Interdependencies of product development decisions and the production ramp-up

Jan Juerging* **and Peter M. Milling****

* phone: +49 621 181 1750; juerging@is.bwl.uni-mannheim.de
** phone: +49 621 181 1577; pmilling@is.bwl.uni-mannheim.de
*,** Industrieseminar, Mannheim University, D-68031 Mannheim, Germany
facsimile: +49 621 181 1579; http://is.bwl.uni-mannheim.de

Abstract:

Many companies, especially in high tech industries, are facing shrinking product lifecycles and increasingly complex production and product technologies. Selling of many goods including semiconductors, disk-drives and telecommunications products has shrunk to a time span of less than a year. These market dynamics 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 production ramp-up will be defined as the time span equal to the difference between 'time- to-market' and' time- to- volume'. A major goal of innovators 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 production ramp-up.

Keywords: *Production ramp-up, product development, change management*

Introduction

The scope and breadth of technological knowledge experience exponential growth. The resulting progress has a direct link to the competition between companies that are selling products in the same technological area: Agile companies try to push technological progress turning the gained insight into new or improved products in order to be more competitive and, at least for a certain time, try to earn extra profits from a monopolistic position (Schumpeter, 1947). As soon as the innovation is established in the market, other companies will imitate the innovation and counterbalance the competitive advantage. To regain these advantages, the search for new innovations must be recommenced.

Empirical survey results show that this spiral of innovation has accelerated over the last 20 years and the product life cycle has been dramatically shortened (Bullinger, 1990). The results imply fundamental changes for the competition; the ability to turn new technologies quickly into sellable products determines the success or failure of a company. This is true for the technological leader as well as the follower, since the follower cannot afford to lose the technological contact. Thus, development speed becomes a competitive factor (Stalk and Hout, 1990, Rosenthal, 1992).

For example, many rapidly innovating Japanese companies have taken advantage of the spiral of innovation and a lot of the Japanese concepts have been transferred successfully to other countries (Smith and Reinertsen, 1991). The duration from the starting point of development until the starting point of production is being continuously reduced. The start of production (SOP) is often falsely regarded as the end of the innovation process. In reality, the diffusion of an innovation should be measured to the length of time that a stable and satisfactory level of production has been reached after the introduction of new products or processes. This time range is termed the "time-to-volume" as can be seen in figure 1.

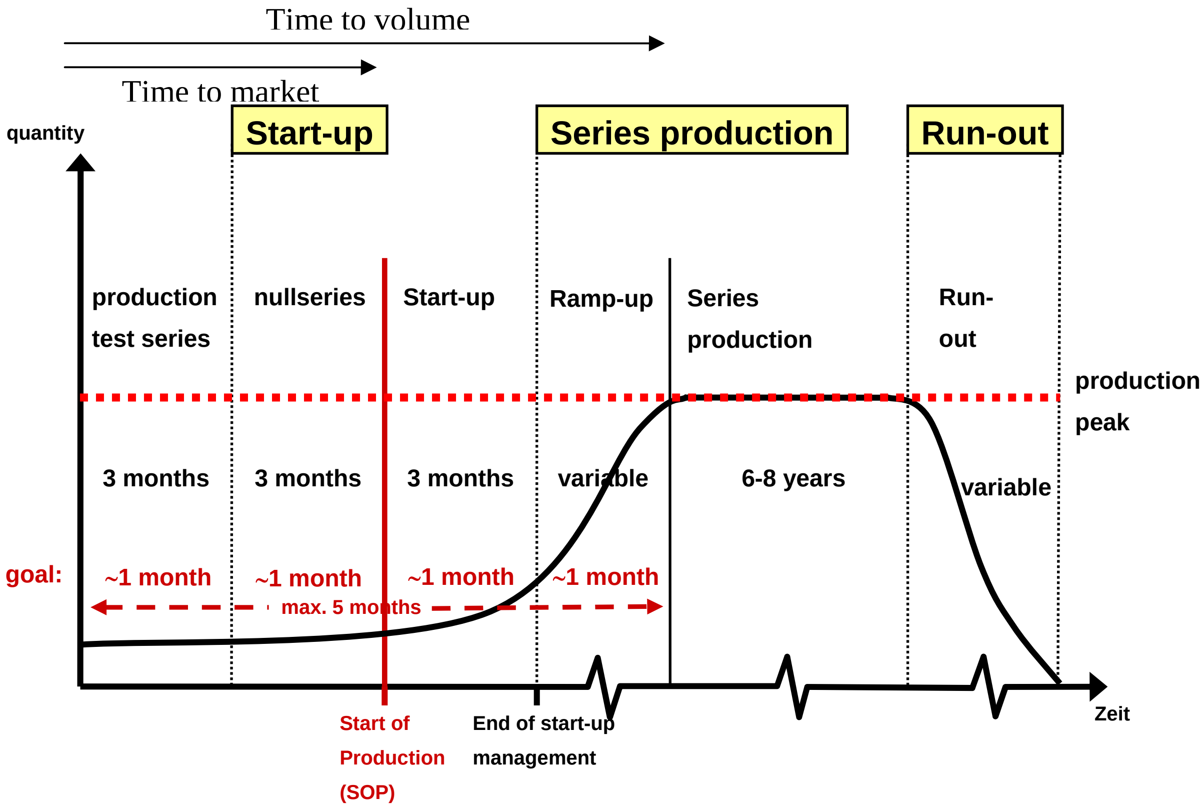

Figure 1 : phases of the production processes in the automobile industrie

Literature review

This paper and the developed system dynamics model analyse the interdependencies between decisions made during product development and the following production ramp-up, which has been identified as an important blank space on the map of product development research (Krishnan and Ulrich, 2001). 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 production ramp-up.

Several researchers have built system dynamics models of product development, with landmarks established by Roberts, Cooper and Ford. These landmarks include a project model which investigated the management of R&D projects (Roberts, 1964); the construction and use of large system dynamics models by Pugh-Roberts Associates of large scale shipbuilding operations for claims settlement (Cooper, 1980); and a model and a subsequent elaboration on the impacts of rework in projects on cycle time (Cooper, 1993; Cooper and Kleinschmidt, 1994).

Richardson and Pugh developed, and explained in detail, a model focusing upon the management of single R&D projects and observed the rework process to analyze resource effectiveness (1981). Abdel-Hamid and Madnick (1989) modeled software development to better understand project management in light of cost overruns, late deliveries, and user dissatisfaction. Homer *et al* (1993) modeled project process structure explicitly by introducing "gate functions" to describe the constraints on work progress imposed by both preceding phases and the work within phases. Ford (1995) and Ford and Sterman (1998) introduced modeling multiple project phases and the availability of work within each phase and in downstream phases. A distinction between rework cycles and voluntarily performed iterations in order to improve work quality has also been made. Repenning (2000) has been working on the resource allocation in multi- project environments. Lyneis *et al* (2001) engaged the strategic management of projects and evaluated the system dynamics capabilities in this field with case studies.

The existing system dynamics literature has a rich history of modeling development projects. All these models contribute to the description and documentation of the tight linkage between development resources, resource management, and project performance. Many of these structures have been tested and applied adequately and can be used as building blocks in the current work. The work structure used by Ford (1995) will also be the basis for the product development module used below in the developed model.

Production ramp-up and its economic impact

Time-consuming production ramp-ups 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 question is where are the problems coming from? According to a study "Fast Ramp-Up" undertaken in Germany in 2002 four main deficits in production ramp-up have been identified (Kuhn *et al.*, 2002):

- There is insufficient knowledge about the inter-functional project progress.
- With the current insight it is not possible to analyze past problems according to their impact on the entire project or their roots.
- Problems or disturbances are recognized only after they occurred.
- Actions taken to solve problems are only based on employees experiences.

Right know it is not completely possible, according to the surveyed companies, to solve problems or encounter disturbances in advance by a more intense or sophisticated planning. Methods and tools are required that take proactive actions to avoid these problems. However, developing these tools requires a deep understanding of the causal relationships occurring within the time to volume. The most recent ramp-up literature shows that a holistic approach on the interconnected processes involved has not been developed enough. Typically, reactive approaches from the project management are chosen to encounter problems (Fischer and Dangelmaier, 2000, Kuhn, 2002, Benedetto, 1999).

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 is at this time 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 ramp-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.

In analyzing the ramp-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 ramp-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 ramp-up.

Theoretically, a factor of 1 would be possible. In classifying a new product development project according to its parameters influencing the required time to volume, five factors are relevant:

- Degree of innovation (F_I): On the product side it can be a new, variant or advancement development and on the process side there are the options to manufacture with existing or new production processes.

- Degree of overlap (F_O): A common practice in product development is a concurrent execution of tasks in order to speed up development. This concurrency factor comprises working with preliminary information, which induces uncertainty in the project, and counteracting this effect a more intense communication between departments.
- Product complexity (F_C): Out of how many parts is the product assembled and how many different manufacturing processes are involved.
- Variant (F_V): The number and the complexity of the variants.
- Process standardization (F_{PS}): The ramp-up can be done on standard machines or product specific ones.

In the model all product specific factors can range from 0 to 1 where 1 indicates the highest level of difficulty.

Monitoring the development process via the series-production readiness

Controlling a goal-oriented innovation process is necessary to define the desired goal. At the end, 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 these three dimensions (Kotha and Orne, 1989), whereas the organizational scope is used for the third dimension. Here, only single development projects are of interest and organizational changes have a rather long term character. The manufacturing capacity, only important for the production ramp-up, is built up and disengaged from other tasks. 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). It is not only the goal that counts, but also the path that is taken in the development cube is of importance, shown in Figure 2.

All dimensions have different goals and perspectives towards the product and the conflicts during the innovation process can be anticipated. The functional areas have different priorities in the timely progress of the innovation process.

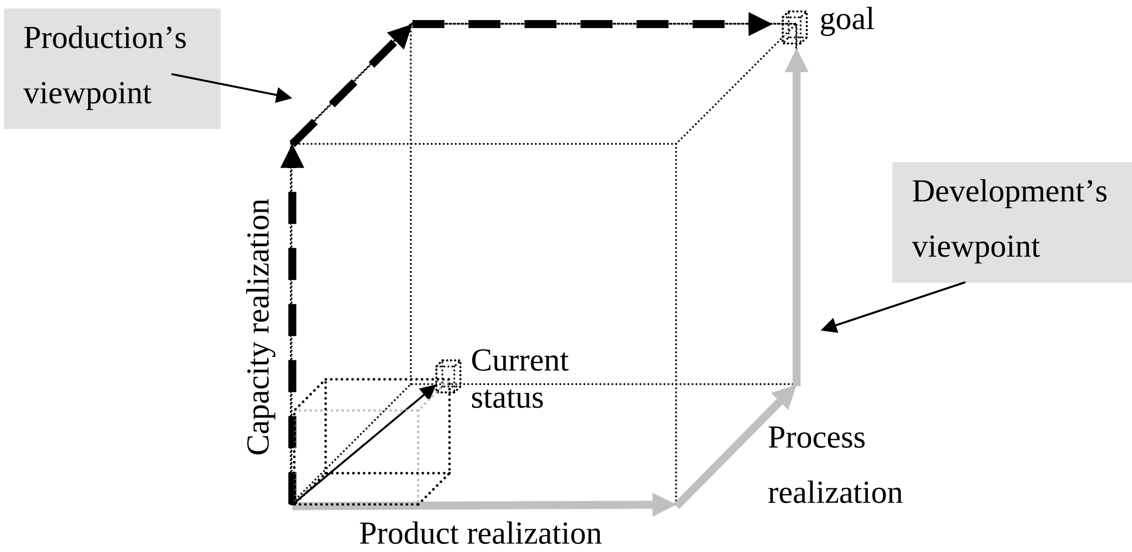

Figure 2: Dimensions of the development progress

Development typically sees the innovation process path differently than production members. Production members have a look at what machines are available and what manufacturing processes are possible. According to that, they can determine if a product can be developed. The development engineering creates the product first and then hands it over to production, where the needed processes are developed and the capacities for production are built up. Neither way is optimal and an aspired development path would progress closely to the cube's diagonal, which, for example, is supported by the concurrent engineering and inter-functional teams. Continuously monitoring this series production readiness also gives notice to take certain actions to bring the development project back on track.

Modeling product development and production ramp-up

The System Dynamics model consists out of four modules that are interconnected. All the work is done in the work-model as it is shown in Figure 3, which is related to the work of Ford and Sterman (1998). A new product development (NPD) project consists of three phases: the product development phase, process development phase, and the production ramp-up phase. Each phase has the generic structure shown in the figure and progress in each phase determines how much work is available in the dependent phases. Consequently, the phases can be simulated in a strict consecutive order, or following the nature of simultaneous engineering, can be performed in parallel with different degrees of overlap.

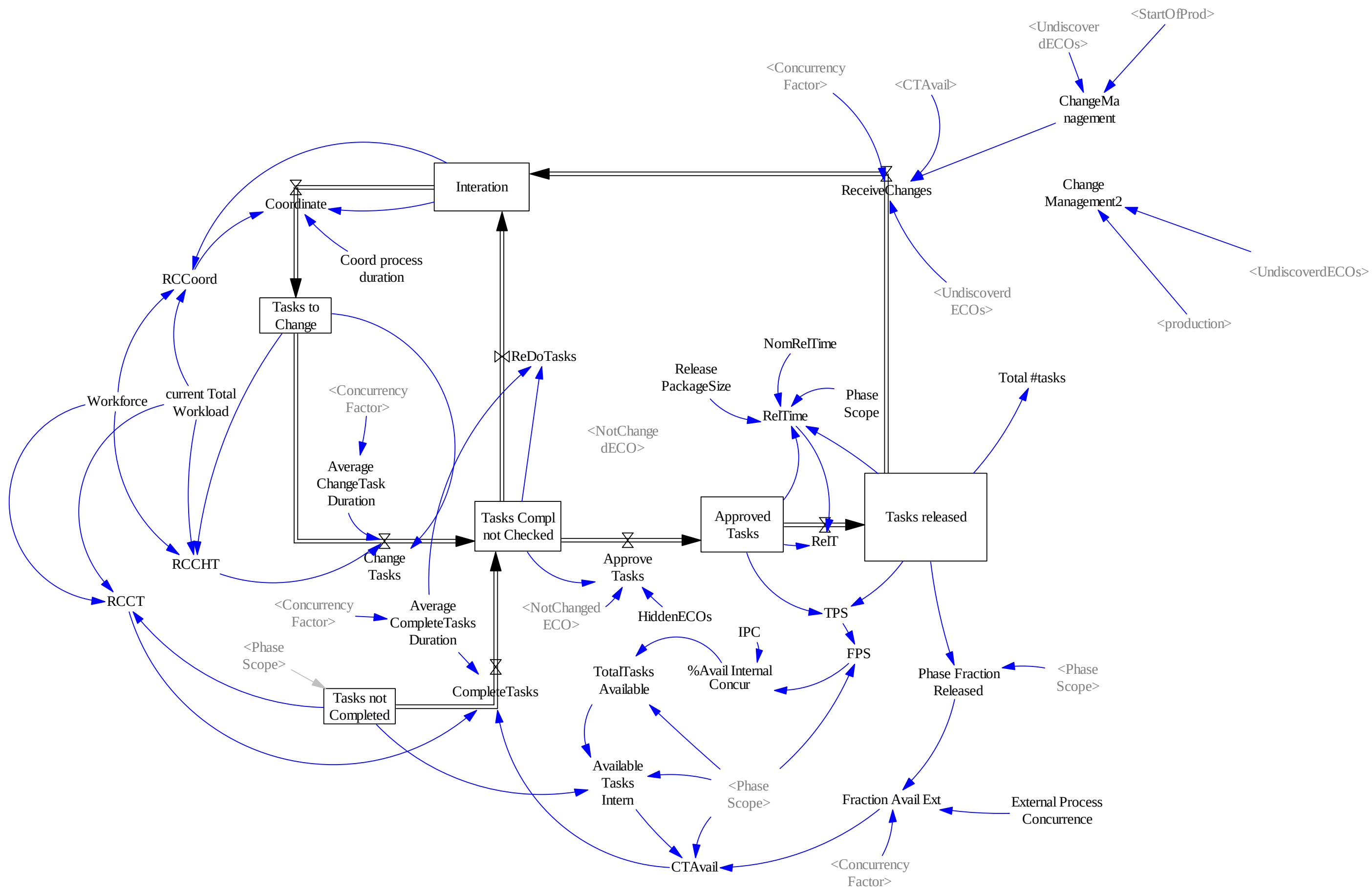

Figure 3: work module

Performing tasks in parallel shortens lead times at first glance. However, more mistakes are also generated because downstream phases begin work upon preliminary information. When already released tasks have to be changed in NPD project, these changes in tasks are called engineering change orders (ECOs). The development of ECOs is modeled in the ECO module, which can be seen in Figure 4.

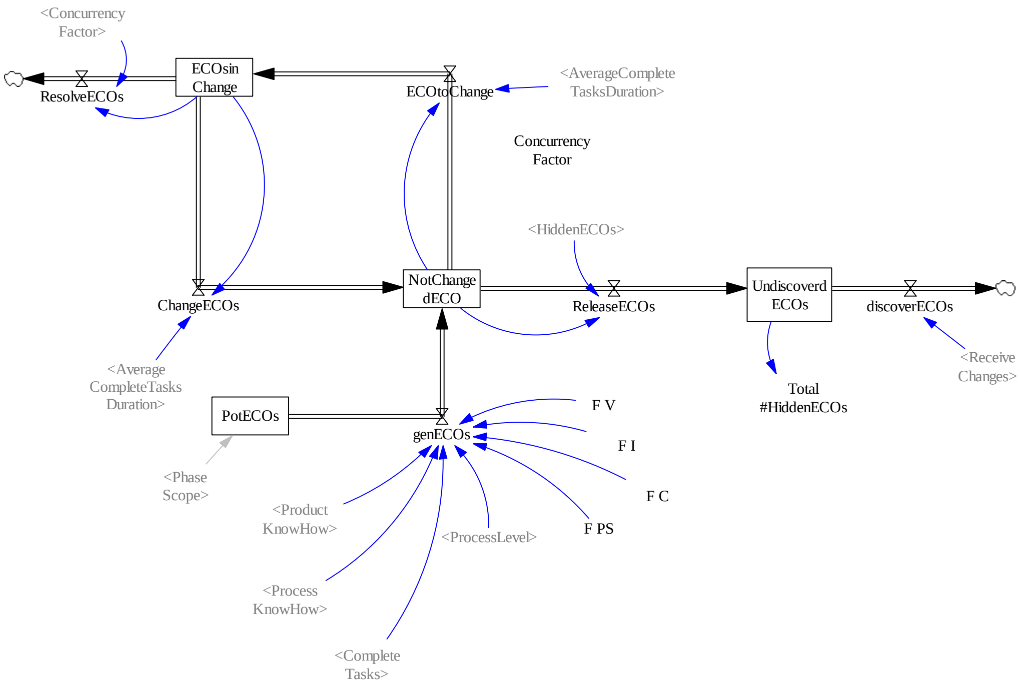

Figure 4: Generation of ECOs (Engineering Change Orders)

As previously mentioned, controlling the project progress is very important and in the series-production readiness a valuable measurement is developed. It is modeled in Figure 5, where you can also see how the Production ramp-up is modeled.

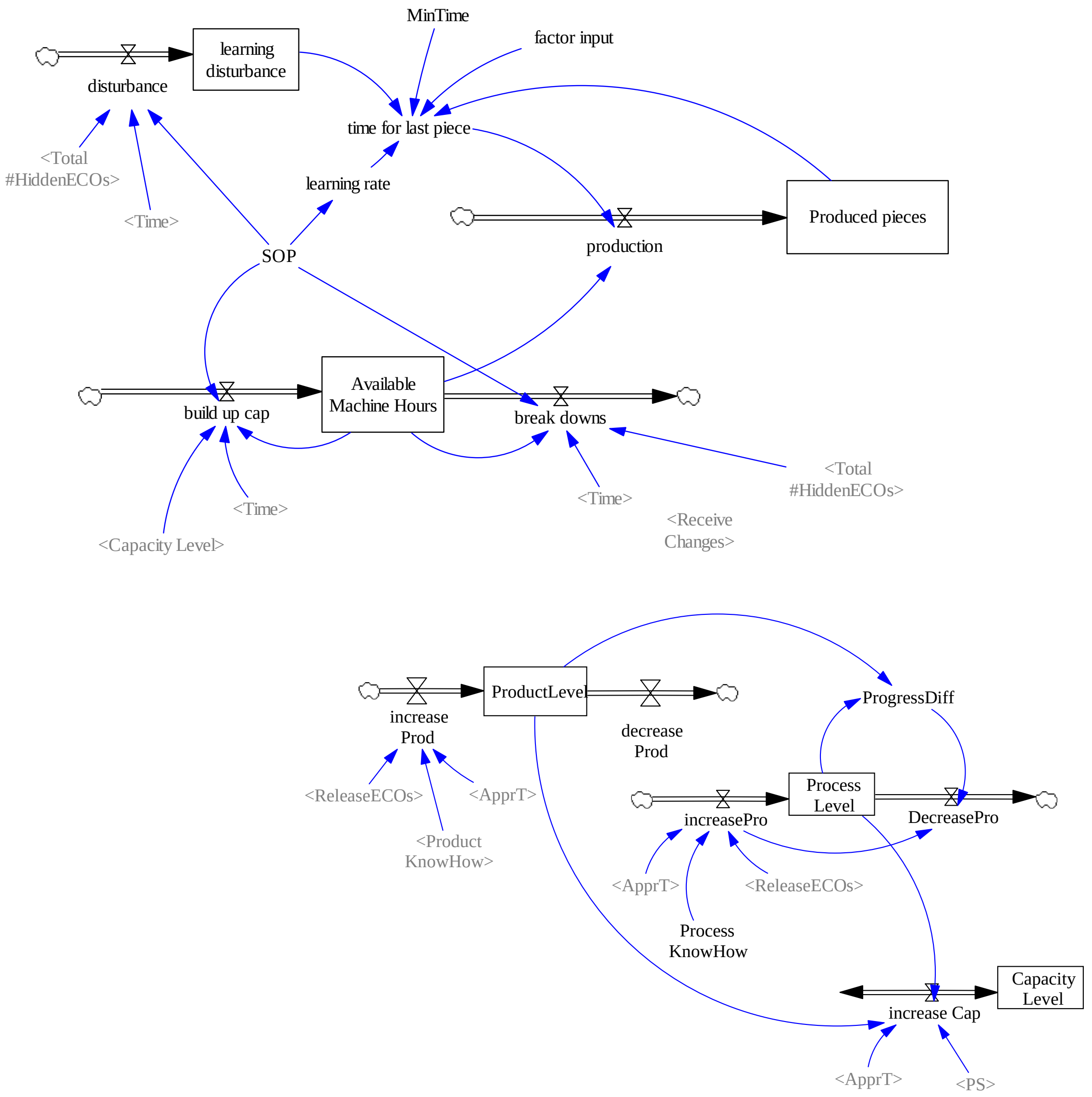

Figure 5: Series-production readiness module and production ramp-up

The following Figure 6 shows the simulations result for four different scenarios, which differ concerning the degree of overlap (F_O) between the phases and innovativeness (F_I) of the product.

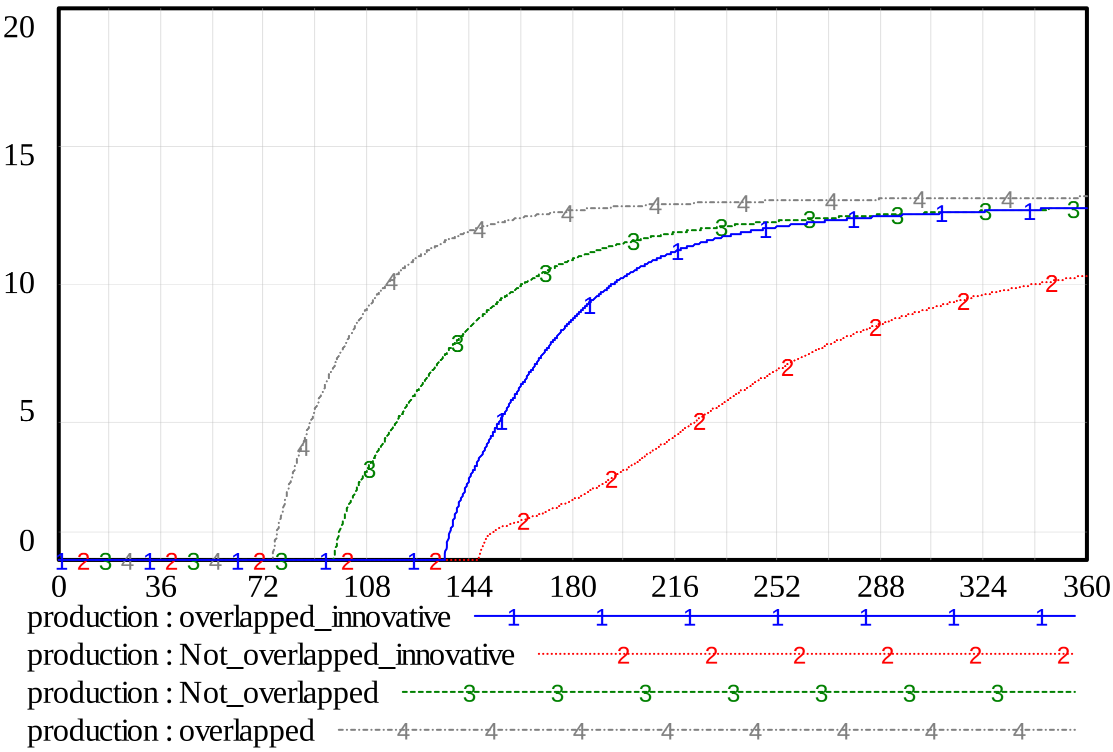

Figure 6: production ramp-up in four scenarios

Both factors, especially the innovative factor, obviously have a great effect on the ramp-up curve. Time to market is influenced by the development time and time to volume by the sum of ramp-up performance and time to market. Overlapping the phases, which initially establishes communication among the phases, improves the ramp-up. The improvement is due to early problem solving, which is supported by concurrent engineering and the parallel execution of tasks. The factor of innovation plays a very important role, which is supported by practitioners who are very cautious with high innovative development efforts.

Figure 7 shows the development of hidden ECOs. In all four scenarios not all ECOs are discovered at the SOP. But clearly the overlapped ones build up a lot less undiscovered ECOs and production can start more smoothly because of less disturbances and changes made to the product or production processes.

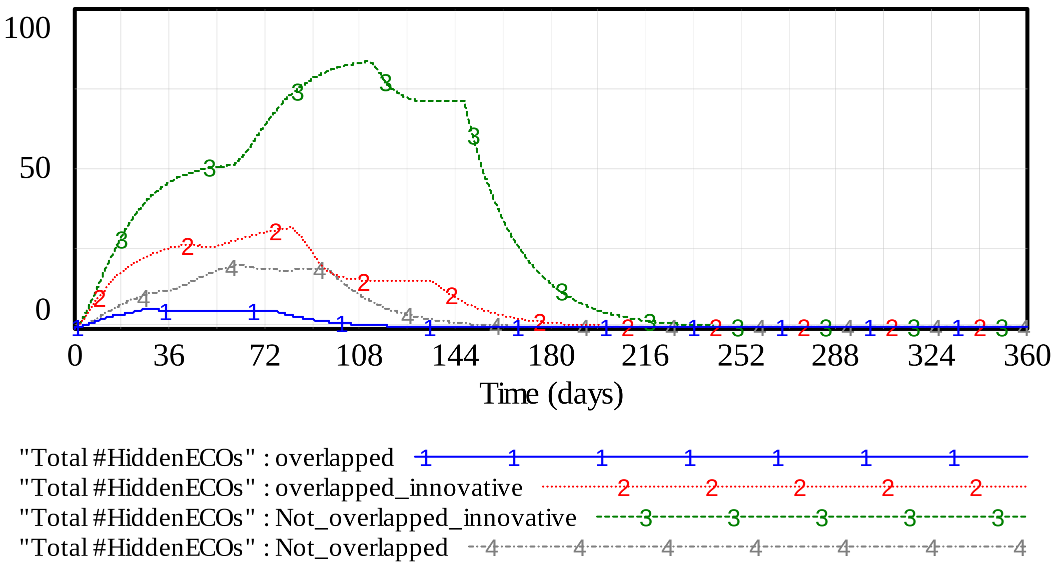

Figure 7: Development of ECOs

It is important to note that every hidden ECO will be revealed as soon production has started and from this holistic viewpoint these ECOs can be regarded as another quality factor for the innovation process. These changes are very important because production depends on two main factors: machines and workers. For the workers' effectiveness the model incorporates a learning curve which starts again at a slightly higher level each time an ECO changes the production process. The availability of machine hours depends on their maintenance and the set-up times. The development of these two factors also follows a learning curve.

These improvements by overlapping the phases are very noticeable, so that the solution for a short ramp-up seems to be found in a maximum degree of overlap. But surprisingly, simulation shows a different systems behavior.

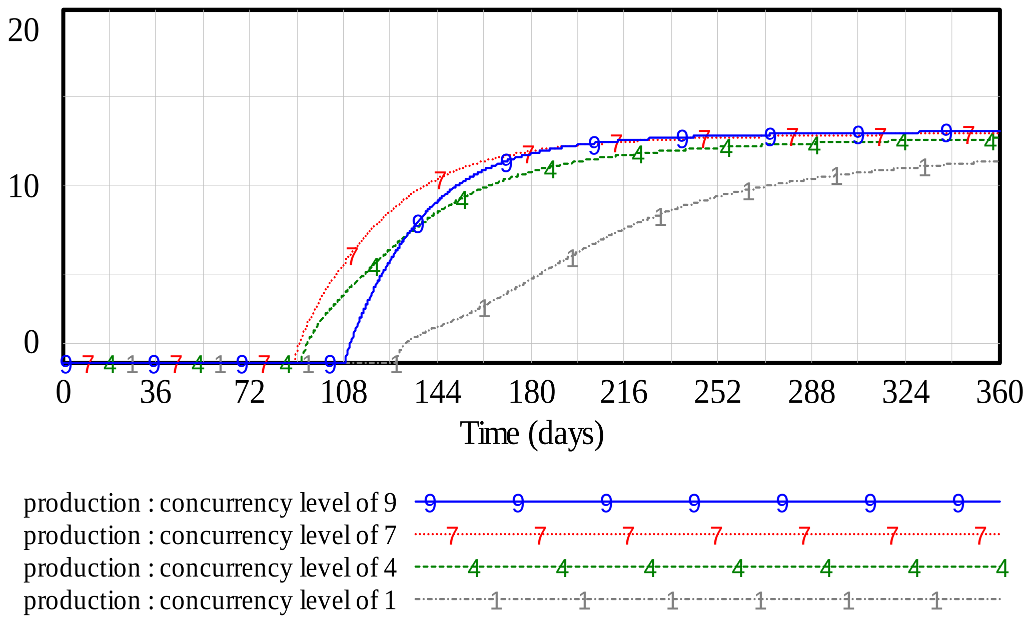

Figure 8: Fixed innovation factor at different overlapping strategies

The optimal degree of overlap is located somewhere in the middle at an overlap level of 7. The degree of overlap can vary on a scale from 1 to 10. A factor of 1 would simulate a strictly consecutive arrangement of the project phases. An upstream phase has to be finished completely until downstream phases can begin their work. A factor of 10 models the project with the maximum degree of overlap possible. The effect that the maximum overlap is not favorable stems from several causes. On one hand, there are congestion effects when all the work is executed in parallel. On the other, downstream phases commence their work with very preliminary information, which results in a lot of rework. The analysis of the series-production readiness development gives insight in identifying the causes for this behavior. The run number 2 in Figure 8 had the most simultaneous development of the product, process and capacity dimension. In the three dimensional cube from Figure 2 it would be the innovation path close to the diagonal. Deviating from this path is penalized in other runs with more ECOs and a longer time to volume and all the economic hazards coming along with that.

Different ramp-up policies concerning the handling of ECOs

During the transition of the product from the R&D laboratories into commercial production, a company finds itself in a difficult situation. On one hand, it wants to begin accumulating knowledge with the newly introduced process in an attempt to overcome the numerous discrepancies between how the process should be operated – as outlined in the process specifications - and how the process is actually operated in the production facility.

The reduction of these discrepancies, a process referred to as waste reduction (Zangwill and Karitor, 1998) and here modeled as learning, will lead to improvements in production efficiency. On the other hand, the company refines the current production process because of discovered ECOs, which is refered to as process or product change. Implementing ECOs is beneficial in the long run, but during the production ramp-up it means disruptions in the company's learning process: routines that were just developed become outdated. This is not a process of 'delearning.' Rather, that built up knowledge becomes partly redundant. The proper timing of the ECO implementation concerning the production ramp-up is questionable.

Two different ramp-up policies will be modeled. First, a so called copy exactly policy is presented. This ramp-up policy, which is copying the production processes as they were applied in production tests during product development, was introduced by INTEL for their ramp of new production facilities. The policy has since then been augmented to the company's fundamental ramp strategy (McDonald, 1998). During the ramp-up not a single change is made to the product or production process. It has been shown that it can be optimal to delay a process change (Carrillo and Gaimon, 2000). Our model differs from Carillo and Gaimon's work as it explicitly captures the details of how change leads to disruption. In the Carillo and Gaimon work, change causes a short term capacity reduction, but it does not really affect the learning curve. Our model can take a more detailed perspective as we model process changes and its effect on the learning curve.

Other companies in the semiconductor industry are aware of copy-exactly, however they favor a direct implementation of ECOs and accept the resulting process changes during the ramp-up, which will be called the process change policy. Moreover, several suppliers and industry observers argue that shorter product lifecycles make copy-exactly an outdated ramp strategy. But what is the influence of the choice between copy-exactly, or a process change policy?

These two different ramp-up strategies were modeled. In the process change policy all detected ECOs were implemented as soon as possible. The copy exactly policy lets the production ramp-up to a satisfactory level. ECOs were detected during this ramp-up, but they are collected and implemented in batches. In the Figure 9 results for these two policies are shown. The concurrency level is a constant for all runs, whereas F_I is altered between 0.1 and 0.6.

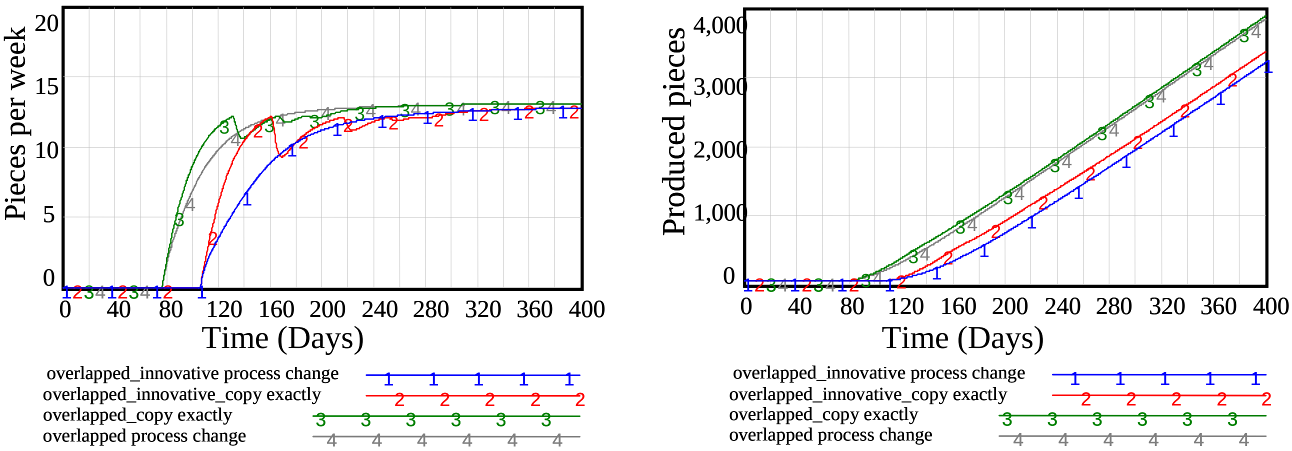

Figure 9: Two different ramp-up strategies

The runs numbered 2 and 3 are following the copy exactly policy. Obviously they ramp-up very quickly, but then the production rate oscillates because of the implemented ECOs. In the right side of the figure the overall production or sales volume is pictured. For the runs 3 and 4, the ramp–up strategy does not have a noticeable impact. This is because there were not many ECOs left undiscovered at the SOP. However, with an innovative product, the ramp-up strategy does make a difference. Especially during the ramp-up, run 2 performs a lot better than run 1. This is also the crucial time, because the new product is introduced and announced at the market and the demand and prices are high.

Conclusion

The level of concurrency in a development project directly influences the series production readiness. The shortest time to market is not the most desirable, because the production ramp-up is highly influenced. Rather, the shortest time to volume must be goal, which can only be accomplished with a moderate concurrency factor and a moderate time to market. There is not one optimal concurrency factor for all projects because it could be shown that the optimal concurrency factor varies with the product development properties. Nothing is gained when production starts with an ill defined product or production process. With the series production readiness the status of the project can be monitored and actions taken, so that proper development results can be handed over to production. But nevertheless, development tasks today are so complex that is illusive to develop flawless products and processes. The handling of changes induced by discovered ECOs has been tested with two different ramp-up policies. The more innovative the product is, the more a copy exactly policy should favored.

References

Abdel-Hamid TK, Madnick S. 1989. Software productivity: potential, actual, and perceived. *System Dynamics Review* **5**(2): 93–113.

Benedetto di, C.A. 1999. Identifying the key success factors in new product launch. *Journal of Product Innovation Management* **16**(6): 557–568.

Bullinger H-J. 1990. *IAO-Studie F&E heute - Industrielle Forschung und Entwicklung in der Bundesrepublik Deutschland*. München.

Bullinger H-J, Wasserloos G. 1990. Produktentwicklung braucht ein Just-in-Time-Management. *Office Management* **38**(1): 22–29.

Bungard W, Hoffmann K. 1995. *Innovationsmanangement in der Automobilindustrie*. Weinheim.

Carrillo J.E., Gaimon C. 2000. Improving Manufacturing Performance Through Process Change and Knowledge Creation. *Management Science* **46**(2): 265–288.

Cooper KG. 1980. Naval Ship Production: A claim settled and a framework built. *Interfaces* **10**(6): 20 - 36.

Cooper KG. 1993. The Rework Cycle: How Projects are Mismanaged. *Project Management Journal* **24**(1).

Cooper RG, Kleinschmidt EJ. 1994. Determinants of Timeliness in Product Development. *Journal of Product Innovation Management* **11**: 381-396.

Dierdonck Rv. 1990. The manufacturing/design interface. *R&D Management* **20**(3): 203–209.

Fischer W, Dangelmaier W. 2000. *Produkt- und Anlagenoptimierung*. Berlin Heidelberg.

Ford DN, Sterman JD. 1998. Dynamic Modeling of Product Development Processes. *System Dynamics Review* **14**(1): 31-68.

Hendricks KB, Singhal VR. 1997. Delays in new product introduction and the market value of the firm: the consequences of being late to the market. *Management Science* **43**(4): 324–341.

Homer J, Sterman J, Greenwood B, Perkola M. 1993. Delivery Time Reduction in Pulp and Paper Mill Construction Projects: A Dynamic Analysis of Alternatives. *Proceedings of the 1993 International System Dynamics Conference*. Cancun, Mexico.

Inness JG. 1995. *Erfolgreicher Produktwechsel*. Landsberg a. L.

Kotha S, Orne D. 1989. Generic Manufacturing Strategies: A Conceptual Synthesis. *Strategic Management Journal* **10**(2): 211–231.

Krishnan V, Ulrich KT. 2001. *Product Development Decisions: A Review of the Literature*, p. 1.

Kuhn A, Wiendahl H-P, Eversheim W, Schuh G. 2002. Fast Ramp-Up: Schneller Produktionsanlauf von Serienprodukten - Ergebnisbericht. *Praxiswissen* **54**.

Kuhn Aea. 2002. Fast Ramp-Up: Schneller Produktionsanlauf von Serienprodukten - Ergebnisbericht. *Praxiswissen* **54**.

Lyneis JM, Cooper KG, Els SA. 2001. Strategic management of complex projects: a case study using system dynamics. *System Dynamics Review* **17**(3): 237–260.

McDonald CJ. http://developer.intel.com/technology/itj/q41998/pdf/copyexactly.pdf. *The Evolution of Intel's Copy EXACTLY! Technology Transfer Method*. available [03.03.2005].

Repenning NP. 2000. A dynamic model of resource allocation in multi-project research and development systems. *System Dynamics Review* **16**(3): 173–212.

Richardson GP, Pugh AL. 1981. *Introduction to System Dynamics Modeling with Dynamo*. MIT Press: Cambridge.

Roberts EB. 1964. *The dynamics of research and development*. Harper Row: New York.

Rosenthal SR. 1992. *Effective product design and development: how to cut lead time and increase customer satisfaction*. New York.

Schumpeter JA. 1947. The Creative Response in Ecomomic History. *The Journal of Economic History* **7**(Nov.): 149–159.

Smith PG, Reinertsen DG. 1991. *Developing products in half the time*. Van Nostrand Reinhold: New York, NY.

Stalk G, Hout TM. 1990. *Competing against Time*. New York.

Wright TP. 1936. Factors Affecting the Costs of Airplanes. *Journal of Aeronautical Sciences* **3**(4): 122–128.

Zangwill WI, Karitor P. 1998. Toward a theory of continuous improvement and the learning curve. *Management Science* **44**(7): 910–920.