Napoli 10/10/2012

Oggetto: Determinazione analitica dell'apporto individuale degli autori nelle pubblicazioni scientifiche in collaborazione

I sottoscritti autori dichiarano che il lavoro indicato di seguito è stato preparato operando in stretta collaborazione e con impegno equivalente degli autori stessi.

"E. Romano, D. Chiocca, G. Guizzi (2012). System Dynamics Approach to model a Hybrid Manufacturing System. In: Hamido Fujita, Roberto Revetria. New trends in software methodologies, Tools and Techniques. vol. 246, p. 499-517, IOS Press BV, ISBN: 9781614991243, doi: 10.3233/978-1-61499-125-0-499"

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New Trends in Software Methodologies, Tools and Techniques
H. Fujita and R. Revetria (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-125-0-499

System Dynamics Approach to Model a Hybrid Manufacturing System

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Abstract. The aim of this work is to create a simulation model of a manufacturing system operating within the supply chain by system dynamics approach heeding dynamics of system-company and factors that may affect performance, so that management can have a useful tool for decision support. The results have shown interesting correlations between management choices and the system outputs.

Keywords. Reworking, System Dynamics, Supply Chain, Decision Support Systems

Introduction

In the production systems, the manufacturing outputs of low quality is inevitable, due to several factors (human resources, machines, uncertainty related to the process technology); for this reason, numerous studies have been conducted in order to manage the problems arising from the production of pieces of poor quality. In some cases, faulty items can be reworked and repaired in order to reduce the total cost of inventory and production. Products that incorporate within them a significant value, for example because the raw material is expensive, rarely are rejected; very often a reworking is made to bring back the faulty product within specifications. Reworking activities are also conducted under appropriate regulations that encourage the reduction of waste or to give the company a "green" image. Companies that produce semiconductors, glass, metals are typical examples of companies where reworking are routinely performed. The uncertainty of process performance must be appropriately considered in the assessment of costs, in performance evaluating, during operational decisions to be taken.

In manufacturing systems, where products are made in-house instead of being purchased from outside suppliers, is used a model known as Economic Production Quantity (EPQ) or as EMQ (Economic Manufacturing Quantity). In the EPQ is considered the rate of replenishment not instantaneous of warehouse from manufacturing process and it is determined the optimal production lot to minimize inventory costs and expected production. The classical models of Economic Order Quantity (EOQ) and EPQ do not consider random returns in supply and production

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The issue that will be addressed with the present work is related to the development of a model to evaluate the performance of a production system that has a yield less than one. This implies the presence of a stream of products to be reworked during production process.

1. Literature review

When product returns are random, the output quantity can differ from the input amounts during production, and the received amount from a supplier may differ from the ordered quantity. In particular, in the production systems, due to several factors, the generations of products of low quality is inevitable. For this reason, numerous studies have been conducted in order to manage problems arising from the production of poor quality parts. Yano and Lee [9] identify different ways to model the uncertainty of the production process efficiency:

- Bernoulli Process: is the simplest model in which it is assumed the number of good units in a lot Q has a binomial distribution with parameters Q and p (probability to generate an output good unit from a unit in input).
- Stochastically proportional yield: in which specifies the distribution of the fraction of good parts (or rate of return) and so, unlike the previous case, we have the mean and the variance of yield. In this model the fraction of good parts is considered invariant to changing of Q.
- Geometric Model: this approach differs from the previous one. It is assumed that the fraction of good parts is not proportional to Q but it changes stochastically to vary of Q. It is hypothesized that the process is in control at the start and then it shifts to one state out of control, creating pieces of poor quality.
- Random Capacity: in which it is assumed that uncertainty of returns is due to breakage of machinery and equipment to unreliable.

In the paper [24] the authors have developed an EMQ model for imperfect production systems, imperfect reworking, rejection random rate and constrained level of service. They claim that, although in the production backlogs scheduling can be a good strategy to lower production costs and inventory, too high and uncontrolled backlogs can lead to an unacceptable service level that may cause losses in future sales.

In the paper [24] is claimed that the lead time behavior of a production system changes from the effective useful of the production system and the amount of uncertainty. The use depends on the comparison between the demand (load) and the supply (capacity). The demand is represented by customers with their orders load the production system, loading which is evaluated in terms of quantity and delivery time. The supply covers the skills and resources available to satisfy the order. The uncertainty is related to both demand and supply with regard to where the supply takes into account possible breakdown of machinery, quality problems, etc., the interruption of supply decreases the effective capacity of the system.. Since the system capacity determined, customer orders generate a completion for resources. In a system that operates in accordance with those uncertainties the results in a congestion leads to the increase of the average lead time.

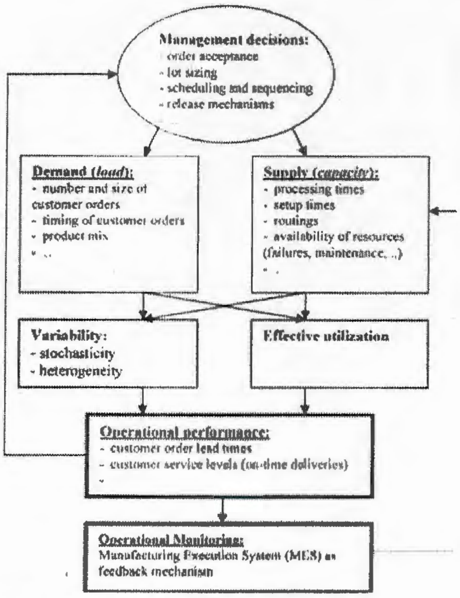

Figure 1. Factors that affect the performance of the manufacturing system

1.1. The initial model

The model from which we started is taken by a paper [24] that studies the dynamic behavior of a moderate complexity supply chain (SC) through the system dynamics technique. The SC modeled consists of a supplier, manufacturer, distributor and retailer. The manufacturing company in the center of the SC follows a Make to Order (MTO) production policy. Consumer demand refers to 10 products; demand rates of the actors in the chain depend on the policies of reordering adopted by the downstream consumer. The simulation refers to a period of one year; the software chosen by the authors [24] for modeling is STELLA® (Isee Systems). We focus our attention on the Causal Loop Diagram (CLD), made for the manufacturing part.

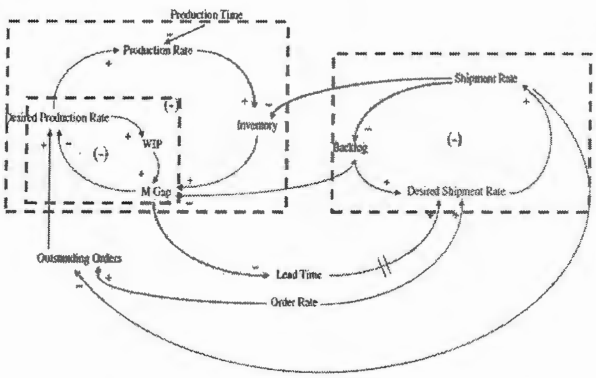

Figure 2. CLD about manufacturing company.

"Mgap" means manufacturing gap and represents a criterion for evaluating a company's ability to meet orders. When the gap is positive, it indicates the presence of parts in the system; if the gap is negative, it indicates the presence of "Backlogs" (i.e. outstanding orders).

The first thing that is observed, by looking causal loop (figure 2), it is that there are three control loops.

The first loop – highlighted by the blue rectangle - is related to the inventory. If "Desired Production Rate" increases "Production Rate" increases too; this last decreases with increasing of "Production Time". This is clear because if time to work a unit of product increases then production rate, that feeds the finished products warehouse, will decrease. The production time is dependent on manufacturer capacity, assumed equal to 50 pieces per week. Increasing production rate "Inventory" will increase too; for this reason the gap (Mgap) will be positive. A positive gap implies the decrease of the "Desired Production Rate", as the company's goal is to prevent that in the system unsold pieces remain that, being customized for a particular customer, would constitute only a cost for the company.

The loop on the WIP (Work in Process) – highlighted by the green rectangle - is also of control. The increase of the "Desired Production Rate" increases "WIP" in the system and this has a positive influence on the gap that, once again, affects in a negative way the desired production rate. If, in fact, the number of orders that it wants to achieve is entered into the system becoming WIP (even if it has not been completed working of pieces that will take them to increase Inventory level), it must consider in order to avoid overproduction.

The third loop – highlighted by the red rectangle - is related to "Backlogs" and it is intended to reduce them to zero. When the "Shipment Rate" increases, the backlogs level decreases and also the "Inventory" decreases because emptied of products that are sent to customers. The order rate has a positive influence both on backlogs both on "Desired Shipment Rate". Increasing backlogs, gap becomes negative and desired shipment rate increases.

"Desired Shipment Rate" is equal to "Order Rate", delayed of "Lead Time", and backlogs. Delaying "Order Rate" of "Lead Time" is made so that order is shipped by the promised delivery date to the customer, considering thus time of realization of the product itself.

Increasing the gap, the lead time decreases because the pieces are going through the system and the moment comes when they are ready to be shipped.

The "Outstanding Orders" are orders pending and increase with increasing order rate and decrease if shipment rate decreases. The desired production rate is the difference between the outstanding orders and the gap. In this way the desired production rate, through the gap, is reduced if in the system there are pieces and then if the gap is positive. Instead, if the gap is negative, the desired production rate increases.

2. Proposed Model

The development of the proposed model is divided in 3 steps:

- development of sub model relating to production;
- development of sub model relating to the warehouse;
- merging of two previous sub models.

2.1. Development of sub model on the production

In the figure 3 is represented the causal loop related to production.

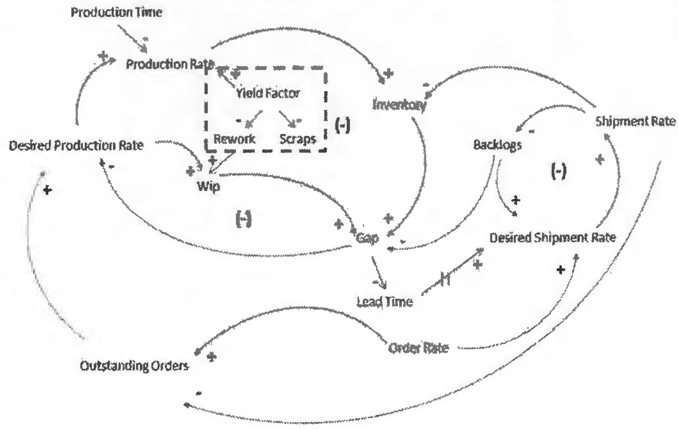

Figure 3. Causal map for productive part

In figure 3 we can see an improvement of the CLD in figure 2 highlighted by the green rectangle. We have introduced the "Yield Factor" that influences positively "Production Rate" and negatively the "Rework" and "Scraps".

In our model, a high yield process leads to an increase of the "Production Rate" which then fills up faster than the finished goods warehouse. Again, the increase of "Yield Factor" there is a decrease of the waste but also a decrease of the pieces to rework. The pieces that require reworking contribute to increase the level of WIP before they can become finished product warehouse or waste. The effects of an imperfect production process will become clear through the gap that will see an increasing WIP, going to affect the "Desired Production Rate". In the follows section we show the stock and flow diagram, which is obtained from the CLD (figure 3).

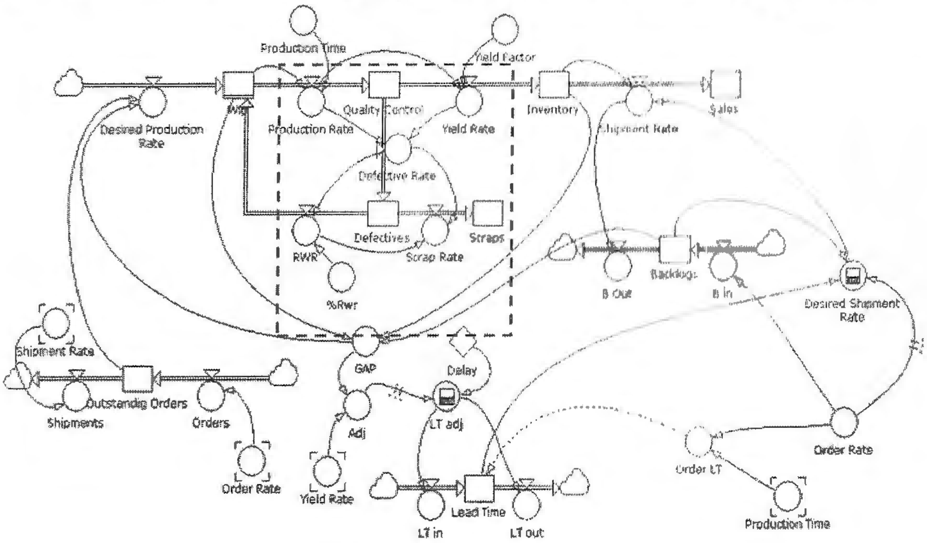

Figure 4. *Stock and flow productive part*

As can be observed in figure 4, between the level WIP variable and the "Inventory", we have inserted a sub structure which takes account of reworking process (this part is highlighted by green rectangle). The "Quality Control" variable is crossed by both flows that represent all pieces of good quality which should be in inventory, and the defective flows. The rate of good parts, the yield rate, which depends on the yield factor, actually, we consider a deterministic parameter obtained from the process capability [26]. If we assume the process capability distributed according to a normal function with a certain average and a degree of variance, according to the limits of assigned tolerance, we can calculate the yield factor as the probability that a piece is compliant. For example, if:

$$C \sim N(\mu;\sigma); \quad LSL=k-\alpha \quad ; USL=k+\alpha \tag{1}$$

where C is capability, LSL is the lower specification limit and USL is the upper specification limit.

The yield factor is represented by:

$$Pr\{LSL<X\leq USL\}=Pr\{\frac{LSL-\mu}{\sigma}<U\leq\frac{USL-\mu}{\sigma}\} \tag{2}$$

The process capability can also be considered in the model as a random variable but in our analysis we consider the yield factor as a deterministic parameter.

The "Defective Rate" fills up the variable of defective parts level (Defectives). From this variable we have designed two output flows: one related to waste and one for reworking units, that become, after, WIP. The percentage of reworking pieces can be assumed constant for the time but after we will define as a random variable.

The production time in the model depends of company ability.

In our hypothesis the firm works with an MTO policy: when it receives the order defines the time needed for its implementation. This time will serve to determine the date of delivery to the customer which can wait the stages of transformation of the desired products. This is the reason because our sub model differs graphically differs from that proposed by paper [24].

The rule that we propose for the adjustment of the lead time is different from that proposed in the paper [24]. This adjustment considers the value assumed by the gap based on a delay that depends on the constant which we have called "Delay" and that represents the smoothing constant. Therefore, the lead time is set right, trying to smooth the information from the random component.

We have carried out a first simulation setting a constant "Order Rate", a "Yield Factor" of 100%, therefore the absence of reworking, and an initial value equal zero of WIP level and Inventory, so to send immediately flows in backlogs and observe the dynamics.

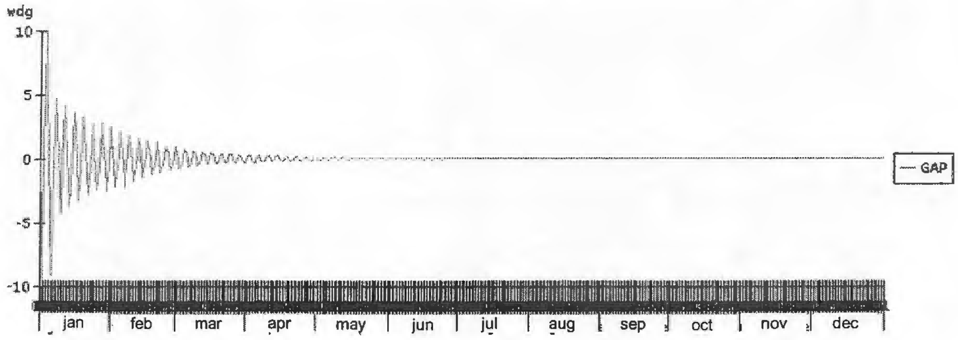

Figure 5. Gap trend in perfect production process hypothesis

As it is possible to see in figure 5, the gap fluctuates during the first periods to settle back down to zero from about the sixth month. This helps us to understand that the system reaches equilibrium and that the negative loop on the Gap operates as intended. The oscillations are due to the presence of delays in the system and to the model parameters assigned.

In the second step we carry out a simulation considering the yield factor equal to 50% and a percentage of reworking pieces equal to 50%, i.e. in the event of imperfect production process.

The tables 1 and 2 show the numerical results obtained by the simulations considering in the first case a yield rate of 100% and in the second case a yield rate and a percentage of defective pieces of 50%.

Table 1. *Desired Production rate, WIP, Inventory, Backlogs and sales values in case of perfect production*

Time	Desired Production Rate (wdg/da)	WIP (wdg)	Lead Time (da)	Backlogs (wdg)	Sales (wdg)
Jan 1 2012	0,00	0,00	0,20	0,00	0,00
Jan 2 2012	20,00	0,00	0,20	10,00	0,00
Jan 3 2012	20,00	20,00	0,20	20,00	0,00
Jan 4 2012	0,00	19,59	0,20	10,01	19,99
Jan 5 2012	0,00	0,39	0,21	0,40	39,60
Jan 6 2012	18,84	0,39	0,39	9,62	40,38
Jan 7 2012	14,81	9,31	0,34	14,72	45,28
Jan 8 2012	5,37	14,50	0,25	10,09	59,91
Jan 9 2012	5,10	5,55	0,25	5,47	74,53
Jan 10 2012	13,88	5,29	0,33	9,64	80,36
Jan 11 2012	14,30	13,71	0,33	14,06	85,94
Jan 12 2012	6,05	14,12	0,25	10,23	99,77
Jan 13 2012	5,50	6,20	0,24	6,00	114,00

Table 2. *Desired production Rate, WIP, Inventory, Backlogs e Sales values in case of imperfect production*

Time	Desired Production Rate (wdg/da)	WIP (wdg)	Lead Time (da)	Backlogs (wdg)	Sales (wdg)
Jan 1 2012	0,00	0,00	0,20	0,00	0,00
Jan 2 2012	20,00	0,00	0,20	10,00	0,00
Jan 3 2012	20,00	20,00	0,20	20,00	0,00
Jan 4 2012	6,86	26,11	0,20	16,68	13,32
Jan 5 2012	2,48	15,54	0,21	9,25	30,75
Jan 6 2012	9,10	7,92	0,39	8,65	41,35
Jan 7 2012	14,21	11,78	0,51	13,07	46,93
Jan 8 2012	11,92	17,92	0,50	15,03	54,97
Jan 9 2012	7,91	17,72	0,48	12,98	67,02
Jan 10 2012	7,89	13,82	0,54	11,02	78,98
Jan 11 2012	10,39	12,54	0,63	11,60	88,40
Jan 12 2012	11,30	14,52	0,68	13,03	96,97
Jan 13 2012	10,06	16,02	0,70	13,18	106,82

From the comparison it is observed that in the case where the reworking process is perfect, desired production rate, WIP, lead time and backlogs have, average, lower values compared to the case where the production process generates waste and reworking pieces. With regard to the sales it is observed a value greater than those in the first case: i.e. the company not sells all that is required because times to process are increased.

The purpose of the desired production rate is to bring to zero the gap and in the case of imperfect process of production we have observed that this does not happen. So we tried to increase the desired rate of production rate scrap and, so, we modified the stock and flow diagram as follows:

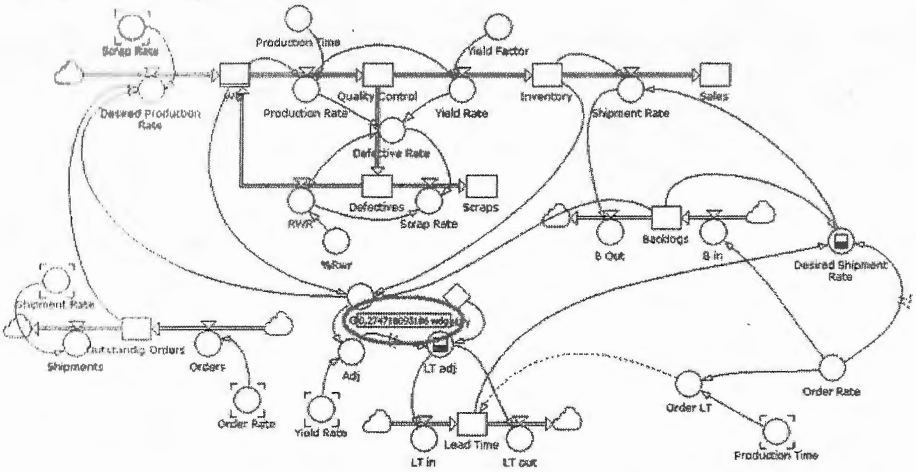

Figure 6. Stock and flow with desired production rate increased scrap rate

What we get from the simulation is a Gap value in equilibrium condition slightly above zero, as it is possible to observe from the figure 7.

The negative loop needs to run best on information of pieces that leave the system because discarded. This also means that in our causal loop lacks the link between Scrap Rate and Desired Production Rate.

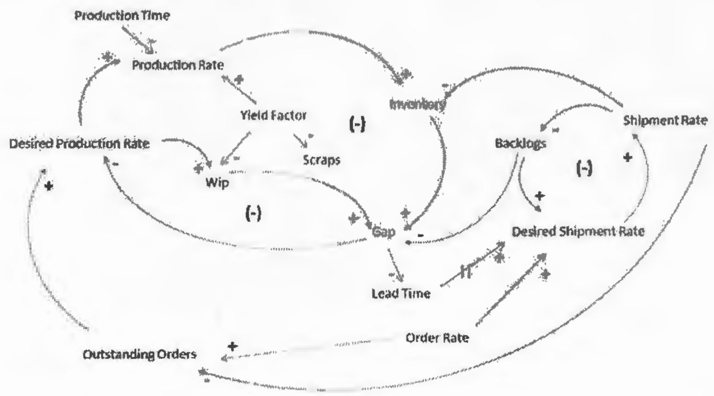

Figure 7. CLD with information about scraps for the definition of Desired Production Rate

Let's see what happens to gap if instead of a constant demand we give to the system a demand as represented in figure 8, returning to the hypothesis of a perfect process.

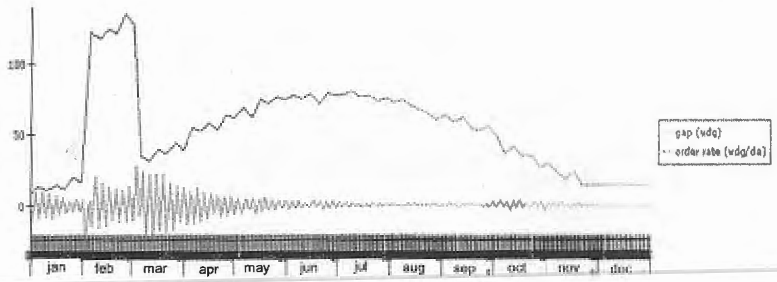

Figure 8. Gap trend relating random demand

As it can be seen, the gap has a highly variable trend in correspondence of the high variability of the application, which causes strong backlogs. When the application takes on a more regular trend, the negative loop tends to zero at the end of the simulation run.

2.2. Development of the sub model related to inventory management

The first hypothesis that we do is that there are no assembly operations for the realization of finished products, as Özbayrak M. et al. [24] suggest. In addition we suppose that the company wants offer a high service level to customers; therefore a stock out of raw materials warehouse may result in delaying or to make impossible the supply of the customer requests. Adopting a policy of ROL type (Re-Order-Level) it implements a continuous monitoring of the available inventory that is well suited to products which are associated with high failure costs or those in category A of Pareto classification. The adopted policy is to reorder variable quantity and, therefore, (s,S) type where "s" is the reorder level and "S" is the level of maximum inventory tenable in stock. Operationally, each time that the level of available inventory goes below the minimum threshold "s"; it issues an order of "S" size less than the available inventory. The variability of the ordered quantities may clash with the flexibility of suppliers.

We will show the CLD on the raw materials warehouse at the beginning without considering the interactions and relationships that can arise with the production processes.

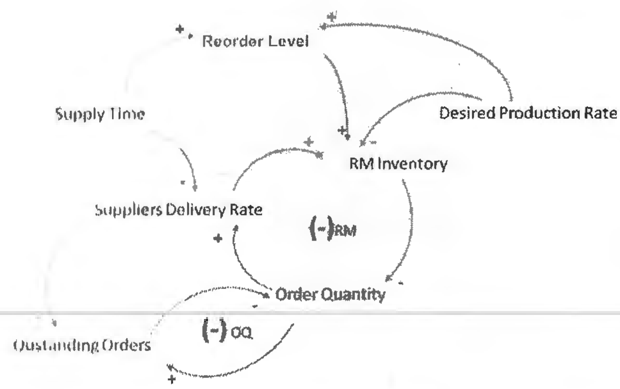

Figure 9. Causal map of raw material warehouse

The first thing that we can see in the causal diagram (figure 9) is the presence of two negative feedback. If the amount of raw material warehouse and orders already launched to suppliers - but not yet received - increase the quantity of goods to order from our suppliers decrease to restore the desired level of stock. Increasing quantity of goods required to suppliers, it must also increase the rate of delivery of these, which in turn increases the stock level. In this way it controls the quantity of goods to be ordered so it is required that is necessary so that the production is not interrupted. The outstanding orders increase with increasing the required quantity of suppliers and they decrease as the goods are delivered, i.e. with increasing of delivery rate of suppliers. The supply time is the time taken by suppliers to give us what is required, for example, can be equal to the days of sailing a ship can be used to reach the port of discharge, or the travel time it takes for a train goods to reach the destination, it is clear, therefore, that an increasing of this, the delivery rate should be decreasing. Now let's focus on the reorder level. We know that in the more general case in which application and reordering of time are variable, the reorder level is given by:

$$s = \underline{d} \times \underline{\tau} + SS = \underline{d} \times \underline{\tau} + z \times (\underline{d}^2 \times \sigma^2\tau + \sigma^2 d \times \underline{\tau})^{½} \quad (3)$$

where $\underline{d}$, $\underline{\tau}$ are the expected values of demand and time of reorganization; "z" is the service level that we want to offer; σ_τ represents the standard deviation of time to reorganize, expressed in the same unit of τ; σ_d is the standard deviation of demand in the same unit of d. From the expression of reorder level it realizes that if it increases the supply time and the rate of consumption, which in the figure 9 is the desired production rate, the reorder level increases causing an increase in inventory stock.

The desired production rate, finally, has a negative influence on Raw Material (RM) Inventory because it deprives this stock. The CLD converted in terms of stock and flow, becomes:

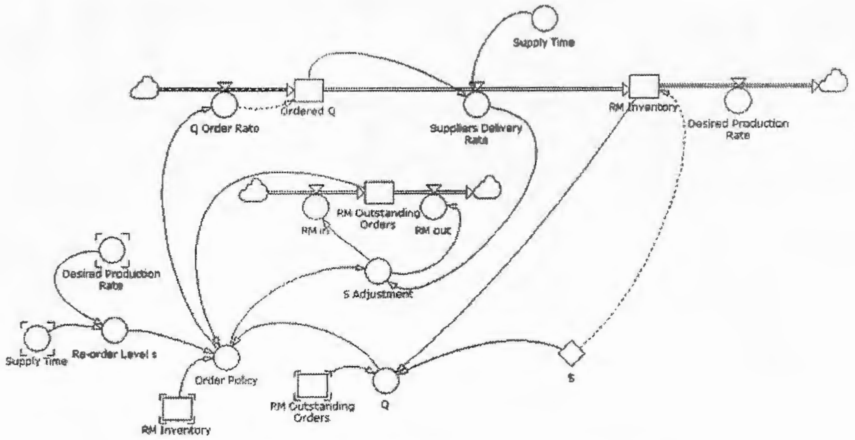

Figure 10. Stock and Flow Diagram relating RM Inventory

In the previous figure "S" is the value of maximum inventory, enabled in stock. As the raw material warehouse is emptied from the desired rate of production, is dynamically updated the value of Q which is the amount that will be ordered to suppliers once the inventory level goes below the reorder level. Lot Q is equal to

$$Q = S - RM\ inventory - Outstanding\ Orders \qquad (4)$$

Then Q takes into account the quantity of ordered goods but not delivered yet and this is understandable if se think that in a policy to reorder point type (s,S), the quantity to be ordered is the difference between the desired level of stock and the available inventory where the available inventory is the sum of the item actually in stock and the incoming that. As explained in literature with "stock on hand" it means the stock is actually in the warehouse at time "t", while "available stock" or "committed", it means the stock on hand plus that ordered but not yet delivered. The stock level on hand and that engaged, differ during the reorder time.

The expression of Order Policy is as follows:

$$IF\ (RM\ Inventory + Outstanding\ Orders < Re\text{-}order\ Level\ s;\ Q;\ 0 \ll wdg \gg) \qquad (5)$$

wdg is an unit of measure and it means widget.

Thus, when the available inventory goes below the reorder level, then it orders a quantity of goods equal to Q. The value generated from order Policy instantaneously fills the variable of ordered Q level.

With regard to the Supply Time, which goes to determine the rate at which the variable Order Q level is emptied, we have choose to place it equal to one day to begin our study but subsequently the value can be changed or even it could be transform in a random variable. The Safety Stock (SS) doesn't appear into the model because we are making references to constant parameters and it takes place when the reorder time and the demand rate are variable, or rather when we have at our disposal the variance of these variables.

Putting, therefore, a constant rate of desired production rate, equal to 30 <<wdg/da>> (da is a unit of measure and it means days), or rather 30 pieces per a day and a S value equal to 300 <<wdg>>, the level stock trend is shown in the table 3.

Reached the reorder point, it is generated an order that restores the level of desired stock the next day. Indeed, we have assumed a Supply Time of a day, the rate of consumption in a day is 30 pieces and when the stock in hand is cancelled, the ordered goods arrive in warehouse, avoiding stock out situations. The Time Table confirms that an order of 270 pieces is released when the stock in hand goes below the reorder level. The released order will arrive to warehouse the next day. In this way, warehouse will be refilled when the stock in hand will be equal to zero, avoiding stock out as we hoped.

Table 3. *Raw material warehouse Time Table Trend*

Time	RM Inventory (wdg)	Ordered Q (wdg)
Jan 1 2012	300	0
Jan 2 2012	270	0
Jan 3 2012	240	0
Jan 4 2012	210	0
Jan 5 2012	180	0
Jan 6 2012	150	0
Jan 7 2012	120	0
Jan 8 2012	90	0
Jan 9 2012	60	0
Jan 10 2012	30	0
Jan 11 2012	0	270
Jan 12 2012	240	0
Jan 13 2012	210	0
Jan 14 2012	180	0
Jan 15 2012	150	0
Jan 16 2012	120	

2.3. Merging of the submodels

From the merging of sub model relating the management of inventory row materials and relating production part that, it obtains an overall model of our company MTO. The Desired Production Rate expression now becomes:

Min((OutstandingOrders-Gap)/Timestep+Scrap Rate;RM Inventory/Timestep) (5)

That is, the function takes the minimum between what it would like to send in production and what it can send in production, according to availability of raw material stock.

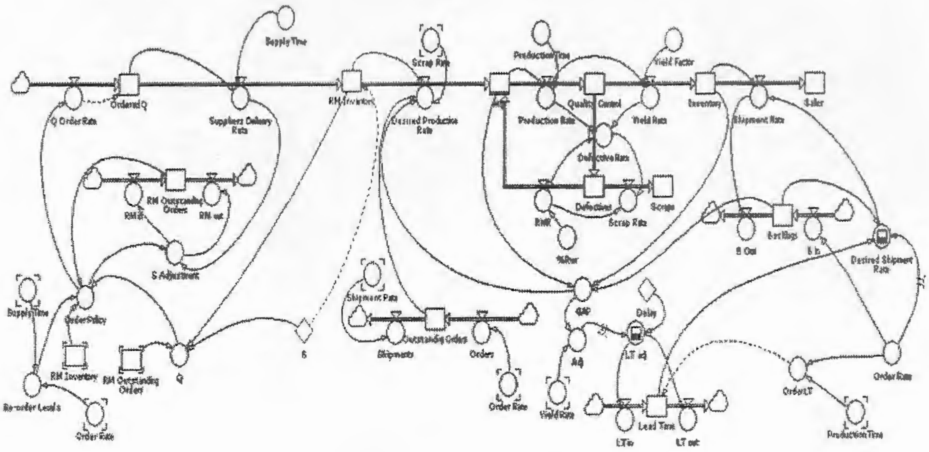

Figure 11. Final stock and flow with RM Inventory and productive part.

So we assume a Constant Order Rate and a 100% yield factor (perfect production process). We begin to see what happens if we consider, as consumption rate, the Order Rate to define the reorder level.

From the simulation we obtain a Gap as follows:

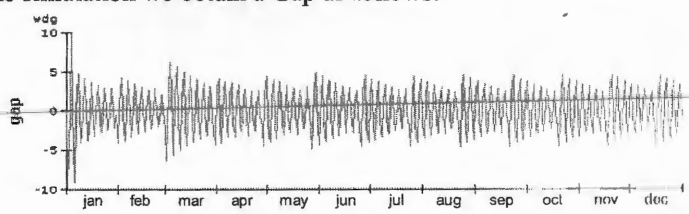

Figure 12. Gap trend with reorder level based on Order Rate and in hypothesis of perfect production process

We know, from previously simulation done for the production part using the same demand rate, that the Gap trend would be the same that is represented in figure 5. Now we think that the oscillations may be due to the inability to pick material needed to produce, because the RM Inventory has not the required availability. So we remove for a moment the constraint placed on desired production rate, or rather we allow the desired production rate" to take all necessary and we see what happens to RM Inventory.

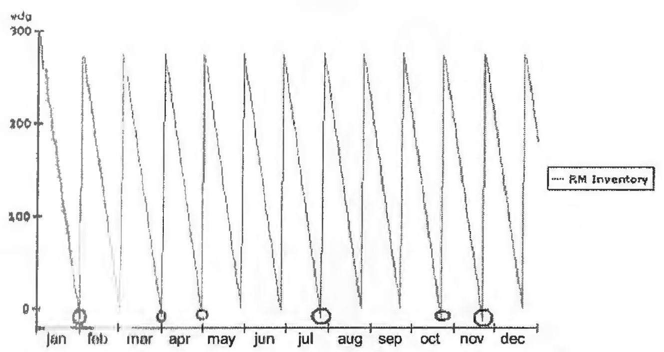

Figure 13. Raw materials stock out in the reorder level based on Order Rate and perfect production process

As can be seen in figure 13, the RM Inventory goes in stock out during same different period (indicated in the figure with blue circles) and this unavailable of material carries the Gap to the new and higher vibrations to indicate a Backlogs increasing. We understand from these observations, that the order Rate is not suitable for defining a reorder level. If we try to consider the Desired Production Rate as Consumption Rate, the situation that occurs is similar to the previous.

It is possible to think that the information about consumption rates that we have before implemented to define the reorder level, are not sufficient so that stock out situations in warehouse will be not occurred and then more oscillations of Gap. Assuming a perfect production process, the only information that we can use for the definition of reorder level is represented by the Backlogs level. In fact, Backlogs that appear in the model are to be intended as a quantity that serves to chase the demand. In fact, the order Rate is such as to fill instantaneously the variable level of backlogs which will serve to define, through the desired production Rate, as send in production to reset the Gap.

The outstanding orders level variable has the same expression of backlogs but they have different conceptual functions. The outstanding orders keep track of pending orders while backlogs are used to register the coming demand, to define the desired shipment rate and to increase or decrease the gap which will subtracted to outstanding orders to create the appropriate desired production rate. It is clear that if there are outstanding orders and there is neither nor WIP inventory, the desired production rate doubles itself and the decreases during the pieces are produced that will refill WIP and inventory. So, if we haven't inventories in the production section, the coming demand becomes backlogs, that is the demand indicator to follow and in this way is sends into production as actually demanded by customers. We must not forget that the use of backlogs is a common strategy in MTO companies that in this way decrease medium levels of stock in hand, aiming to have no inventory of customized products. We see, therefore, what happens defining the reorder level based on the desired production rate and the level of backlogs as in the figure 14.

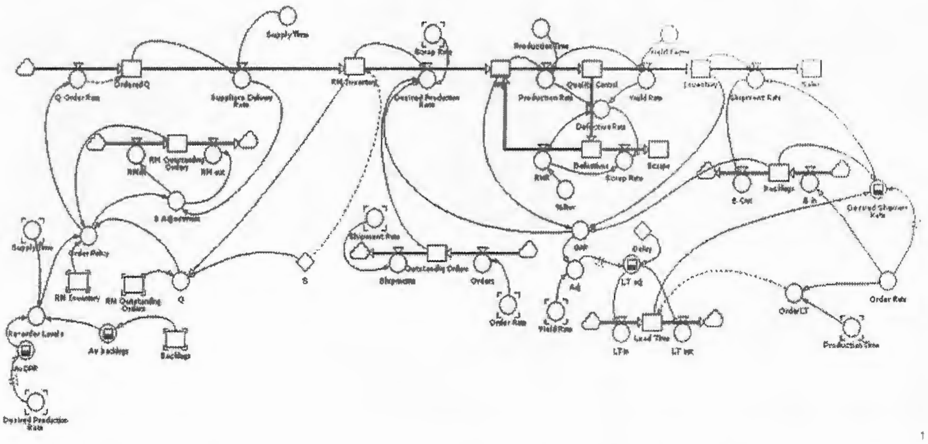

Figure 14. Stock and flow with information about Backlogs and Desired production rate for the definition of reorder level and perfect production process

The gap returns to have the pattern shown in figure 5 and in fact the RM Inventory doesn't go in stock out. The same occurs if we consider together backlogs with order rate, instead the desired production rate to define reorder level. We see now what happens to the gap if we consider an imperfect production process and we maintain information on backlogs for the definition of the reorder level by virtue of what was experienced previously.

As consumption rate for the definition of the reorder level, we suppose initially the Order Rate and then we analyze the Gap trend.

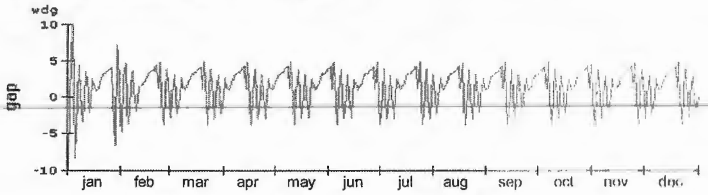

Figure 15. Gap trend in imperfect production process case.

As it can see in figure 15, the gap oscillates all over the simulation time horizon. Gap is moving towards positive values, due to high WIP but then falls into new backlogs caused by the inability to collect what it need in production from raw material warehouse. Removing, again, the constraint on the desired production rate it is observed frequent stock outs of the raw material warehouse.

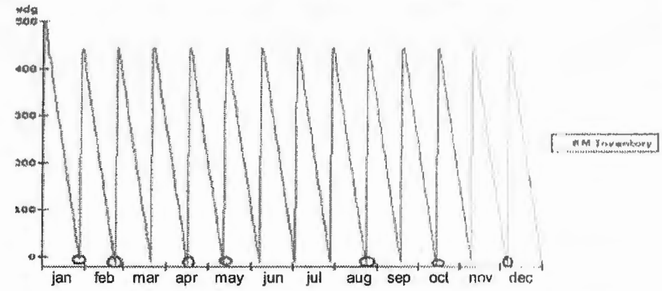

Figure 16. Raw material stock out during imperfect production process and information about order rate to define reorder level.

We try, now, to give as consumption rate in input in the reorder, the desired production rate and we observe what happens to the gap.

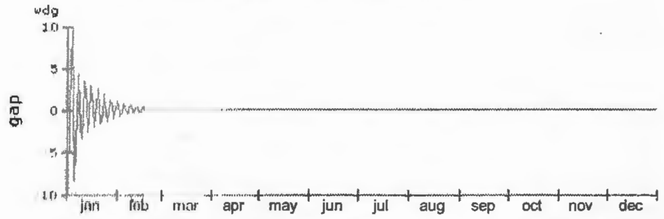

Figure 17. Gap trend during imperfect production process and reorder level based on desired production Rate.

Gap reaches equilibrium near zero as we have hoped and this means that the raw material warehouse is able to provide what is required to the production part without causing further delays in the execution of received orders. In summary, we have observed for the definition of the reorder level when the order rate is constant:

- Perfect production process (100% Yield Factor): setting the order rate or desired production rate as consumption rate, gap has also fluctuations throughout the simulation horizon, and it indicates the stock out raw material warehouse. Adding the information on backlogs both order rate that desired production rate give the same results and they reveal suitable for defining the reorder level.
- Imperfect production process: setting order rate as consumption rate, the gap has fluctuations throughout the simulation horizon, that represents the choice of this is not appropriate to define reorder level. In fact, it observes significant stock outs of raw material warehouse in some periods. Setting, instead, the desired production rate as consumption rate the system reaches equilibrium and the raw material stock level is such as to always satisfy the requirements of production process. This is understandable, since in case of imperfect production process we observed in the previous paragraph that the desired production rate should be increased by scrap rate if we want the negative feedback stating gap to assume values close to zero. This means that when the manufacturing process generates waste, consumption rate required by production process is greater capabilities to meet a particular order.

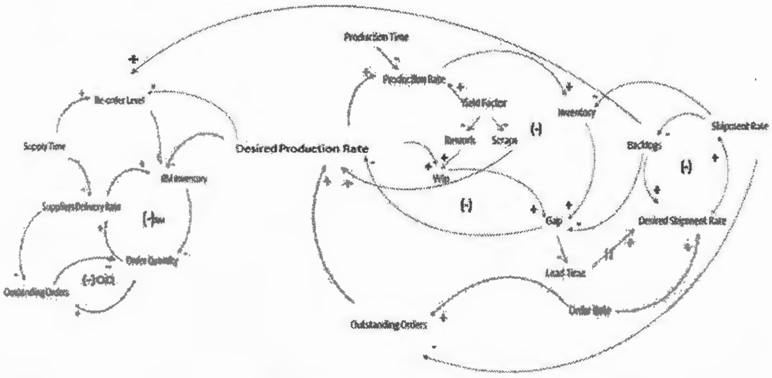

Figure 18. *General CLD*

Causal map of complete model is shown in figure 18; definitive stock and flow is shown in the figure 14.

3. Conclusions and future developments

The simulation model developed in this work is related to a MTO (make to order) company and its implementation took place in a modular way. At the beginning the section relating to the production has been developed, which differs from that presented in the article object of study [9] for the introduction of the flow of faulty parts. The new reorder level management policy, applied to raw materials, was implemented. The management policy of stocks of raw material is implemented to reorder level and it is different from the policy presented in the start article. It was finally perfected the model of development, through the representation of the CLD and the stock and flow. The results of simulations of the overall model, in fact, have showed new cause / effect relationships between the involved variables.

The present work lends itself to many developments. The first one could be the building of a cost structure. Of course, for a MTO company, costs will have a greater importance because function of service level that company wants to offer. For example, if the demand that company receives, exceeds the production capacity resulting in high backlogs, related costs will increase and if the analyzing product has a high profit margin it can evaluate the advantages of a larger production capacity. Of course, the convenience to increase production capacity is determined paying attention to delays in the acquisition of skills but also the type of product that is taking place, because we know that if it has a short life cycle it will be realized for a limited period of time, leaving the producer with excess capacity that maybe in the future will not be exploited. It may also be that the company's inability to meet an increasing demand is due to the excessive generation of scrap and reworking pieces in the system, therefore, the fact of having to rework of the pieces or enter new material into the system to meet the same order, determines a decrease in the production capacity that cannot be exploited for realization of the orders. So, in this case, it may consider the economic advance of an intervention aimed at improving the capability process. It could also consider a scenario in which the production capacity is reduced, due to failures on the machines causing interruptions in the production process. Also in this case could be made on the economic analysis relating to the implementation of a preventive maintenance program. For the management of supply, we have chosen to implement a reorder point policy, but it could also implement a different policy and perhaps compare the results arising from these by choosing the policy that poses the greatest advantages.

Another interesting thing is going to alter the value of the parameters in the model and see at what values the system tends to behave as desired. In particular it could alter the smoothing constants and see which values enable the system to maintain the reactivity enough to cope with unforeseen changes in variables that are referenced. In our model to derive the interrelations between the variables we considered constant demand, the factor of process rate and time of delivery. It would be very interesting to consider these quantities as random variables, characterized therefore from a statistics relating to average and variance, and evaluate through appropriate scenario, the influence on corporate performance. Altering the average and variance of these variables in the analysis of the scenarios is to go to assess the impact of variability and uncertainty have on inventory management and strategic decisions relating to capacity, the level of offered service. If the delivery time is considered as a random variable, it can evaluate the effect that would have an unreliable supplier on our company performance. If we consider what has been said in previously, take into account the uncertainty of supply process may mean going to evaluate the convenience to receive suppliers from a foreign manufacturer or consider sourcing from multiple vendors that have benefits in terms of time, cost and different quality. Consider a market demand described by a random variable, means considering the effect that uncertainty in demand has on business performance. This of course affects the strategic and operational decision within the company.

Finally, considering an imperfect process rate, means testing the effect of the uncertainty in the production process on business performance and assess the appropriate decisions at various levels of business planning taking to get the maximum benefit.

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