Manufacturing start-ups in the automobile industry

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Abstract:

Automobile manufactures are facing shrinking product lifecycles and increasingly complex production and product technologies. Both of these phenomena pressure production facilities to begin full scale operations at a point when the underlying process technology is still poorly understood. Consequently companies suffer from substantial yield losses which can dramatically affect the economics of the product, the production facility, and business. The manufacturing start-up will be defined as the time span equal to the difference between 'time- to- market' and' time- to- volume'. A major goal of automobile manufacturers is to reduce the 'time–to-market', however they cannot evaluate the effects on the 'time- to- volume'. This paper will give insight into these interdependencies and compare two policies for the management of changes during manufacturing start-up.

Keywords: *manufacturing start-up*

Introduction

This paper deals with the manufacturing start-up in the automobile industry on the basis of experiences made in the Swedish automotive industry and the theory underlying the learning curve concept. The objective during the manufacturing start-up is to attain quality and quantity targets with a predetermined production lead time at the lowest possible cost. During the 1980s, many companies used time-based concepts, such as time to market, to give them a competitive edge and market advantages. Time to market is widely viewed as a key source of competitive advantage, particularly in fast –cycle industries (Stalk, 1988). Time based competition, meant that development throughput time should be reduced (Takeuchi and Nonaka, 1986) and companies should introduce new products at a more frequent rate (Pawar *et al.*, 1994). It is widely accepted that early entrants to the market enjoy higher profit margins and longer product life-cycles, and can thus establish a dominant market position (Smith and Reinertsen, 1991). At present companies are generally responding to global competition by broadening their product variety and by reducing product life-cycles. Thus the time to market and/or the time to volume have become a strategic goal for many manufacturers. The period between time to market and time to volume is illustrated in Figure 1. Earlier research performed in labor intensive and machine intensive production systems has shown that start-up phases when new combinations of work organization and technology are to be tuned in, tend to be very complex (Baloff, 1966). Pisano and Wheelwirght discuss the importance of a rapid start-up. Factors such as overall project revenue, market penetration, and the freeing of valuable engineering resources are discussed. Few papers discuss the management of start-ups and what factors affect efficiency during start-up. The system dynamics model developed here aims to be applicable in labor intensive production systems as well as technically controlled production systems, as the final assembly of automobiles.

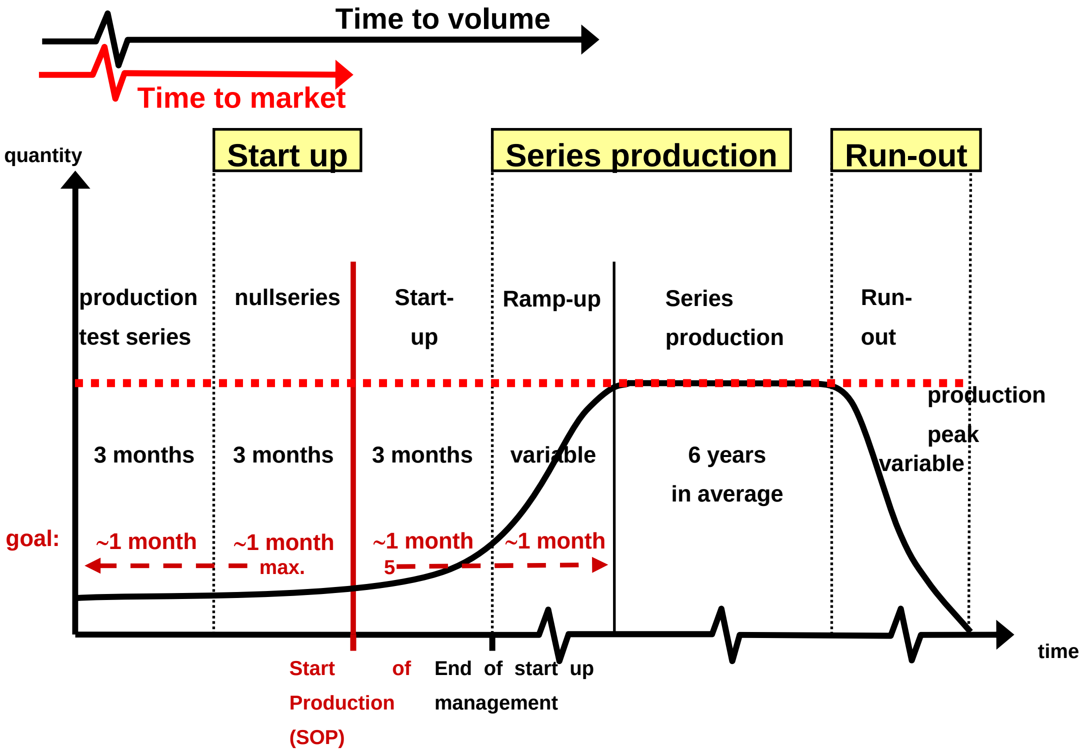

Figure 1: phases of the production processes in the automobile industry

As the general pace of technological innovation and the rate of product introduction increases, the general trend among automotive manufacturers is for product life cycles to become shorter and investments in product development and fixed assets to increase (Lamming, 1993). This trend indicates that time from start of sales until the product is taken from production is decreasing; resulting in a reduced time for profit making, Another illustration of the effect of timing on profits is the importance of hitting the market at the right time in order not to miss sales opportunities. It is generally accepted that companies are facing a diminishing window of opportunity for each newly developed product. Any disruption of the start of production or in the rate of increase in volume can have a devastating effect on life-cycle revenue.

In contrast, Bullinger (1993) reports, on the basis of a survey of 140 enterprises operating worldwide, that the average product life cycle of automobiles has decreased from 10 years in 1983 to 9 years in 1993. The same study reports that pay-off time for investments has increased by 28 percent. Bullinger used this data to demonstrate a reduction in the profit window, which illustrates the relationship between product life cycles and the pay-off time for investments. For the European models we displayed the life cycles in Figure 2 and the trend of shortening life cycles becomes very obvious.

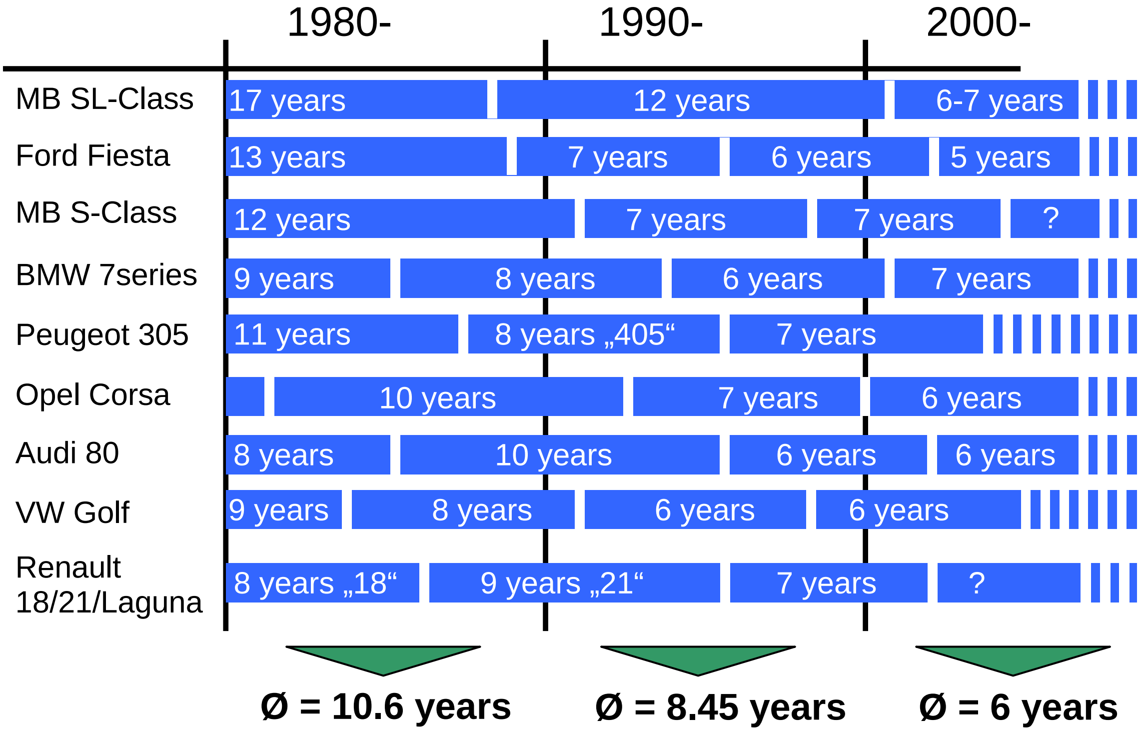

Figure 2: Lifecycles of European Models

House and Price (1991) use the ‘return map’ to show the effect time has on cost and profit. Especially, how development costs affect profit. Warranty costs as the product reaches the market is an important aspect to keep in mind. These costs emphasis the need for designing reliable products, that first are dependable and second easy to maintain. High start-up and warrants costs can significantly reduce profits. The research of House and Price shows that a product that is introduced late to market but misses up to 1/3 of the potential life-cycle profit. Being on time but 50 percent overspent cuts profit only by 4 percent. Time to market and profits are interconnected.

Design errors leading to unreliable new products can have a devastating effect on the market. Unreliable product quality may show up in increased resource consumption in the factory, warranty costs or, in the worst case, functional failure. Focusing on quality and manufacturability during development is crucial for competitive success. Sullivan (1987) shows a relation between pre-production costs, start-up costs and the implementation of Quality Function Deployment (QFD). His study shows that introducing fewer engineering changes late in the development can reduce the cost of quality.

As far as manufacturing engineering is concerned, many articles (e.g. Sullivan, 1987) are concerned with the negative effects of incomplete development and with the negative effects of engineering changes. Engineering change that takes place late in the product development often results in increased costs and reduced yields (Coughlan, 1992). The literature shows that deploying manufacturing engineers in the product development process is positively correlated with improved product development performance (Coughlan and Wood, 1992).

Another area of research is the learning curve. Research on the learning curve discusses aspects of manufacturing start-up on an individual, group, and organizational level, often with a focus on operational analysis, where models are constructed to predict future performance (Cochran and Sherman, 1982; Badiru, 1992). A pioneering work by Wright (1936) introduced the ‘aircraft learning curve’ in an attempt to predict the cost of manufacturing as a function of accumulated production volume. Conway and Schulz (1959) concluded that the cost of manufacturing and yield improvements during start-up is, in part, the result of activities performed before start-up. Baloff (1963) argues that problems during manufacturing start-up are largely related to individual and organizational behavior, management planning, leadership and material supply, as well as to the creation of specific competencies among operators. The literature on the learning curve has identified a number of underlying factors affecting performance, but mostly we only find an enumeration of these factors and research is lacking a quantification of their impact on the manufacturing start-up performance.

Literature review

This paper and the developed system dynamics model analyses the manufacturing start-up, which has been identified as an important blank space on the map of product development research (Krishnan and Ulrich, 2001). Manufacturing start-up is not always considered to be part of the product development, but taken separately, the field of product development itself, and in connection with system dynamics, has received a remarkable attention. The production ramp-up is coming slowly into the focus of research. Although despite its importance, it has been ignored for a long time. Innovation research normally takes into account the period up to the time-to-market and operations management usually considers the production process to be stable after the manufacturing start-up, or when the time-to-volume has been reached. A system dynamics model focusing on the manufacturing start-up has yet not been build and published to the best knowledge of the authors.

Manufacturing start-up and its economic impact

In analyzing the manufacturing start-up, first, the economic consequences of quantity losses have to be evaluated. Next, the complexity has to be categorized in order to take proper actions in advance to minimize these losses. An overdrawn start-up management can over compensate the potential further earnings. The economic losses because of ramp up disruptions can be analyzed on two levels: sales volume and cost. Evaluation on the business volume side considers that, especially in the phase of market entrance, a unique selling position can be achieved which is rewarded by customers purchasing at higher prices. On the cost side, all costs are taken into account, which differ from an optimal start-up.

Time-consuming manufacturing start-up have disastrous economic consequences because of increased competition in innovations and shortened life cycles (Bullinger and Wasserloos, 1990) for these reasons:

- The market cannot be supplied with sufficient new products and the ‘aspired to’ position as the technological pioneer is lost to a competitor with shorter ramp-up times.

- Because of lower cumulated production quantities compared to competitors with shorter ramp-ups, experience curve effects cannot be realized and the cost position becomes worse.
- Profit contributions lost at the very beginning of a product life cycle because of lower sales cannot be compensated later when the market is in its saturation.
- At the start of sales, the cumulative cost of a development project reaches its maximum and, if then the earnings are delayed because of lower production volumes, smaller companies with a narrow product portfolio will run into liquidity issues.
- Releasing products late can result in 1/3 lower life-cycle-earnings (Hendricks and Singhal, 1997).

When a company experiences a decrease in financial resources, the result is lower budgets for new or variants developments. The lower budget and time pressure to release new or modified products to the market can lead to a longer production ramp up.

From the goals of production, such as short lead times, low costs, and flexibility in the processes, the requirement for its ramp-up can be derived: a controlled achievement of the stable production status. The problem is obvious: "Companies can simply not afford any more to design a product, transfer it into production and debug or adapt it during a period of sometimes two years" (Dierdonck, 1990).

The transfer from development into production seems crucial from a temporal and an economic perspective: the product is close to its market entry and time lags no longer exist. Simultaneous with announcing the next product generation, at least part of the customers will delay their consumption and wait for the next generation. Because of that sales will decrease and the demand for the product in ramp-up is rising and it has to be released quickly in sufficient quantity (Inness, 1995).

Factors influencing the production ramp-up

How are the differences in production ramp-up determined? By the 1930s, the ramp-up of production processes had already been empirically tested and individual and collective learning processes had been identified as a reason (Wright, 1936). Differences in ramp-up times cannot only be based on learning curves, especially in an automated production environment. Perhaps the reasons can be found at the transfer point from development to production. Two aspects have to be considered:

- On one hand, the transfer involves the cooperation of departments of development and production.
- On the other, a physical transfer of development results from laboratory environments into series production.

An isolated view of the ramp-up is completely deficient. The idea that at the SOP the buying department has all the parts, at the right time and in the right quantity and quality, in their place; the producer switches on the machines; and full production capacity is reached at this time is too removed from reality. Complexity, dynamics, and interdependencies of parallel executed processes, e.g. product development and the build up of manufacturing resources require time consuming start-up management. Securing a goal oriented procedure requires an evaluation of economic connections, an evaluation of the technical complexity of a new product, and the identification of the main reasons for disturbances.

Series-production readiness as a result of product development and starting point for manufacturing

At the end of a product development process, there should be a product that fits in form, function and price to the customer’s demands, but also within the company a production system that is capable of producing quantities in the quality the market is asking for. Therefore, the result of the innovation process has three dimensions:

- The product dimension fulfills the customer’s demands towards the product concerning form and function. During this process the product properties are fixed.
- The process dimension concerns the company’s ability to produce a product in the right quality.
- The capacity dimension, where the company provides the required manufacturing resources, also includes services and products by suppliers.

For the purpose of the system dynamics model, a degree of series production readiness is developed based on three dimensions (Kotha and Orne, 1989), whereas Kotha and Orne use the organizational scope for the third dimension. Here, only single development projects are of interest and organizational changes have a rather long term character. This multidimensional status of the innovation process is a measurement for the series-production readiness and most of the troubles during the ramp-up are linked to unready products (Bungard and Hoffmann, 1995). In our model we specifically use the product and process conformance and the workforce in assembly can be regarded as the capacity dimension.

Modeling manufacturing start-up in the case of the Volvo S70

Almgren (1999) published an empirical research where the replacement of the old Volvo 850 through the new S70 is analyzed. The start-up phase for the new S70 model was scheduled to last only four weeks. Within these four weeks it was worked in one shift, but also on the weekends. Before start-up the old model ran out and the production line was emptied. It took two days to build new material facings and installs the new equipment for assembling the S70. In our System Dynamics model the old model runs out on day 15. Production lead time is five days, so that emptying the production line takes five days. After rebuilding the production facilities the production start-up begins in the System Dynamics model on day 22. Almgrem uses in his paper two performance indices to keep track of the efficiency gain during the start-up phase. The capacity performance index is measured as the ratio between the number of produced cars and the number of scheduled cars per day. The quality performance index is the number of cars that leave production with an assembly remark divided by the produced cars. Both indices are included into our System Dynamics model. The model contains five views and the first comprises the production process itself and is shown in Figure 3.

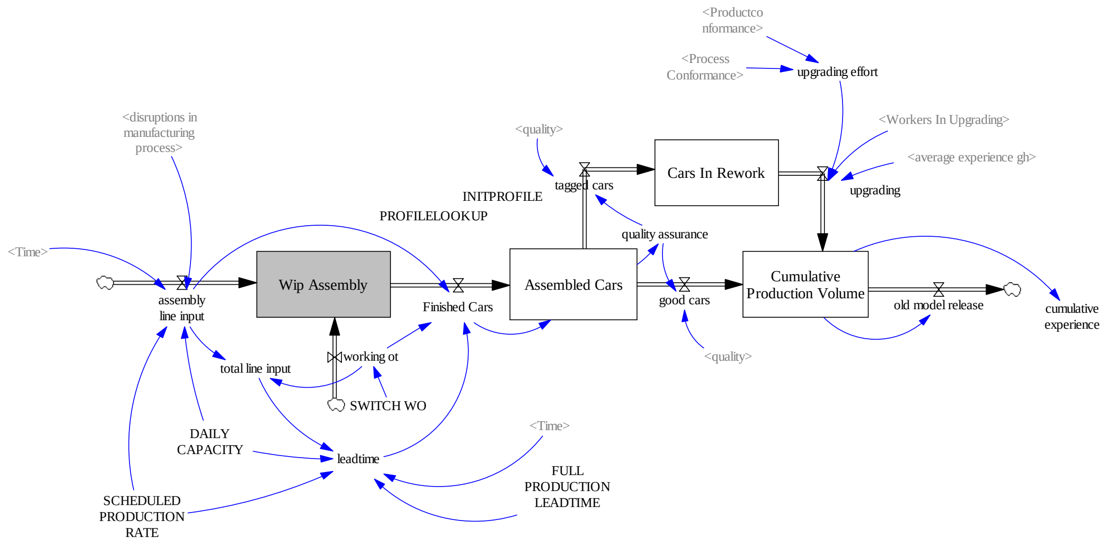

Figure 3: View of the production line

In the ‘scheduled production rate’ table function we modeled the managements target to ramp-up production within four weeks. The grey stock represents the work in progress and is modeled with a conveyor delay, which is one of the special delays offered by Vensim, and it perfectly models the delay in a production operating with a conveyor belt. No matter what the production lead time is the work in progress holds a constant level. Here we assumed 750 cars on the production line. Whenever the lead time is changed the output is also changed with no delay, so that in our model and in reality the rates ‘assembly line input’ and ‘finished cars’ are completely synchrony. The production rate, or ‘assembly line input’ is influenced by a number of factors. First there is the managements’ scheduled production rate, but the people working in assembly only have a certain workforce which is mainly influenced by their experience. Thus we have a ‘scheduled workload’ and a ‘manageable workload’, which slows down the production line if the workforce cannot keep up with the line speed. In this case a production backlog accumulates is the so named stock, which only can be worked off in overtime. We assumed a maximum daily overtime of 20 % of the regular working time. Once scheduled production capacity will earlier or later be fulfilled, depending on how soon the manageable workload is high enough to handle the scheduled workload plus working off the production backlog.

The manageable workload depends mainly on the number of workers in assembly and their experience. Workers can be shifted into upgrading, which is the reworking area in the automobile industrie. The corresponding module of our system dynamics model is shown in Figure 4.

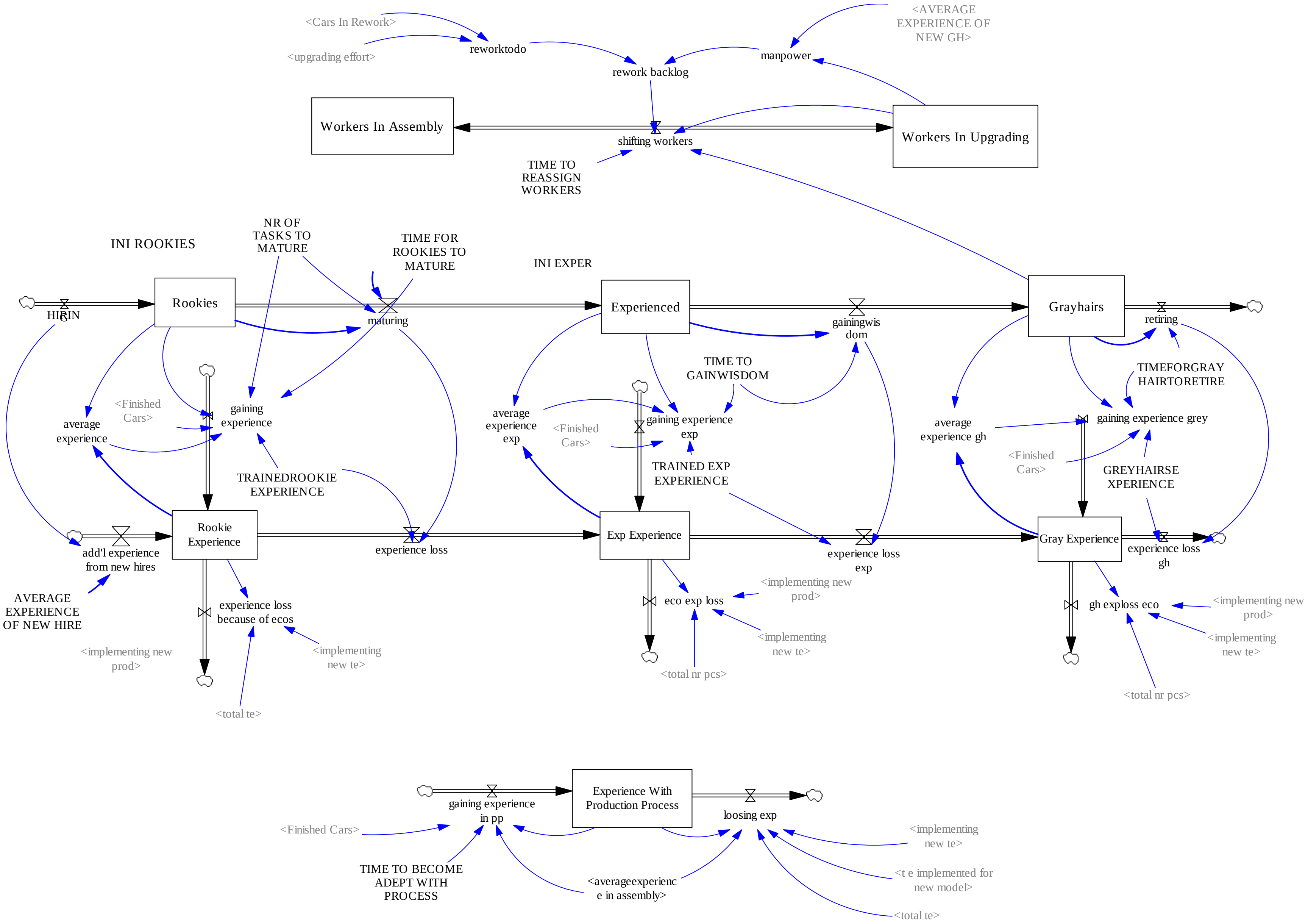

Figure 4: Workers in assembly and workers in upgrading and their experience development

The development of workers is modeled in the well known structure of an aging chain with a coflow to keep track of their experience. Workers experience is connected to the cumulative production volume. This is called ‘learning on the job’ or ‘learning by doing’. This type of learning falls in the category of autonomous learning, where as worker’s training scheduled by management would be an induced learning. Since our model boundaries are so narrow induced learning is not implemented yet in our model. Before the start of production training sessions for the assembly workers is one of the managements’ possibilities to take influence on the start-up performance. It is one of the future possible amendments to the model. The workers in production are separated into two groups, people working in assembly and people working in upgrading. All cars that are tagged during assembly need to be reworked or upgraded. Because cars are such a high price product it is worth upgrading every car until it can be sold to the customer. Because all kind of work operations can occur during the upgrading operations only the very experienced workers are scheduled to work in the upgrading group. If there are now a lot of cars in the upgrading cue a lot of experienced workers are shifted away from assembly and the average experience in assembly is dropping. A lower average experience in assembly leads first to a lower manageable workload and of course also to a higher ratio of tagged cars, because more assembly errors are made.

There are more sources for efficiency gains that we modeled. First new tools and equipment is installed in the production line. The workers first have to get used to the new equipment and the equipment has to mature and bugs in the equipment have to get fixed. Next new product components are build into a new car model, so that normally suppliers are involved into the design of the new product components. New product components also have to mature and often engineering changes occur after production has started and mistakes in the product design become obvious. Production itself is only one of the sources to discover mistakes in the product design; the other source is the feedback from customers. Customer dissatisfaction with a product design comes from changed requirements, wrongly perceived requirements, or just an incorrect product design. Both sources of efficiency gains are modeled in a similar aging chain structure. Figure 5 shows the structure of how the product conformance evolves.

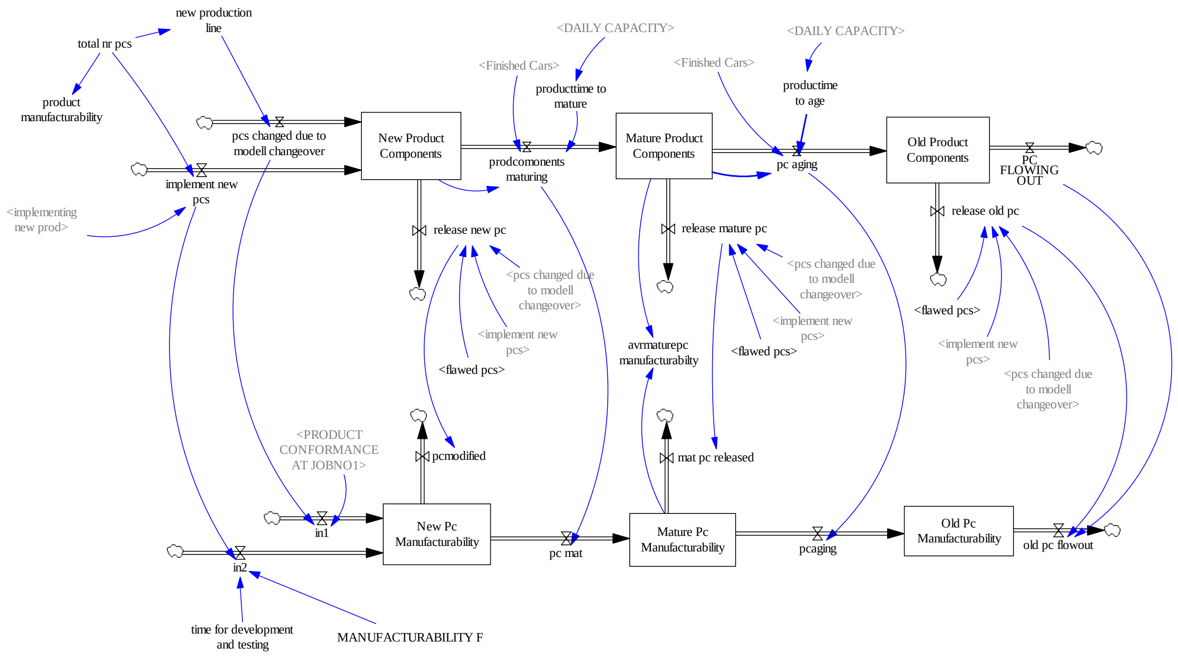

Figure 5: Product Conformance

The main focus is on product conformance which represents the conformance of the product to the customer’s requirements. There is a conformance level at the beginning of production, which depends on the development quality and the ability to percept the customers’ requirements. This can be done with methods like the Quality Function Deployment, but the starting level is an exogenous constant here in the model. The gap in product conformance can be closed on the one hand in the production, which is modeled in the aging chain. Every newly build product component has to mature to prove its design. It is either flawless and it becomes a mature or old design, or it is still flawed and has to be redesigned and begin at the beginning of the aging chain. On the other hand engineering changes can be trigged by customer feedback. If feedback from customers requires a redesign of product components the gap in product conformance is enlarged and has to get closed again. The negative effect of engineering changes lies in the need for new product components to mature and prove their reliability and next the workers in assembly have to get used to new assembly processes, when new product components have to be assembled. This is modeled as a loss in the workers experience.

There are two major variables that affect the efficiency of the production process: productivity and quality. By what factors these variables are influenced can be seen in Figure 6.

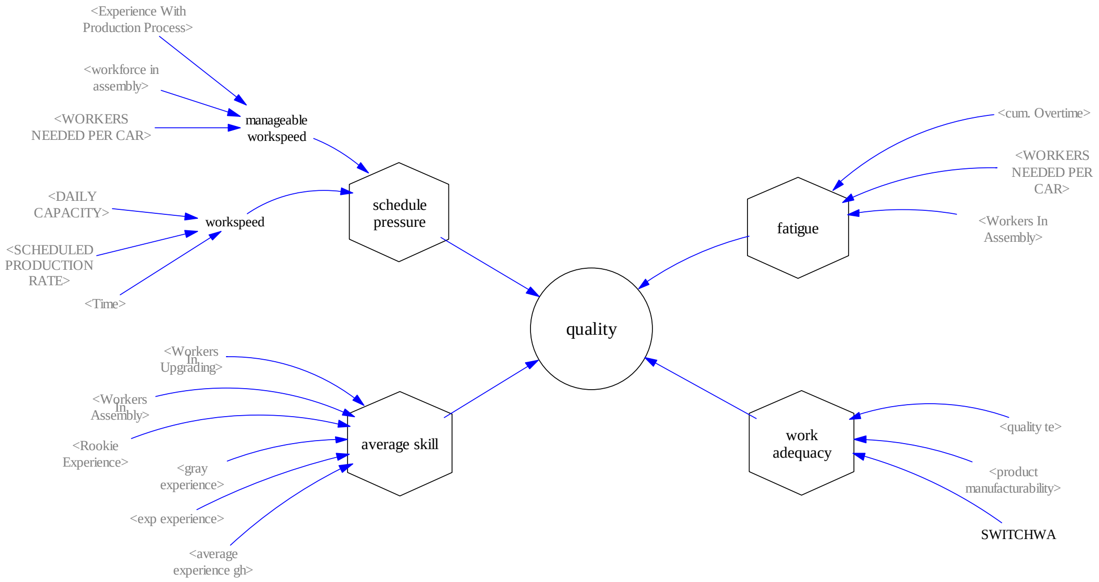

Figure 6: Quality with its influencing factors

There are four factors we modeled that have an influence on quality. These are the average skill of the assembly workers, the work adequacy, schedule pressure, and fatigue. Fatigue sets in when the workers have to spend overtime for a longer period. The work adequacy mirrors how well the assembly process is organized and it is influenced by the quality of the tools and equipment used in the assembly process. Schedule pressure arises when the tact time of the production process is too quick for the workers. Once the workers gather experiences in the assembly process the time needed to perform their assembly tasks will go down. But if the time available is too short, workers will perform their tasks in a hurry and quality will suffer.

Modeling the manufacturing start-up

The time span of four weeks to ramp-up production to full scale as described in Almgren's (1999) work is very ambitious. It can only be the result of a very detailed product and process development and intensive training of assembly workers. On the other hand **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the details of the production system and the circumstances in which the manufacturing start-up had to be performed. There were 1800 engineering changes included in the change from the old Volvo 850 model to the new S70. This is a relatively low number and the factor of newness, a constant in our model, is lower than in an average manufacturing start-up. But still, in our model only a very high level in product and process conformance at the start of production of the new S70 model enables such a quick manufacturing start-up.

Production System		***Work Organization***	
Type of System	Paced assembly line	Mode of organization	Team based
Cycle Time	110 sec.	Work enrichment	Yes
Working condition	One shift	Work rotation	Every 40 min.
Product		Performance Norm	111 MTM
Variety	high	Technical autonomy	low
# of Engineering changes	1800	Work pace	Processed based
Production Organization		Work method	standardized
Span of control	narrow	Time of employment	7 years in average
Operator specialization	Low degree	Absenteeism	Less than 1 %
Decentralization	High degree	3	4

Figure 7: Production System of the Volvo S70

Almgren publishes in his paper only ratios, because he was of course not allowed to publish secret production figures. The first ratio is the quantative ratio of production rate divided by the scheduled production rate. Our baserun shown in Figure 8 is coming close to the published development of the production rate during start-up. After about day 55 the ratio becomes greater 1 because production backlogs are made up by working overtime. Here only 150 cars are scheduled per day, but with 20% overtime the workers are capable to assemble more than that.

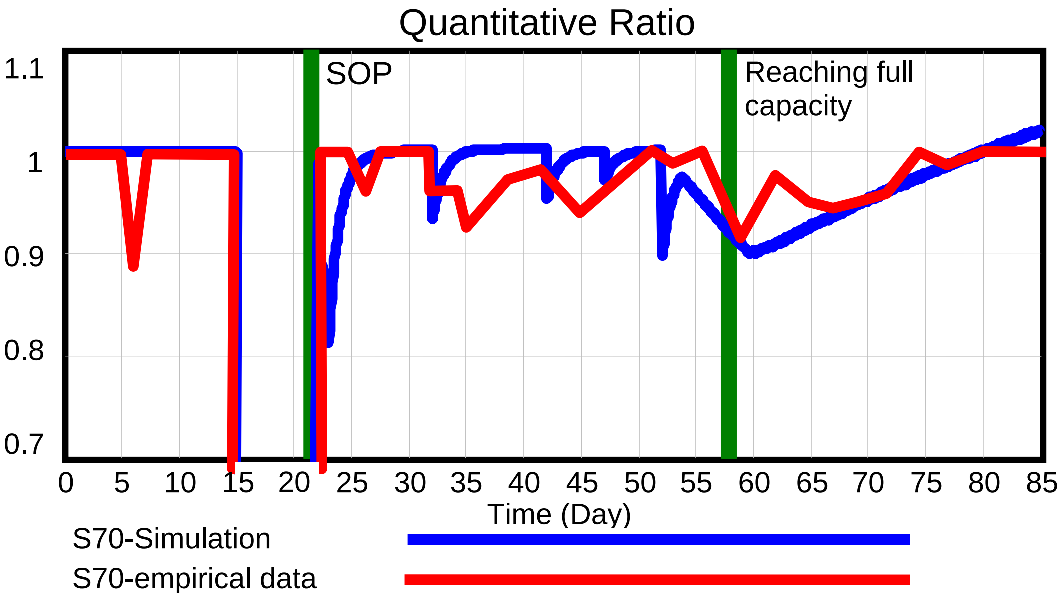

Figure 8: Base run of the manufacturing ramp-up

Although the manufacturing start-up must have been planned ahead meticulously it is reported that the start-up phase was not with out problems. The quantitative ratio was indeed most of the time very close to 1, but especially the quality was not as high as expected and it took longer than planned to reach its aspired level. The baserun in Figure 9 shows how quality as the ratio of tagged cars, which need to be upgraded and produced cars evolves in our simulation run. The baserun is very similar to the published run and shows very slow improvements during the start-up. Volvo's aim was to achieve a quality of 90 % thirty days after the start of production, which is day 57 in the simulation runs. This goal is achieved 70 days late on day 125 in our simulation run. At Volvo start up the 90% quality target was achieved about 80 days after the SOP.

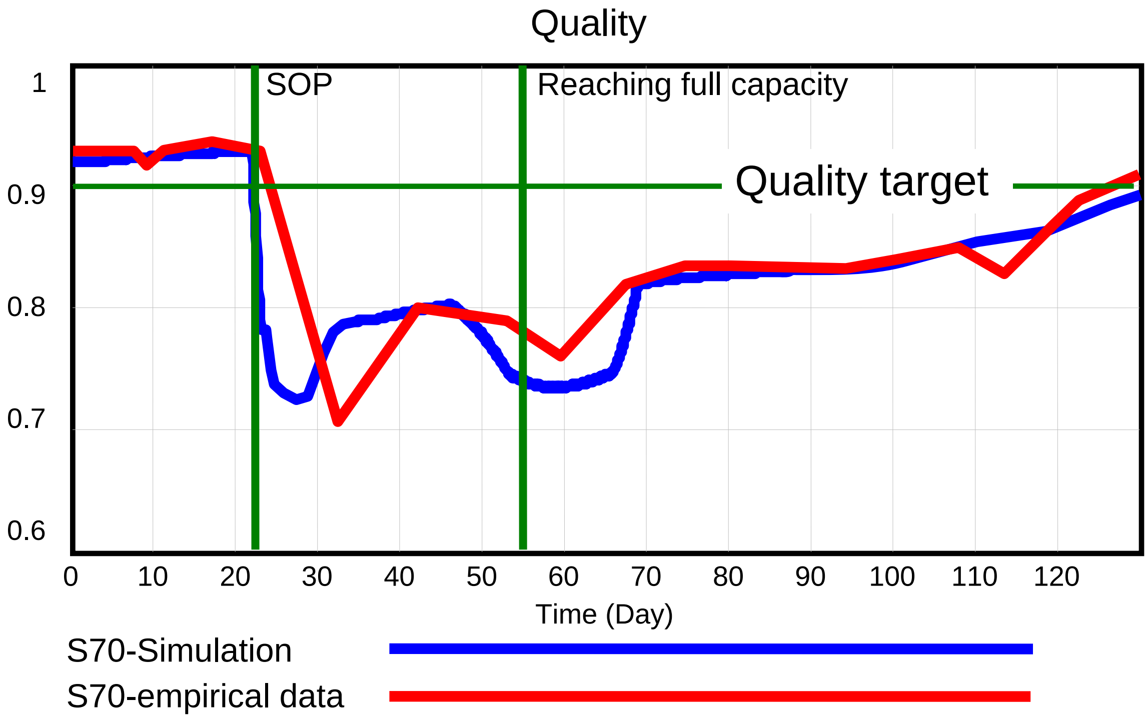

Figure 9: Quality evolution during manufacturing start-up

With this calibration of the model concerning the product and process conformance and the workforce we tried to find ways for improving start-up performance. Since Volvo's performance already has to be considered a world-class performance there were not too many point's available for bringing a leverage to bear on. What we found was that the scheduled production rate was not aligned to the manageable workload. In the very beginning the workforce in assembly was capable of a higher production rate than the scheduled and then the scheduled production rate was increased too much. We aligned manageable and scheduled production rate. The too rates are shown in Figure 10. The aligned production rates and their effect on the quantitative ratio and quality during the manufacturing start-up can be seen in **Fehler! Verweisquelle konnte nicht gefunden werden.** and Figure 9 in the second simulation run named 'run continuous'.

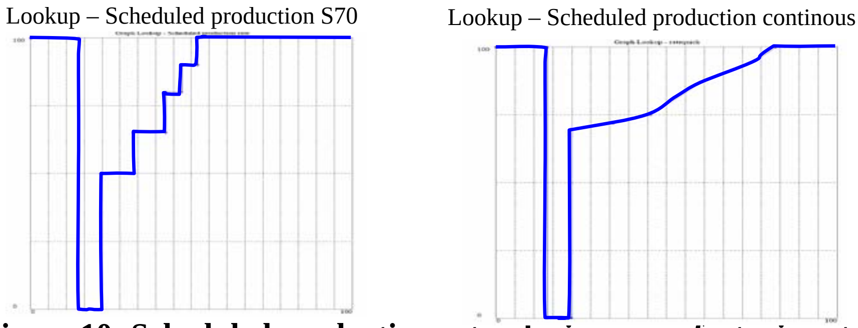

Figure 10: Scheduled production rates during manufacturing start-up

The quantitative ratio performs just a little better, but the major problems that occurred in the start-up of the new S70 were due to quality issues. The evolution of the quality rate has been improved a lot by adjustments to the scheduled production rate. All negative effects when the scheduled production rate is too high for the workers abilities are removed.

Transfer of the system dynamics model to a more general case

The manufacturing start-up in the case of the S70 was somewhat special, because the scheduled time was very short. Normally these times are kept somewhere between 3 to 12 months. It is very likely that this very quick start-up has been paid by a very detailed product and process development. We now assume lower levels of product and process conformance and also simulate with normally skilled workers that have been trained for the new assembly process in a normal amount and not as copious as it must have been in the Volvo case. With the new circumstances a manufacturing start-up is scheduled to last 80 days, in the simulation run, which would be four months, calculating with 5 workdays a week, in real world. The performance is illustrated in Figure 11.

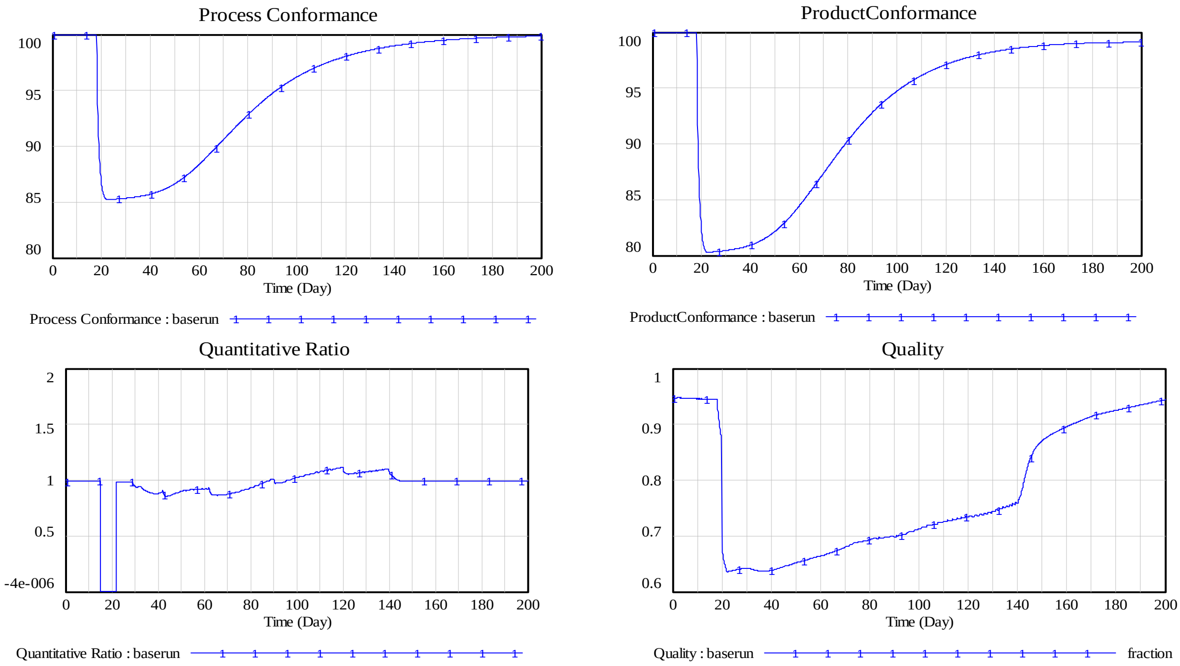

Figure 11: Manufacturing start-up performace

In our baserun the product and process conformance started at the SOP at a level of 80 and 85 respectively out of 100 possible points. That means a not perfect product is introduced in manufacturing and production processes are not perfectly defined. This inevitably leads to a need of engineering changes, which are executed in the base run as soon as they are discovered. The start-up phase is very crucial, because workers still gather experiences and engineering changes during this period induced extra disturbances into the learning process. Another strategy to handle engineering changes would be to gather them and implement them as soon as the manufacturing start-up is over. At this moment the workers are already familiarized with the production process, organizational, logistic structures are working, and the supplier has solved most of their own start-up issues. We modeled such a fast ramp-up strategy and the results can be compared to the baserun in Figure 12.

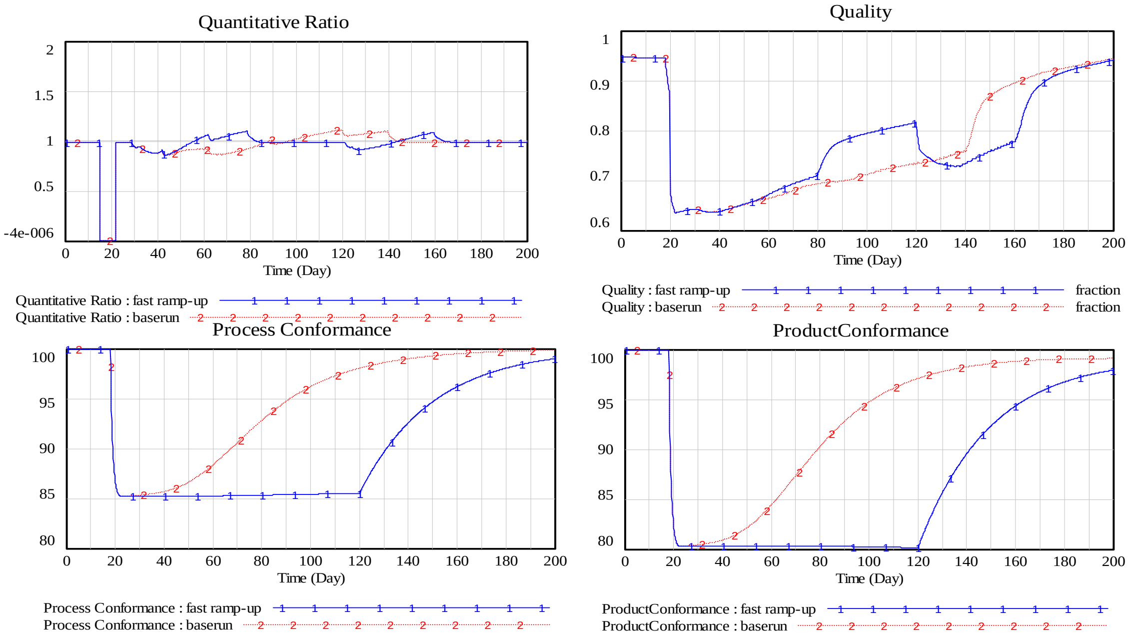

Figure 12: Fast Ramp-up strategy in comparison to the base run

The quantitative ratio stays more stable during the manufacturing start-up phase, which ends on days 120. Then disturbances are induced because all engineering changes to that point discovered are implemented. For a better evaluation which strategy works better Figure 13 shows the cumulative production volume.

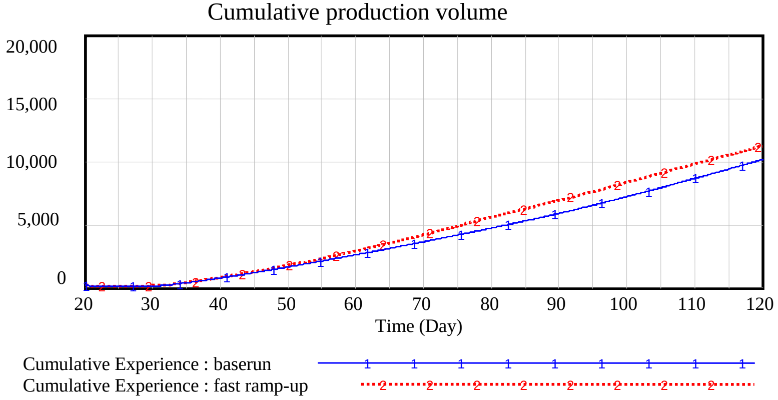

Figure 13: Cumulative production volume

First of all the production rate is closer to the scheduled production rate, which means promised delivery dates are met, which is very important for customer satisfaction and next the production output rises significantly faster than in the baserun.

Conclusion

The shortest time to market is not the most desirable, because the manufacturing start-up is highly influenced by the quality of the product development outcome. Product and process conformance and availability of capacities have to have a minimum level and have the potential to be the foundation of a quick manufacturing start-up to high production volumes and a high quality. Rather than just a short time to market, the shortest time to volume must be goal, which can only be accomplished with a certain level of series production readiness. Nothing is gained when production starts with an ill defined product or production process. But nevertheless, development tasks today are so complex that is illusive to develop flawless products and processes. Efficiency gains during manufacturing start-up and thereafter are mostly based on learning effects on an individual, group, and organizational level. Especially in the beginning of a new production process the experience gains are of high importance, because of learning rates are higher. To bring disturbances into the learning process when learning rates are high has an enormous effect on the efficiency evolution of the production process. Because of that we modeled the handling of changes induced by discovered engineering changes andtested two different ramp-up policies. In our model setup the fast ramp policy was cleary in favour, and a next step is to provide policies for a fast ramp-up depending on process and product conformance at the SOP. Companies usally track the number of changes during product development and observe an increase in changes at the end of the development process. Such an incease of changes late in the process can be avoided with methods that support an early problem solving. Simultaneous engineering is one of these methods. The number of changes late in the development process is an indicator of how high product and process conformace are. A high number suggest a lower level of conformace and warn that there a more changes to come during the manufacturing start-up. If automobile manufacturers can estimate their conformance level we will provide policies of how to manage the manufacturing start-up.

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