Engineering Change Orders influencing manufacturing start-ups in the automobile industry

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Abstract:

Many companies, especially in high tech industries, are facing shrinking product lifecycles and increasingly complex production and product technologies. 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' When production is started at a point of low series production readiness a lot of engineering changes are likely to be detected during the ramp-up phase. This paper will compare two policies for the management of changes during production ramp-up.

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

Introduction

A specialty of German car manufacturers is the very intense customer focus, by offering very individualized cars, which results in high variability of each product and wide product range. Shorter product life cycles and a broader range of offered car models lead to an increase of manufacturing start-ups in quantity, but also in complexity. In the light of shortening lifecycles successful manufacturing start-ups, from an economic point of view, have become a crucial factor. Lost sales at the beginning of a product's lifecycle, because of a late introduction or a low incline of the start-up curve, cannot be compensated later. Product profit margins are highly influenced in the early market phase, because demand exceeds manufacturing capacity and customers are less price-sensitive. The economic consequences of manufacturing start-ups are immense and experts estimate that this early market phase can be responsible for up to 5 % of a models profit margin (Kuhn *et al.*, 2002). Despite its importance manufactures do not achieve their start-up goals, because they have either neglected the topic or have not gained sufficient insights in the underlying factors that influence manufacturing start-up performance. The Boston Consulting Group figured in a survey in 2003 that 47 percent of the companies undertaking start-up activities do not achieve any of their self set start-up goals. 20 percent achieve their technical goals concerning quantity and quality und only one third of the companies are managing to meet their technical and economic goals.

Not only that the companies do not seem to be able to cope with manufacturing start-up despite its immense importance, but further more this field is rarely touched in academic treatises. In a recent literature review on product development Krishnan and Ulrich identified the manufacturing start-up as an important blank space on the map of product development research (Krishnan and Ulrich, 2001a). The few available publications mostly come from the engineering field and focus on a detail of the start-up phase. Publications concerning the management of the start-up phase are rare and a holistic approach is completely missing. The low number of publications results partly due to an assigning problem. From an engineering point of view product development is concerned with developing products that meet the customer's expectations and are easy to fabricate. Design guidelines like the VDI 2221 represent the iterative steps in the development process but never mention manufacturing start-ups and how to take it into account. Operations and innovation management has the manufacturing start-up not as a focus as well. On the product development side it is concerned with the factors that are responsible for a product's success or failure and on the fabrication side of a product subject of examination is the steady state production following the start-up. The manufacturing start-up has been neglected by academia because it is an interface between two academic fields, neither field feeling responsible, and it must be promoted until they seamlessly merge into one another. Further research with a holistic view that identifies the underlying causes and effects influencing start-up performance seems to be the most reasonable next step. This is the target of the here presented research.

An area of research touching this topic is the learning curve theory. 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, 1936a, introduced the 'aircraft learning curve' in an attempt to predict the cost of manufacturing as a function of accumulated production volume. Conway and Schultz, 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, 1970, argues that problems during manufacturing start-ups 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. It is, however, questionable whether these factors already provide enough knowledge to enable the study of manufacturing start-ups and the analysis of changes in performance during the start-up phase, because it is just an enumeration of the factors and an analysis of their relationships is missing.

Literature review

This paper and the developed system dynamics model analyze the influence of engineering change orders on the performance during the manufacturing start-up, which has been identified as an important blank space on the map of product development research (Krishnan and Ulrich, 2001b). The Manufacturing start-up is an interface between product development and production. Taken separately, the field of product development itself, and in connection with system dynamics, has received a remarkable attention. The manufacturing start-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, Pugh, 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 Richardson and Pugh, 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 manufacturing start-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, 1936b). 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 employee's experiences.

Right now 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 *et al.*, 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.

Modeling product development and production ramp-up

We put the factors that have an influence on the manufacturing start-up into a framework that builds the foundation of our System-Dynamics-Model. Some factors have their origin before the start of production, but still have an enormous influence on the manufacturing start-up performance. These factors are the newness of the production and the newness of the production system. Many journal articles (e.g. Sullivan, 1987; Wood and Coughlan, 1988) are concerned with the negative effects of incomplete development and, especially, with the negative effects of engineering change. Incomplete development is expressed in our model by the variables product- and process conformance and it represents in how far does the product meet the customer's requirements and in how far do the manufacturing processes meet established standards.

The lower these two conformance variables are at the start of production the more likely is the need for engineering change orders. A product change will also have an effect on the underlying production processes. We identified four main sources of disturbances during the manufacturing start-up, which are: (1) materials supply (e.g. lack of materials, quality of materials, and status of materials); (2) production technology (e.g. breakdowns, minor stoppages); (3) personnel (e.g. individual learning, level of skills); (4) product concept (e.g. engineering changes).

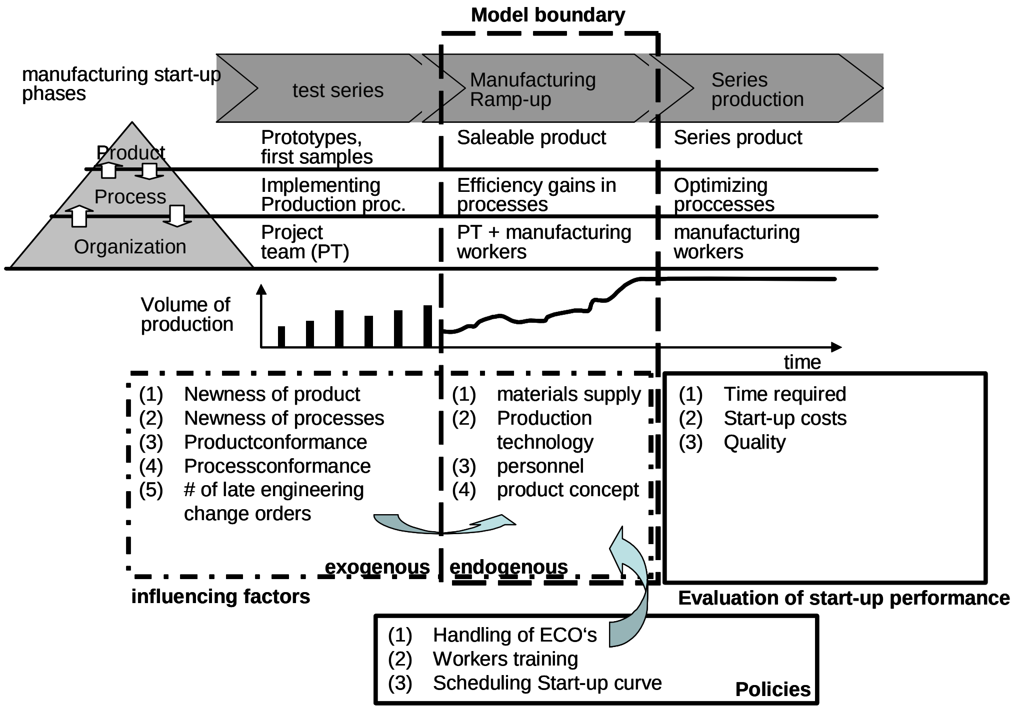
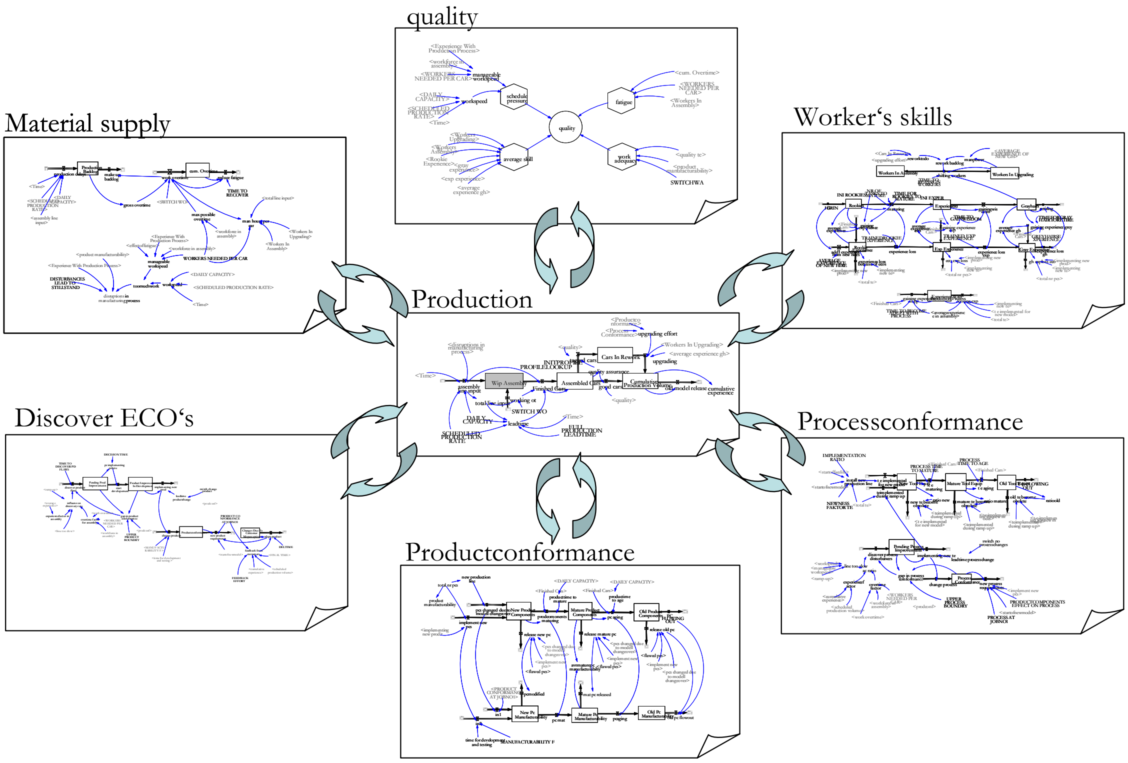


Figure 1: Phases of a manufacturing start-up with model boundary and influencing factors

During the manufacturing start-up the management can influence the start-up performance with different policies, whereas their impact on the start-up performance can be evaluated with the here developed System-dynamics-model. Engineering change orders during the start-up period can have a devastating effect, because the production system is not robust yet and working on the edge of its capabilities. The effect of engineering change orders is analyzed and implementing policies can be derived depending on the exogenous influencing factors.

The System Dynamics model consists out of seven modules that are interconnected. Production takes place in the production module. Following the learning curve theory experience is gathered with every newly build car in the production module. This is driving the other modules, the worker become familiar with the new production process.



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 referred 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. The exogenous influencing factors we used in our simulation were set to represent an average ramp-up in the automobile industry. The newness of product and process technology can be represented in a matrix, which is shown in Figure 2.

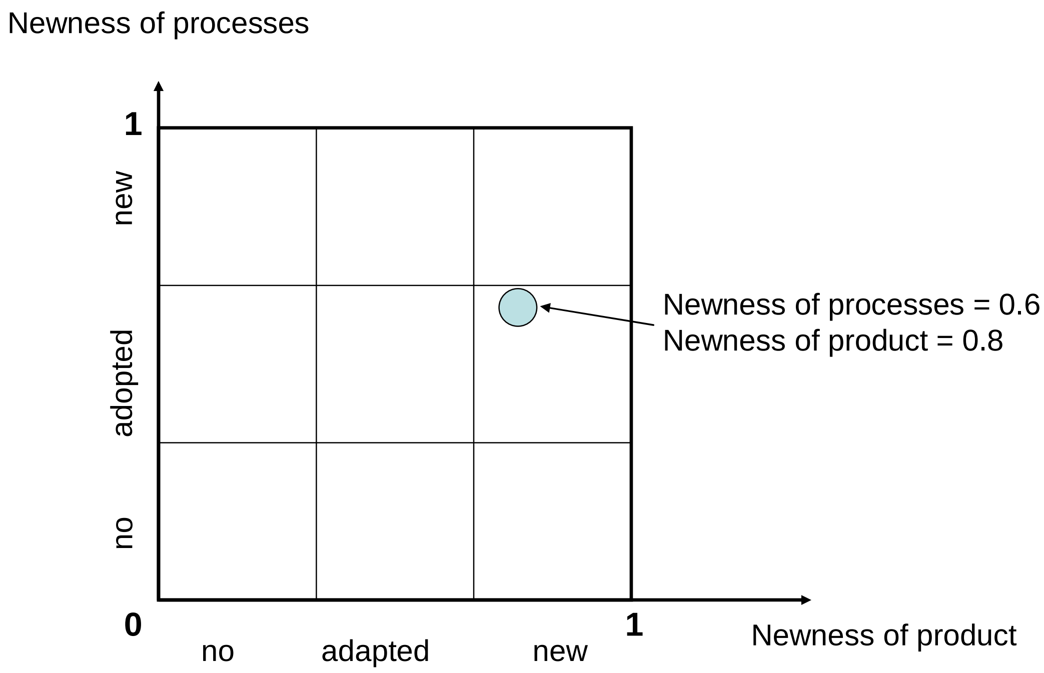


Figure 2: Setting the exogenous influencing factors

With these settings we ran three different simulations at different levels for the series production readiness (the level of 85, 95, and 98 percent). The series production readiness comprises the product and process conformance, shown in Figure 1. It is a percentage in how far the product and processes meet established standards. The series production readiness at the start of production has a direct effect on the number of engineering changes that come up during the ramp-up phase.

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? The result of two different ramp-up policies at different levels for the series production readiness are shown in Figure 3.

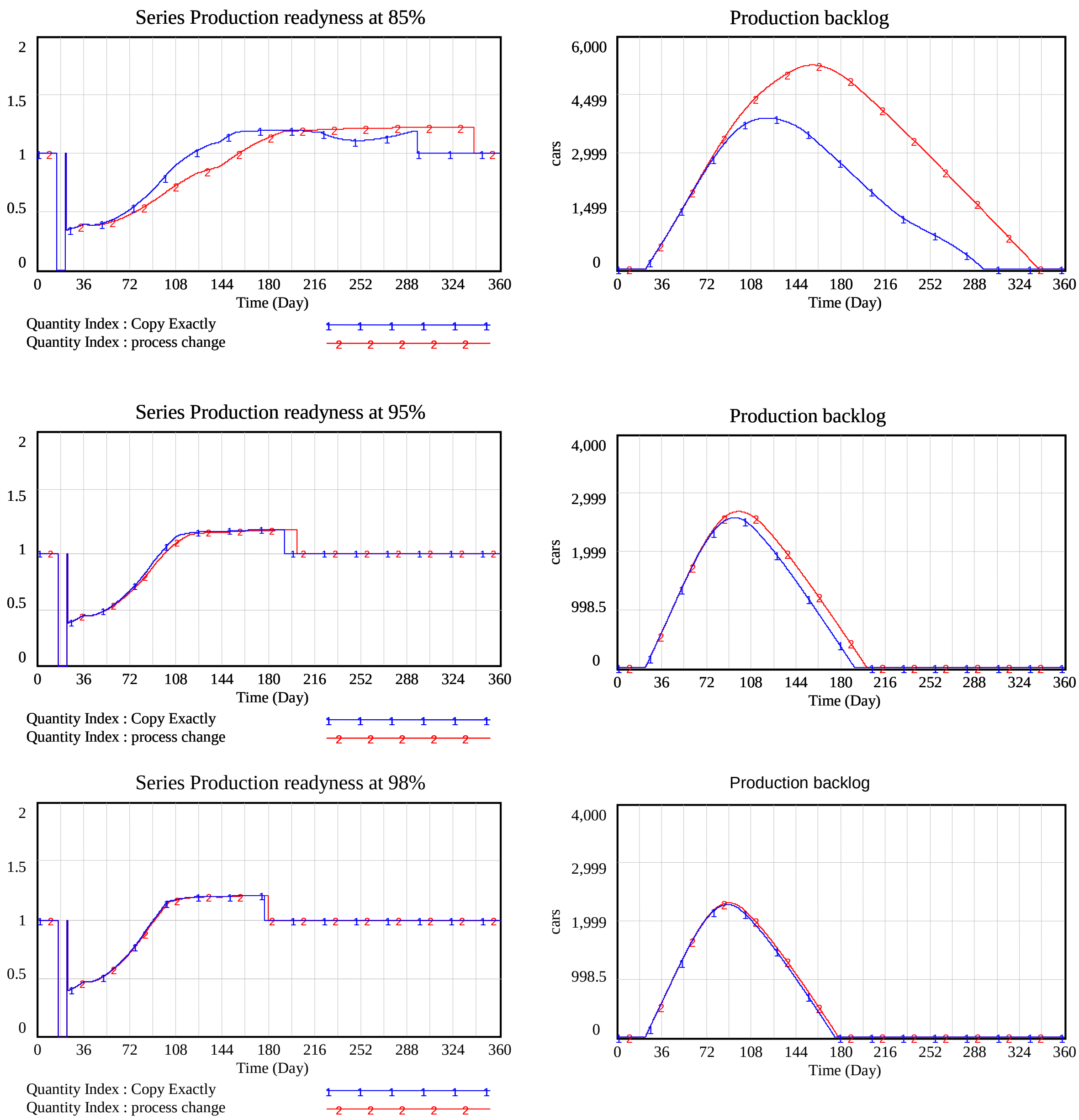


Figure 3: Simulation results

In our simulations runs the old model is still produced till day 15 and then the line is emptied. The start of production for the new car commences in our simulation on day 22. On the left of the figure we displayed the quantity index, a percentage in how far the scheduled production volume is accomplished. The index exceeds one in the case when a production backlog has to be worked off. The corresponding production backlog is shown in the right side of the figure. In each case the copy exactly strategy works better! It is also interesting to see the effect different degrees for the series production readiness have on the ramp-up performance. The higher the degree the quicker production reaches full capacity and the backlog is in the best case on its peak 2000 cars, at a daily production of 150 cars, and in the worst case it reaches over 5000 cars. This means a much higher number of late deliveries. The effect of late deliveries lies outside our model boundaries, but one can image that some customers will changes their choice and order at a manufacturer, who meet their promised delivery dates. The importance of a high series production readiness at the start of production becomes clear. Some companies rush their development projects in order to shorten their time to market. Just rushing the project will lead to a low series production readiness at the start of production and will increase the time to volume and nothing gained but a poor image when products are delivered late. Implementing the simultaneous engineering approach for the development has the effect of shortening development cycle time, but not implemented properly the development quality suffers. We encourage the implementation of simultaneous engineering, but one has to keep the development quality under control. Only if a company can shorten development time and simultaneously keep up or improve, the development quality the "time to market" and "time to volume" can be improved.

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