# Improving the logistic performance in a food company using a system dynamics model for the internal supply chain: a case study

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*Abstract*

*A system dynamics model has been built to simulate the internal supply chain of a food company enabling research into the effects of logistic improvement options on four selected performance indicators. Selected indicators were: product inventory level, delivery lead time, delivery reliability and profit. Model parameter and input values were collected from operation, sales and planning departments of the food company to describe current practice. Model output has been compared with company data over a production time period of one year to validate the model. Five policies to influence the values of the above mentioned performance indicators have been investigated. Policies were combined into strategies to reduce undesired side effects. To investigate effects of external influences, four scenarios have been drawn up to capture different possible future conditions.*

## Introduction

This paper will present a framework for modelling the internal supply chain of a food company using principles of System Dynamics. The model which has been developed is a key part of a method for estimating the improvement potential of planning and scheduling in a batch-wise processing company (Roeterink, 2003). The method involves a characterization of the actual planning and scheduling situation and supports systematic exploration of improvement options and their benefits. It is aimed at supporting industrial decision makers in deciding whether to invest in hardware i.e. production and storage capacity, or software i.e. batch scheduling and sequencing, or to focus on strategic planning issues like target delivery time policy and safety stock coverage. The explorative case presented here was aimed at developing industrial based simulation models to analyse the effect of options on planning and scheduling performance indicators. The research project is being conducted in co-operation between university and industry and is financially supported by the Dutch Ministry of Economic Affairs and Ministry of Education, Culture and Science.

## Case study: a food company

The case study has been performed in a production plant for food products. There are basically 6 main raw materials, which are converted into 17 intermediate products. These products are either delivered in bulk, big bags or sacks; thus, in total there are 51 possible end products. Customer orders arrival and shipment occurs from Monday until Friday. The company produces full time from Monday until Saturday with Sunday as an optional working day. Working on Sunday is more costly due to overtime payments.

The bottleneck resource of the production street comprises one batch unit. Production of the bottleneck resource can be regarded as semi-continuous. Intermediate products are stored in silos. Bulk products are delivered directly from the silos whereas big bags and sacks need an additional packaging unit. Big bags and sacks are then stored in a warehouse. Scheduling activity comprises the allocation of bottleneck resource, silos and packaging units over time, on an hourly basis, and is performed by one human planner. The same planner is responsible for the customer order acceptance and delivery which is clearly an important planning function. Integration of planning and scheduling functions is personified here in the human planner.

Benefits expected from optimizing the production sequence of the bottleneck resource were shown to be marginal (Roeterink, 2003). The company decided to focus on strategic and tactic planning issues to improve their logistical performance.

The main questions addressed in this case study are:

1. How to model the internal supply chain to estimate the impact of policies on selected performance indicators?
2. How robust are these policies and strategies under different scenarios?

## Modeling the internal supply chain

To represent the internal supply chain in a company all activities, from the receiving of the raw materials to the shipment of the products, should be incorporated into a model. A system dynamics approach is used to capture the dynamic relationships and feedback structures. The presented internal supply-chain model is an adaptation of existing models for manufacturing supply chains at an aggregated level with regard to customer orders, materials and production resources (Sterman 2000, p. 709-729).

In this model the internal supply chain has been divided here into three sectors named customer order, production & inventory, and raw materials (see Figure 1). Each sector will be discussed briefly. An extensive model diagram can be found in Figure 2 in the Appendix.

### CUSTOMER ORDER SECTOR

Customer orders which cannot be filled immediately are not lost, but will accumulate in a backlog of unfilled orders. Order fulfillment is a production control function determining the ability to fill customer orders based on availability of product inventory. Levels and flows in this sector represent information. Production control decisions are sometimes based on historic customer order information whereby recent information is weighted more heavily. Single exponential smoothing of customer reflects this behavior.

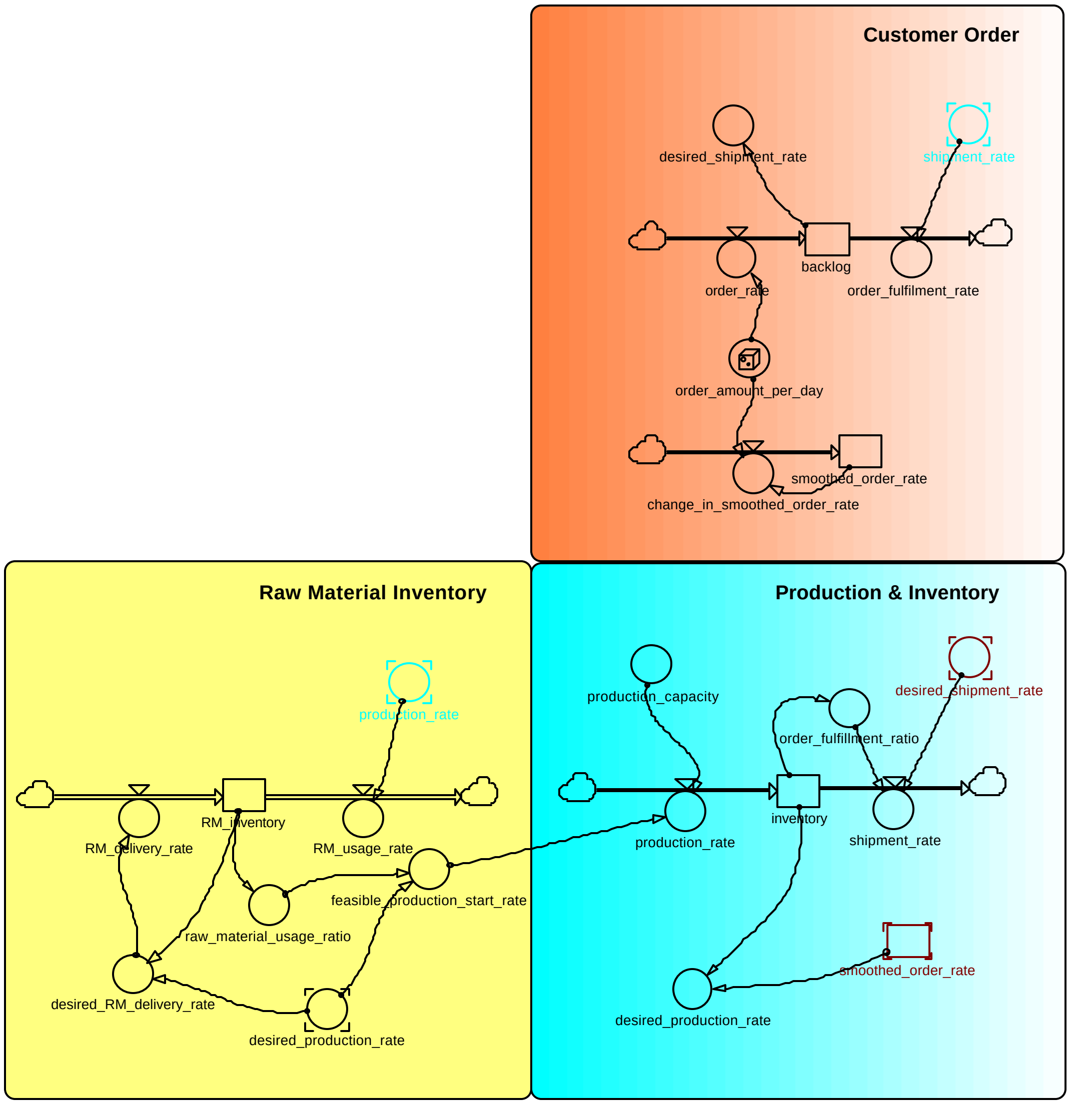



Figure 1. General overview of three sectors of the internal supply chain

## PRODUCTION AND INVENTORY SECTOR

Residence time of materials in the production street is negligible as compared to the total residence time in the factory. Also the amount of materials in the production street denoted as work in progress is negligible as compared to the product inventory level. Work in progress is not relevant for modeling the behavior of the internal logistical supply chain. Production scheduling is an important production control function determining the production rate based on the availability of raw materials and production capacity. Production capacity is determined by the bottleneck resource of the production street being the batch unit. Because of time losses as a result of product changes, maintenance and process disruptions, the bottleneck resource is not always available. The availability of raw materials for production is determined in the raw materials sector. The shipment rate is determined by the ability to fill customer orders based on inventory position. We used order fulfillment ratio as a concept to describe this ability (Sterman 2000, p.712).

RAW MATERIALS SECTOR

The availability of raw materials to start production is an important output variable of this sector to the production and inventory sector. Here we used the material usage ratio concept analogous to order fulfillment ratio. Inflow of raw materials is controlled by procurement which tries to keep raw material inventory at a sufficient level. There are no constraints in getting raw materials from the external suppliers. Outflow of raw materials depends on the actual production rate from the production and inventory sector.

**Performance indicators**

Four indicators were selected in consultation with the company to evaluate logistic performance over a certain production period: product inventory level, delivery lead time, delivery reliability and profit.

- product inventory level is defined as the total amount of products in the silo's and warehouse expressed in tons of products.
- delivery lead time is the amount of time used to fulfill a customer order.
- delivery reliability is defined here as order fulfillment ratio being the ratio of the amount of actual delivered products and the amount of planned products to deliver.
- profit is the difference between revenues from product deliveries and costs for making products. Costs for making overtime and product stock holding costs are incorporated.

Values of the performance indicators over a time period are calculated as follows:

$$\text{product inventory level} = \frac{1}{T} * \int_0^T I(t)\,dt$$

$$\text{delivery lead time} = \frac{1}{T} * \int_0^T DLT(t)\,dt$$

$$\text{delivery reliabilit y} = \frac{1}{T} * \int_0^T OFR(t)\,dt$$

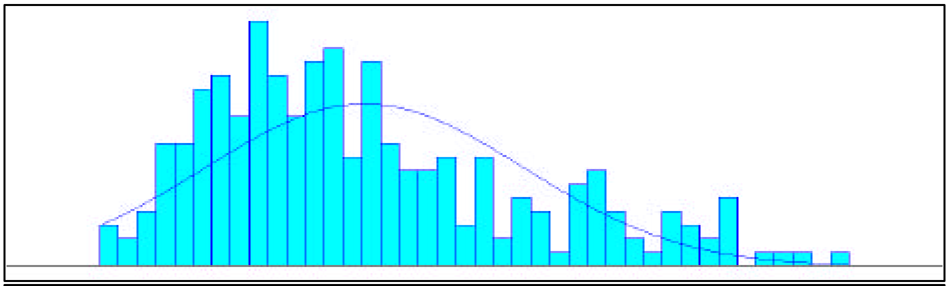
$$\text{profit} = \frac{1}{T} * \left\{ \mathrm{W} * \int_0^T SR(t)\,dt - \mathrm{C_I} * \int_0^T I(t)\,dt - \mathrm{C_O} * \int_0^T O(t)\,dt \right\}$$

with

T = time period in day
I(t) = product inventory level at time t in ton
DLT(t) = delivery lead time at time t in day
OFR(t) = order fulfillment ratio at time t
SR(t) = shipment rate at time t in ton/day
O(t) = Sunday overtime rate at time t in hour/day
W = net profit constant of shipped products in $/ton
$C_I$ = stock holding cost constant in $/ton*day
$C_O$ = Sunday overtime cost constant in $/hour

## Model input and parameters

Customer order is a main model input. From customer order data collected over the period of one year it was shown that the daily demand for products, from Mondays until Fridays was fluctuating highly. The weekly and monthly demands are constant. There is no seasonal demand. Daily demand was fit onto a normal distributed function (see Figure 3). Customer order rate is described as a probability function following a normal distribution N(277,161) from Mondays until Fridays. No customer orders are received during the weekends.



**Distribution Summary**

| | |
|---|---|
| Distribution: | Normal |
| Expression: | NORM(2.77e+005, 1.61e+005) |
| Square Error: | 0.69% |

**Chi Square Test**

| | |
|---|---|
| Number of intervals | 19 |
| Degrees of freedom | 16 |
| Test Statistic | 53.4 |
| Corresponding p-value | < 0.005 |

**Kolmogorov-Smirnov Test**

| | |
|---|---|
| Test Statistic | 0.157 |

**Data Summary**

| | |
|---|---|
| Number of Data Points | 254 |
| Min Data Value | 9700 |
| Max Data Value | 768000 |
| Sample Mean | 277000 |
| Sample Std Dev | 161000 |

**Histogram Summary**

| | |
|---|---|
| Histogram Range | = 9.7e+003 to 7.68e+005 |
| Number of Intervals | 40 |

Figure 3. Daily product demand distribution

From collected company data it was estimated order fulfillment ratio is 1 if the maximum shipment rate is 2.3 times the desired shipment rate. It states one needs e.g. 230 tons of inventory at the beginning of the day to be able to ship 100 tons of product in one day. If the maximum shipment rate equals the desired shipment rate, the order fulfillment ratio has a value of 0.75. The order fulfillment function is depicted in the graph below. Material usage ratio is less sensitive for variety in types of raw materials and can be regarded as one type of raw material.

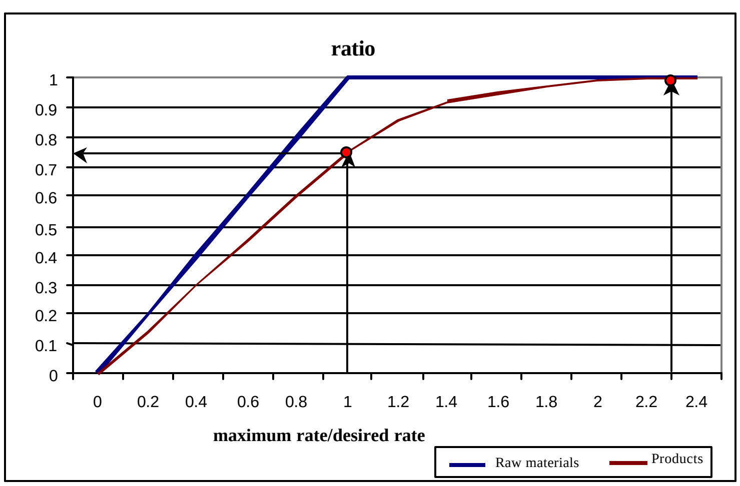



Figure 4. Order fulfillment ratio and raw materials usage ratio

A survey of model parameters is given in Table 1 (see Appendix). All values are based on company data.

**Simulation set-up**

Simulation has been performed using Powersim software. The numerical method used was Runge-Kutta 4 with a fixed time step of 0.125. One unit step is equal to one day. Simulation run time is 350 days. In validating the system dynamics model various tests were carried out. First, each relation was studied, while no model run was performed. Following this, the model was tested by running it under extreme conditions and by performing a sensitivity analysis and seeing whether the model produced the expected behavior. Finally, model behavior was compared to actual system behavior.

**Model behavior**

The model developed is an aggregate model, not aimed at reproducing point to point fit with the actual company data. Its purpose is to show patterns of behaviors and to understand the relationships amongst the aggregated variables and the influence of model input data and model parameters. Model behavior is illustrated in this section by production rate, shipment rate and product inventory.

Production rates vary over the year from 150 to 250 ton/day with minimum values of 50 ton/day (see Figure 5). From Figure 8 it is clear that production rates climb to available production capacity on Monday and drops to minimum values at the end of Sunday. From Figure 9 it is clear that there are no shipments in the weekend. Shipments rates fluctuate between 250 and 300 tons/day over the year (see Figure 6). Product inventory is built up in the weekend and diminishes in the week with a minimum at the end of Friday. Maximum inventory is reached at the end of Sunday (see Figure 10). Inventory fluctuates over the year between 500 and 800 ton (see Figure 7).

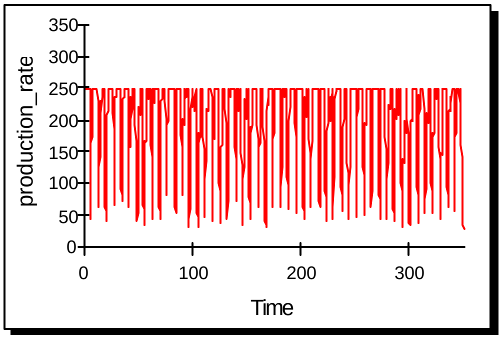



Figure 5. One year production rate

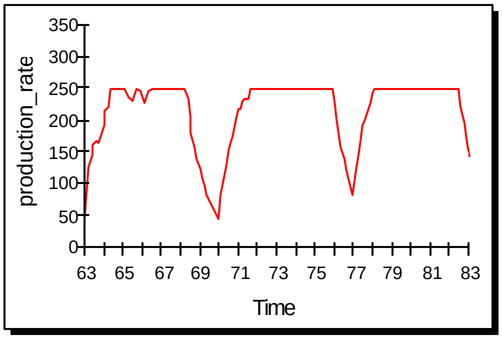



Figure 8. Three-week production rate

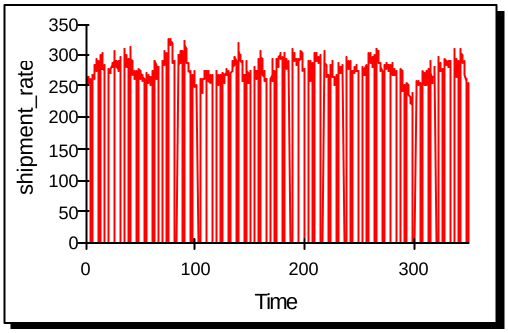



Figure 6. One year shipment rate

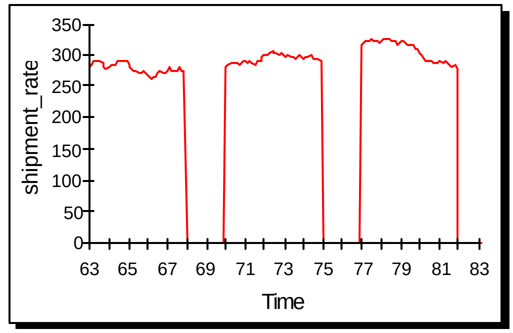



Figure 9. Three-week shipment rate

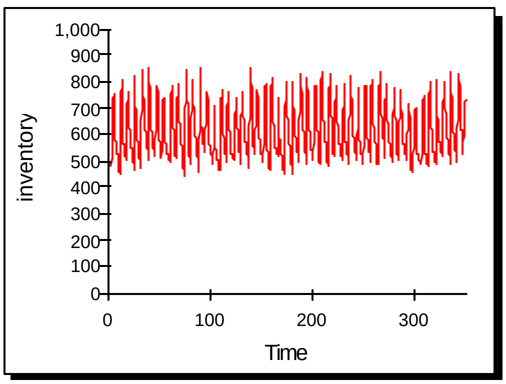



Figure 7. One year inventory

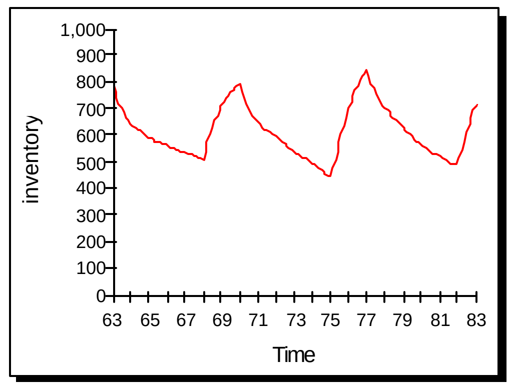



Figure 10. Three-week inventory

## Actual and simulated behaviors

To validate the model we compared the trends, value ranges and average values of the above discussed model variables with the collected company data over one year. Actual and simulated values of performance indicators based on a time period of one year were also compared.

From Figures 11 and 12 it becomes clear that actual daily production varies from 200 to 300 tons with often no production on Sunday at all. Differences with the simulated behavior are due to the following reasons: the model uses average production capacity values and spreads time losses in maintenance and disturbances out evenly for the whole simulation period. In actual production some days showed much lower rates due to shorter production runs caused by disturbances or maintenance. Other days showed higher rates due to longer production since there were no disturbances, product changes or maintenance at all during those days.

Product inventory levels are only measured from Monday till Friday. From these actual inventory data over one year it is clear that inventory levels vary in the range of 350-700 ton, with peaks above 800 tons and other days lower than 250 tons (see Figure 13). A closer look at a 3 week detailed inventory (see Figure 14) reveals a peak on Monday.

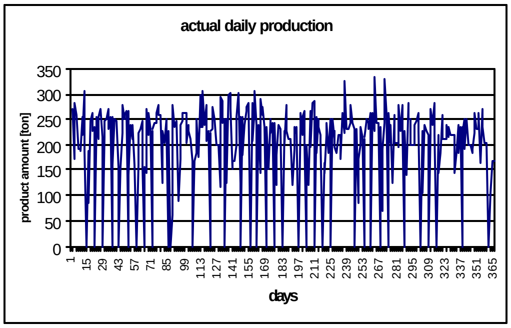



Figure 11. One year actual daily production

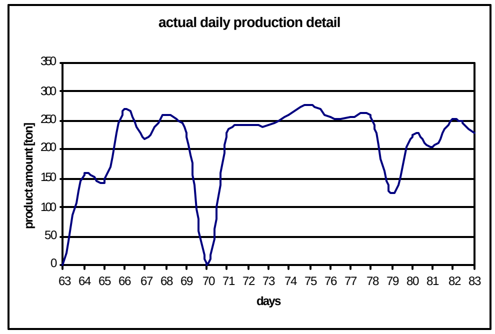



Figure 12. Three-week actual daily production

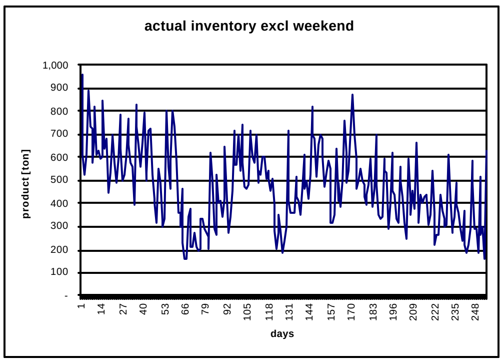



Figure 13. One year actual inventory

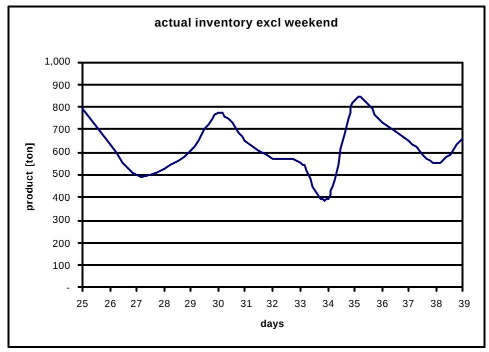



Figure 14. Three-week actual inventory

The following table presents a summary of simulated and empirical data of variables discussed in this section. Trends, ranges and mean values of simulated variables are quite similar to the empirical data. Actual mean product inventory level however is lower than in the simulation. In general actual fluctuations of variables are stronger than in the simulation.

Table 2. Comparison amongst actual and simulated model variables

| Model output | Actual behavior | | Simulated behavior | |
|---|---|---|---|---|
| | range | mean value | range | mean value |
| Production rate [ton/day] | | | | |
| - Monday till Saturday | 200-300 | 220 | 150-250 | 219 |
| - Sunday | 0-250 | 78 | 50-150 | 89 |
| Product inventory level [ton] | | | | |
| - Monday till Friday | 350-700 | 477 | 500-700 | 587 |
| Shipment rate [ton/day] | | | | |
| - Monday till Friday | 100-450 | 280 | 250-300 | 280 |
| - weekend | 0 | 0 | 0 | 0 |

In the next table actual and simulated values of performance indicators are shown. The company did not systematically collect all data necessary to calculate the values of the defined performance indicators.

Table 3. Comparison amongst actual and simulated performance indicators

| Performance indicators | Actual value | Simulated value |
|---|---|---|
| Inventory [ton] | - | 615 |
| Delivery lead time [day] | 6 | 5.07 |
| Delivery reliability [%] | 90* | 99 |
| Profit [$/day] | 100** | 97** |

*estimated by the planner

** indicative of a confidential value

**Policies**

The developed model was used to study effects of improvement options on the values of the performance indicators and on the behavior of model variables. These values should not be taken as an exact prediction, but rather should be interpreted relative to the base case simulation run. In consultation with the company five promising policies to improve the actual logistic performance were selected. Effects of these policies were studied with the simulation model by adapting the basic values of the model parameters. All other model inputs like customer order demand and model parameters were left unchanged. Relative effects of policies on performance indicators are presented in the next table.

Table 4. Effects of policies

| **Policies** | **Relative effects on performance indicators** | | | |
|---|---|---|---|---|
| | Product Inventory | Delivery Lead time | Delivery Reliability | Profit |
| **Policy 1:** Longer series of production run (50% longer) | +0.6% | -0.2% | +0.1% | +0.3% |
| **Policy 2:** Capacity expansion (25% increase) | +4.2% | -0.8% | +0.7% | +2.2% |
| **Policy 3:** Reducing time loss of product change (50%) | +1.0% | -0.2% | +0.1% | +0.5% |
| **Policy 4:** Reducing safety stock coverage (50%) | -22.3% | +7.4% | -6.9% | +0.6% |
| **Policy 5:** Reducing target delivery lead time (40%) | -1.0% | -40% | -0.2% | -0.4% |

It is clear that policies 4 and 5 have the highest impact on the performance indicators while the effects of the other policies are marginal. Policies 4 and 5 will be studied in more detail.

POLICY SPACE OF SAFETY STOCK COVERAGE

Reducing safety stock coverage by 50% has a desirable influence on the product inventory level, however adverse effects on other performance indicators are quite high. It is interesting to investigate how far the safety stock coverage can be reduced without jeopardizing other performance indicators.

In Figure 15 the influence of safety stock coverage on performance indicators is shown. Reducing safety stock below 0.3 day will drastically increase delivery time and decrease delivery reliability and profit. Backlog will keep increasing demonstrating setting safety stock level below 0.3 day creates an unstable situation. It also indicates that safety stock coverage above 1.2 day does not improve the delivery lead time and delivery reliability. This behavior can be explained with help of the order fulfillment ratio graph (see Figure 4). If product inventory gets too low, maximum shipment rate and thus shipment rate are smaller than the mean product demand resulting in ever increasing backlog. Delivery lead time and delivery reliability will run away. On the other hand if product inventory gets higher and higher, desired shipment rate and thus shipment rate will not be restricted anymore by the maximum shipment rate. Keeping more inventory is then superfluous and only costly.

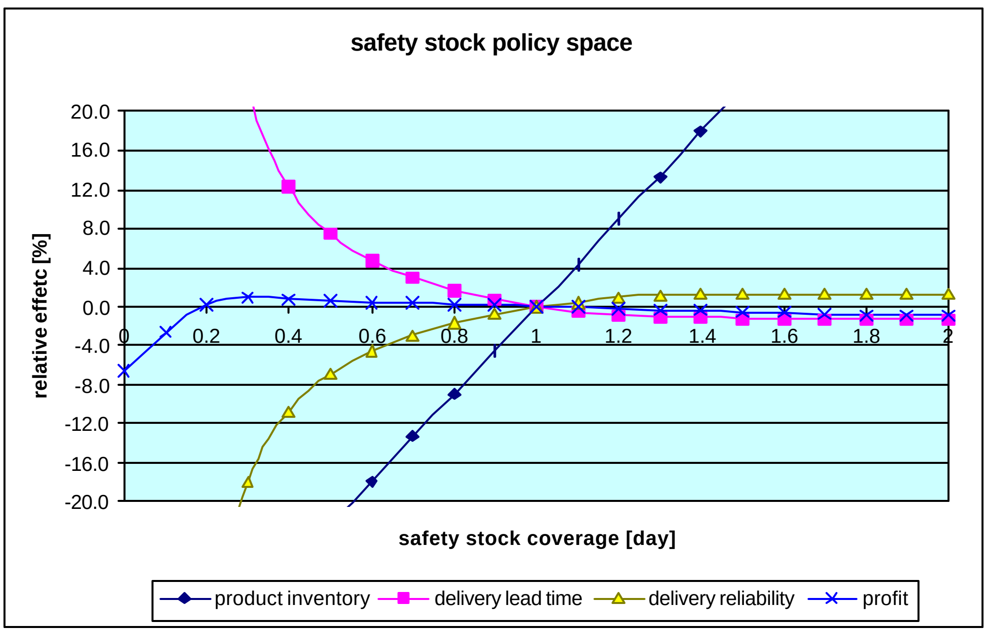



Figure 15. Safety stock policy space

POLICY SPACE OF TARGET DELIVERY LEAD TIME

Reducing target delivery lead time by 40% leads to a desirable 40% reduction of delivery lead time, but has undesired effects on delivery reliability and profit. In Figure 16 policy space on target delivery lead time is depicted. It has a strong influence, as expected, on the performance indicator delivery lead time. Target delivery lead time has a weak influence on the other performance indicators. However lowering target delivery lead times, especially below three days, will decrease the values of the other performance indicators.

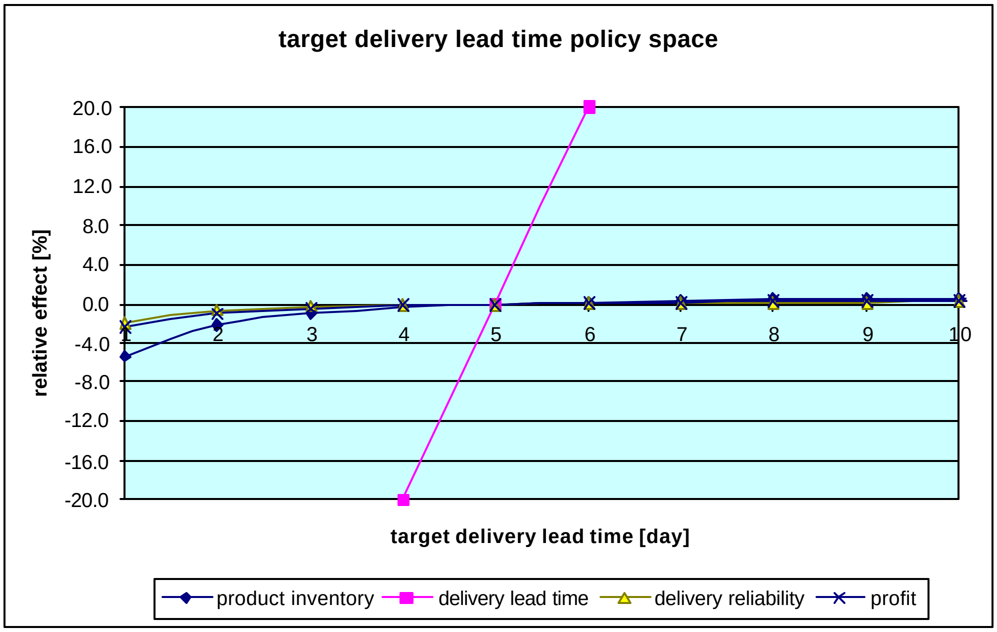



Figure 16. Target delivery lead time policy space

**Strategies and scenario's**

Discussion with the company revealed that policies (1+3) can be implemented together, and they would like to know the combination with other policies. Following are the strategies to be experimented with the model:

- Strategy A – Tightening up: Combination of policies 1+3+4
- Strategy B – More responsive: Combination of policies 1+3+5

Table 5. Effects of combining policies into strategies

| **Strategies** | **Relative effects on performance indicators** | | | |
|---|---|---|---|---|
| | Product Inventory | Delivery Lead Time | Delivery Reliability | Profit |
| A-Tightening Up | - 20.8 % | + 6.3 % | - 5.8 % | + 1.1 % |
| B-More Responsive | + 0.5 % | - 40 % | 0 % | + 0.2 % |

Results of the model runs are presented in Table 5. Applying these strategies show better improvement than just an individual policy due to the synergistic effects when policies are applied in combination

Strategies consist of measures which could be taken by the company in order to improve performance. In addition to developments which can be influenced by the company, there will also be developments which cannot be influenced by the company. In order to investigate the effects of these external influences, a number of different scenarios have been drawn up. Maani (2000) has defined four categories of external factors influencing the company's performance namely market, operations, human relations and finance factors. In market factors, one interesting scenario is the impact of market consolidation. This will mean market players will merge, forming larger companies, and thus although the total order quantity will remain the same, their variance will be less. Another market development is a rapid growth of product demand. For operation factor scenario, it is interesting to see the impacts of a serious disruption in the production street. In addition to these scenarios, base line scenario where there is no change in the external factors is also included. Consequences of these scenarios for model input is shown in Table 6.

Table 6. Scenarios and model input changes

| **Scenarios** | **Model input changes** |
|---|---|
| **Scenario 0: Business as usual** | No change to the model |
| **Scenario 1: Market consolidation** No growth, bigger orders from smaller number of customers | Change of customer order from Normal (277,161) to Normal (277,50). |
| **Scenario 2: Market rapid growth** 25% within the second semester of next year | Increase customer order by addition of a ramp function at run time of 175 with slope 25%*277/175 |
| **Scenario 3: Operational disruption** of 1 week stoppage in the beginning of second semester | Introduce disruption to the production street by setting production capacity to zero from run time 175 till 182 |

Each of the strategies has been simulated in all of the scenarios to investigate whether the company strategies are robust towards the scenarios. The results of scenario runs for different strategies are presented in Table 7. From these results it can be concluded scenario 2 have a substantive effect on profit due to increased revenues from product shipments. Profit growth is tempered because of increased Sunday overtime costs. Scenario 3 has a large influence on product inventory, delivery lead time and delivery reliability. During production disruption, inventory will be empty soon and customer orders will accumulate fast resulting in bad delivery lead times and bad delivery reliability. Especially the tightening up strategy with its low inventory level is seriously affected. After production disruption it will take time to come back to a stable situation.

Table 7. Influence of scenarios

| **Relative effects on performance indicator values** | **Scenario 0: Business as usual** | **Scenario 1: Market consolidation** | **Scenario 2: Market rapid growth** | **Scenario 3: Production disruption** |
|---|---|---|---|---|
| ***Product inventory*** | | | | |
| 0. Base case | 0 % | + 0.5 % | + 1.5 % | - 4.7 % |
| 1. Tightening Up | - 20.8 % | - 20.3 % | - 19.5 % | - 24.1 % |
| 2. More responsive | + 0.5 % | + 1.6 % | + 2.9 % | - 3.9 % |
| ***Delivery lead time*** | | | | |
| 0. Base case | 0 % | - 0.4 % | + 0.8 % | + 15.2 % |
| 1. Tightening Up | + 6.3 % | + 5.3 % | + 9.9 % | + 33.5 % |
| 2. More responsive | - 40 % | - 40.2 % | - 39.6 % | - 28.4 % |
| ***Delivery reliability*** | | | | |
| 0. Base case | 0 % | + 0.2 % | - 0.7 % | - 4.8 % |
| 1. Tightening Up | - 5.8 % | - 5.1 % | - 8.8 % | - 12.9 % |
| 2. More responsive | 0 % | + 0.4 % | - 0.5 % | -4.8 % |
| ***Profit*** | | | | |
| 0. Base case | 0 % | - 0.1 % | + 4.1 % | - 0.4 % |
| 1. Tightening Up | + 1.1 % | + 0.8 % | + 5.4 % | + 1.0 % |
| 2. More responsive | + 0.2 % | + 0.4 % | + 4.9 % | - 0.1 % |

**Conclusions**

A system dynamics model has been built to simulate the internal supply chain of a food company enabling research into the effects of logistic improvement options on the selected performance indicators. Model parameter and input values were collected from operation, sales and planning departments of the company to describe current practice.

Model output has been compared with data of the company concerning a production time period of one year to validate the model. Trends, ranges and mean values of simulated levels and flows are quite similar to empirical data. Actual mean product inventory level however is 20% lower than in the simulation. In general, actual daily fluctuations of logistic variables are stronger than according to the simulation. Data necessary to validate simulated values of defined performance indicators were not available.

Reducing safety stock coverage and reducing target delivery lead time showed to be promising policies with some undesired side effects. Setting safety coverage below 0.3 day is detrimental to the other performance indicators. Target delivery lead time has a weaker influence on other performance indicators. However, setting target delivery lead times below 3 days will affect the values of other performance indicators. In this case, safety stock coverage is a key parameter for logistic performance. Strategies show better improvement than just an individual policy due to the synergistic effects when policies are applied in combination. To investigate effects of external influences, four scenarios have been drawn up to capture different possible future conditions. The scenario of one week production disruption showed a large influence on performance indicator values for all strategies. In this case, having a low safety stock coverage will be bad for delivery lead time and delivery reliability.

## Final remarks

The internal supply-chain model presented here has an aggregated character with regard to customer order product amount, delivery lead time, raw materials, products and production resources. Its purpose is to show patterns of behaviors, and is not aimed at reproducing point to point fit with the actual company data. However the 20% difference of actual mean product inventory and simulated mean product inventory level seems rather high, even for an aggregated approach. Future research should explain this difference, by adaptation of model parameters and input values for the actual situation or by structural model changes.

The simulation model developed is expected to be applicable for a class of industrial situations. Conditions for which such an aggregated level approach is useful for analyzing trends and values for a specific situation are subject of investigation. To what extent relaxations of the aggregated level approach can be incorporated into a system dynamics model, especially with regard to the production sector, will be subject of future research.


## Acknowledgement

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## Appendix

Table 1. Survey of model parameters

| Model parameter | Baseline value | Description |
|---|---|---|
| raw material (RM) safety stock coverage | 9 days | Together, they reflect the level of RM Inventory the company would like to keep, which is for around 10 days of usage. Minimum RM inventory coverage represents the minimum time to prepare RM for production, and the safety stock coverage is to buffer variations in usage. |
| minimum RM inventory coverage | 1 days | |
| RM inventory adjustment time | 5 days | Raw material purchasing interval is 5 days |
| RM usage per unit product | 1.053 | Production yield is 95%, thus to produce 1 ton of end product, it will require (1/0.95) ton of raw materials |
| target delivery lead time | 5 days | This is the average delivery duration promised to the customers |
| bottleneck capacity | 12.24 ton/hour | This is the controlling capacity in the production line. There are two possible groups of raw materials which have different production rates. Weighted mean value is calculated from 0.44*12.8 + 0.56*11.8 ton/hour |
| production run length | 22 hours | This reflects the average production run length on the bottleneck production resource. |
| production change time | 1 hour | This represents the time lost when there is a product change after a production run, due to the set up time as well as the time for a change of raw materials or products. |
| maintenance | 6% | Fraction of company time used for maintenance of the production street |
| disruptions | 4% | Fraction of company time lost to production disruptions like machine breakdowns. |
| safety stock coverage | 1 day | Together, they reflect the level of product Inventory the company would like to keep, which is for around 2 days of delivery. Safety stock coverage represents the amount of inventory the company always wants to keep to cushion the unpredictable customer demand. Order processing time is the average time needed to process an order from incoming to delivery. |
| order processing time | 1 day | |
| inventory adjustment time | 1 day | This reflects the cycle time for the production order. It is assumed that the inventory level can only be adjusted through production |

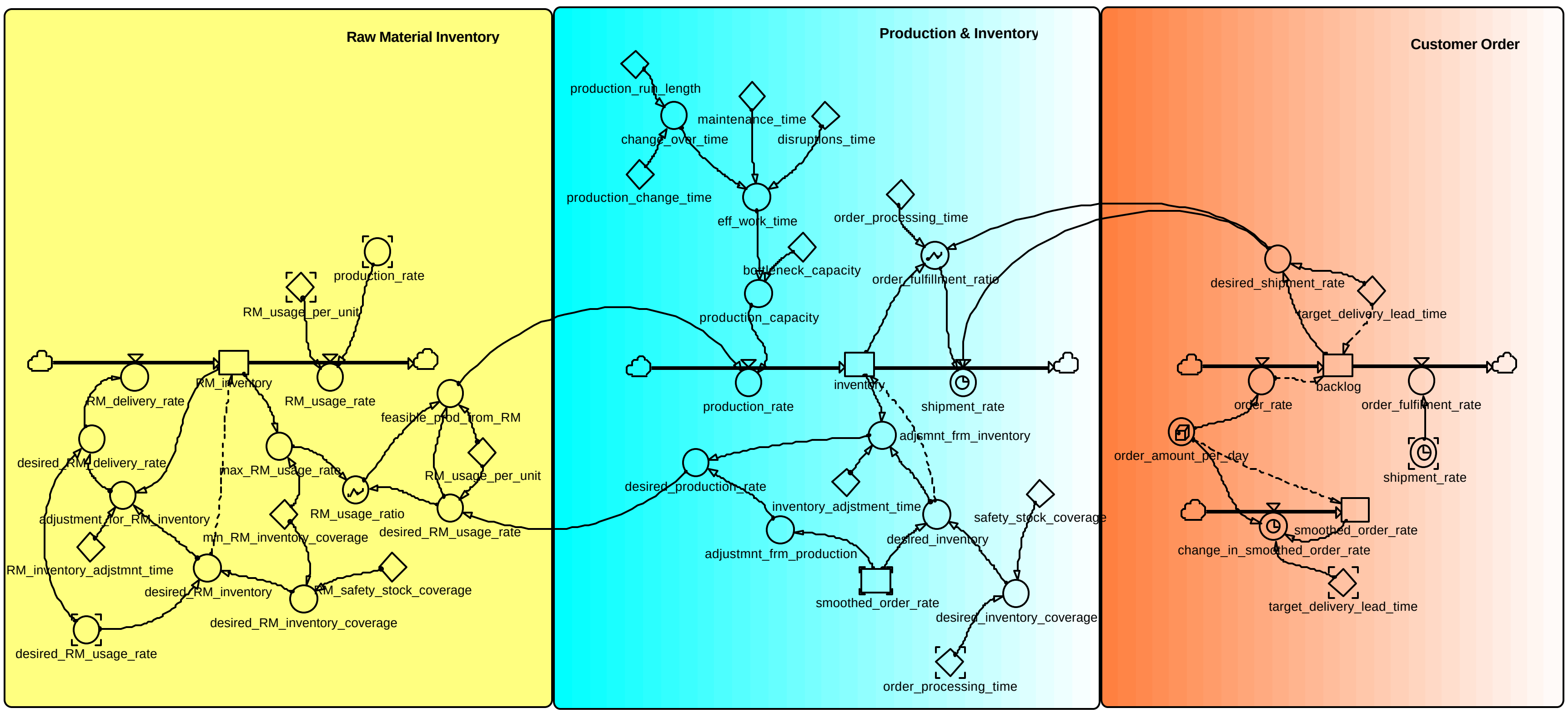


Figure 2. Model representation

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