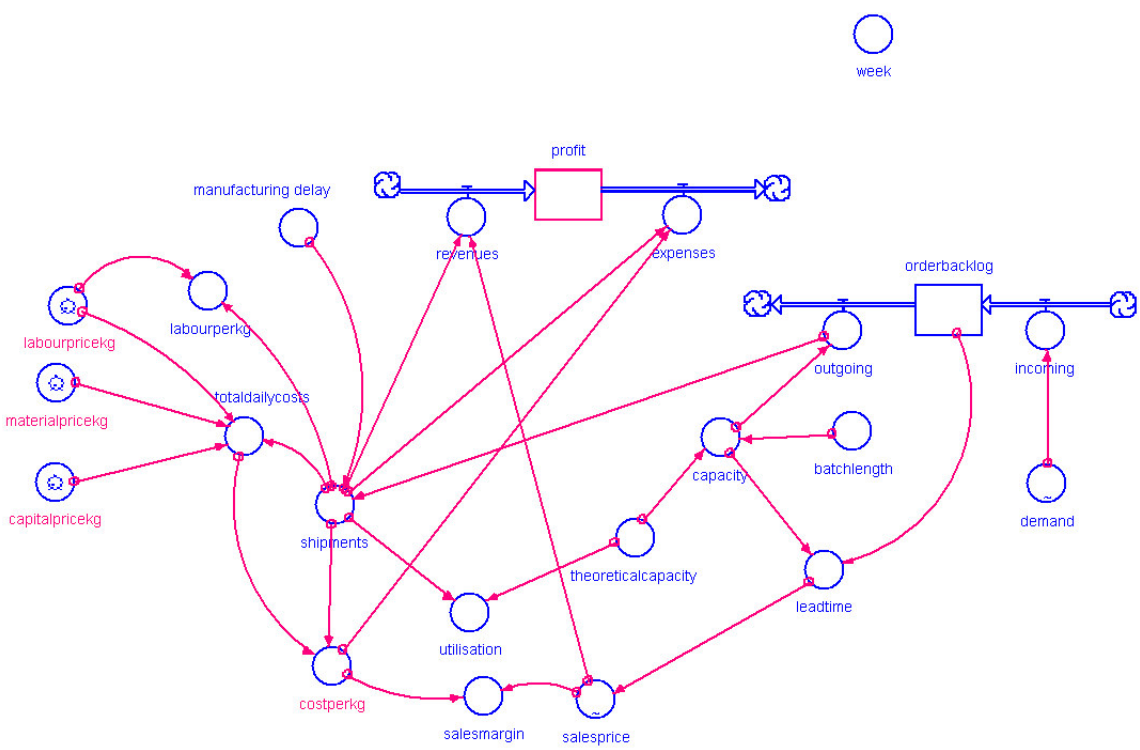

Figure 9. Food factory model in Stella.

The key parameter is the cost aspect of the model. The user may simulate different kinds of input structure, e.g. cost of labour, cost of different types of machines, for analysing how the profit for one year develops.

Figure 10 shows the behaviour of the model when running 52 weeks of production and when the demand has a peak variation. Products that are shipped during the lagging period may be more fresh albeit the slower lead-time. Most of retail sales days are lost when there is oversupply and the demand is getting lower. In this case the inventory gets older and valuable sales days are lost. In practice, the demand and supply are never in balance and inventory is generated somewhere. However, taking lot size decisions and the cost of adjusting capacity into account, one should be able to optimise the level based on most productive level.

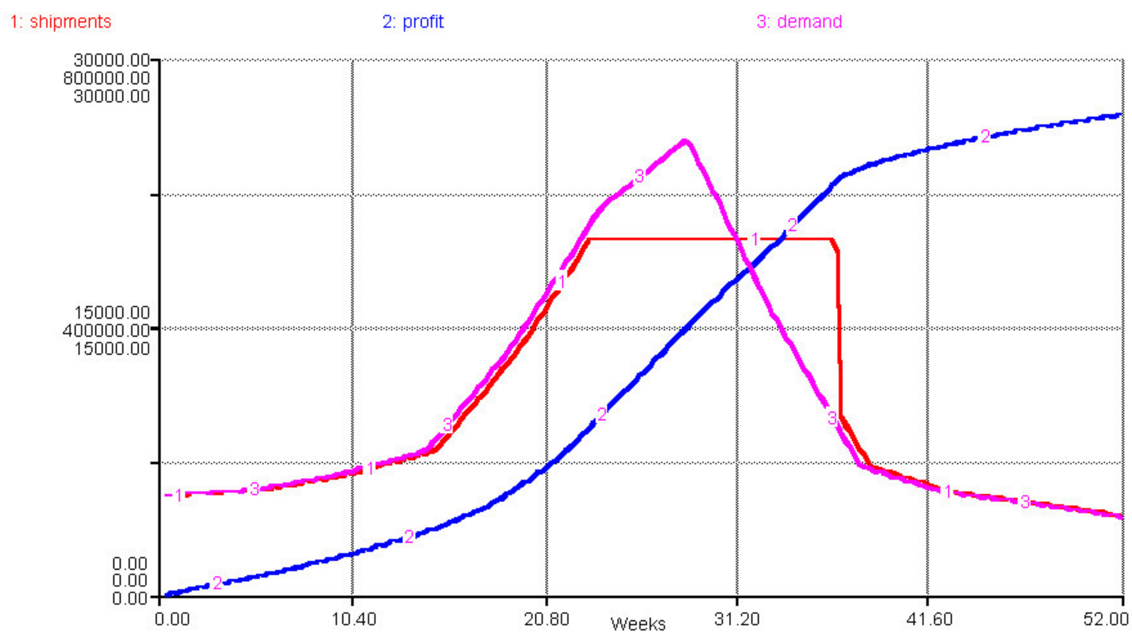

Figure 10. Capacity lags demand - demand for food products and despatches. Lead-time for orders in different situations – increasing delivery time takes time from retail days.

The cost structure of the manufacturing defines what kind of cost-volume curve is developed (figure 12). The same issue from another perspective may be described by the sales margin for different volumes (figure 11). The most important results of the model are (1) how profit develops with different freshness sensitivity of market (price elasticity) and volume peaks; (2) how the cost structure develops in different cases of manufacturing settings; and (3) how the company may respond to different lead-time requirements by adjusting the capacity utilisation (see figure 13).

Figure 11. Simulation results: shipments vs. salesmargin.

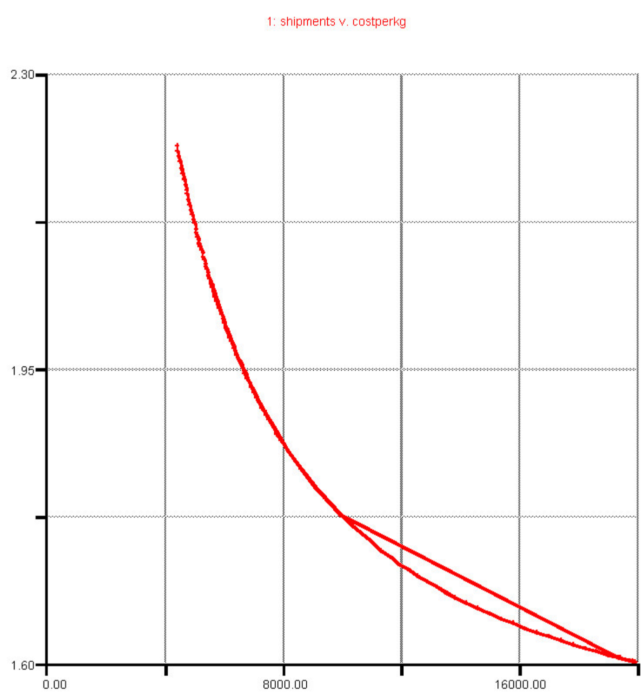

Figure 12. Economy of scope: costs are decreasing while volume increases (simulation data).

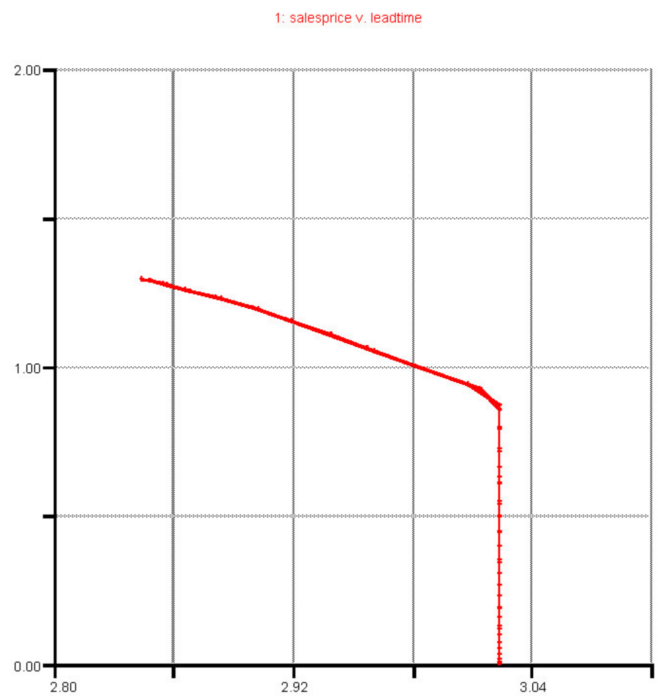

Figure 13. Salesprice of a foodproduct versus lead-time (simulation data).

This simple simulation model can demonstrate that the effects in the chain are dynamic and there are delays caused by limited capacity and fluctuating demand. The model may be used as a managerial cockpit for simulating different kinds of business decisions. The questions could include, for example, how to adjust the capacity on required level or what kind of lot-sizing policies to use. Taking account the previously presented value of sales days, salvage and dumping costs as well as manufacturing lot sizes, it is possible to find an economic stable level, where the total process is in control. Challenges are presented by lumpy demand. Seasonal variations and cycles are typical effects in food business as well as random effects. An appropriate knowledge on markets and manufacturing capacity is essential for productivity measurement of a whole supply chain.

5 Conclusions

The productivity of food manufacturing and distribution is a result of several dynamic parameters. The system dynamics simulation has demonstrated that demand uncertainty and valuing the time aspect are very important issues. Choosing the right cost structure type for each demand type may essential for profitable operations. Controlling the production and distribution of fast moving consumer goods that are made to stock needs several aspects taken into account. The main issues for productive supply chains include the following issues:

(a) Low manufacturing cost allowed by flexible capacity and cost structures

(b) Lot sizing decisions that take the time aspect into consideration

(c) Valuation of stockout situation for the retail business

(d) The cost of excess stock and cost of lost customers due to short sales days

As shown in several examples, the objectives are really controversial. High capacity utilisation with low cost and fast order-fulfilment time is impossible to maximise at the same time. There is a clear trade-off between these parameters. This in food industry context shows that there is a trade-off situation between expire days of the product and the capacity utilisation. The figure below presents this phenomenon: the capacity utilisation is a function of variability (standard deviation) in order arrival as well as manufacturing lead times. Maximising utilisation and thus achieving low fixed costs may lead to a slow response system. This implicates that the benefits of fast delivery process should be compared against the costs due to lower utilisation.

The main conclusion of this all is that productivity perspective needs to be taken in supply chain level (see Sumanth 1984, 1998). The shown examples from food industry may be extended to other fast moving goods business as well. The examples given are, firstly, to justify the importance of system level view on the performance measure, and, secondly, to show the importance of total productivity measure, which is able to combine different types of inputs and outputs into the very same measure.

The limitation of the model presented in this paper is that in its current form the model is hypothetical and based on discussions, rather than actual price elasticity data or demand. However, the model demonstrates similar behaviour described in production and logistics managers interviews. A more comprehensive study with empirical data should be conducted in the future. This would show whether the model captures all relevant aspects of perishable good production.

An interesting possible managerial implication could be considering introducing make-to-order type of production in food business. If the orders are received about one week before the actual delivery, it would be possible to implement a better performing supply chain that would be able to deliver additional sales days for products in the retail stage. The value of extra retail days would be beneficial for the retailer. Assuming margin level of 15 % in product with current 10 days of sales days and a major percentage of excess units due to expired sales dates, the value of adding one more day to retail would be very significant. There is a great possibility to achieve better productivity level by combining the offering variety and the practical order-fulfilment.

From the methodological point of view, there are many issues rising from the management of lead-time. Lead-time is connected to value and costs of the process. As the management of demand uncertainty is crucial, also other possible tools could be used in addition to newsboy approach. The question behind is about sharing risks in the supply chain. Potentially real options theory (Copeland & Antikarov 2001; Amram & Kulatilaka 1999) could be applied to conduct further research on this field. This approach could help actors in decision-making process value the options.

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Appendix.

(1) orderbacklog(t) = orderbacklog(t - dt) + (incoming - outgoing) * dt
(2) INIT orderbacklog = 0

(3) INFLOWS:
(4) incoming = demand

(5) OUTFLOWS:
(6) outgoing = capacity
(7) profit(t) = profit(t - dt) + (revenues - expenses) * dt
(8) INIT profit = 0

(9) INFLOWS:
(10) revenues = salesprice*shipments

(11) OUTFLOWS:
(12) expenses = costperkg*shipments
(13) batchlength = 0
(14) capacity = theoreticalcapacity-(theoreticalcapacity*batchlength)
(15) capitalpricekg = 2000
(16) costperkg = totaldailycosts/shipments
(17) labourperkg = labourpricekg/shipments
(18) labourpricekg = 1000
(19) leadtime = orderbacklog/capacity
(20) manufacturing_delay = 0.4
(21) materialpricekg = 2
(22) salesmargin = salesprice-costperkg
(23) shipments = delay(outgoing,manufacturing_delay)
(24) theoreticalcapacity = 20000
(25) totaldailycosts = (shipments*materialpricekg)+labourpricekg+capitalpricekg
(26) utilisation = shipments/theoreticalcapacity
(27) week = time

(28) demand = GRAPH(time) (0.00, 5550), (4.73, 5850), (9.45, 6750), (14.2, 8100), (18.9, 14100), (23.6, 21750), (28.4, 25650), (33.1, 15600), (37.8, 7200), (42.5, 5700), (47.3, 5100), (52.0, 4350)

(29) salesprice = GRAPH(leadtime) (0.00, 3.03), (0.3, 3.03), (0.6, 3.03), (0.9, 3.03), (1.20, 2.90), (1.50, 2.73), (1.80, 2.58), (2.10, 2.55), (2.40, 2.40), (2.70, 2.33), (3.00, 2.40)

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