

Strategic Management of Production Systems – a Longitudinal Analysis on the Evolution of Models: Experiences from a Research Project

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Abstract

Between 1982 and 1999 the University of Stuttgart carried out an extensive interdisciplinary research project dealing with flexible production systems. Within this project the Department of Strategic Management developed several System Dynamics models in co-operation with various companies. The objective was to support strategic decision making in production management. The models were designed to prepare and to evaluate decisions considering the achievement of both long term profitability and sustainable competitive advantage foremost. The paper shows how the different System Dynamics models have been changed over the years. As they were all referring to the same basic issue it is thoroughly possible to compare them in a longitudinal analysis. This study on one hand concentrates on the development of modeling methods, i.e. by combining System Dynamics models with knowledge based tools, or by creating a modular modeling concept. On the other hand it focuses on aspects like model size and aggregation level. Another intention of the paper, however, will be to answer the question if and how the different kinds of models – e.g. in terms of model size and level of aggregation – had influenced decision making and its results. It will be discussed how and to which extent these model features had an impact on making either strategic or rather operative decisions in production systems.

Introduction

The turbulent, open change in the market place today is shaking the traditional foundations of successful business management. This can be seen in radical changes in the political, legal, socio-cultural and technological environment as well as in the field of competition. These changes inevitably result in serious consequences for the task environment of the referred companies and demand a great deal of flexibility. The field of industrial production is particularly affected by these developments.

Industrial production is undergoing fundamental and far-reaching changes as a result of the above mentioned development in the enterprises' environment. The requirements of the market place, based on the transformation of supply-driven into consumer-dominated markets find expression in lower prices combined with higher demands in product quality, short delivery times, a high variety of products and short product life cycles. The transition from

traditional mass production to today's mass customization is highlighting the paradigm shift taking place within industrial production (Zahn et al. 1998, Pine 1993).

In the past only little importance was attached to production as a source of competitive advantage. Since, as a response to the changes in the market requirements, flexibility and responsiveness as well as the ability to provide high quality products at low prices are increasingly considered critical success factors, managers are paying much more attention to their companies' production systems. For more than a decade management research and engineering science have targeted the flexibility of production systems as an adequate answer to the challenges arising from new market and performance demands. After all these years, however, these strategic objectives are still relevant, and, in the future, competitive advantage in manufacturing industries will depend more than ever on how a company is able to react to changes in market conditions (Zahn et al. 1998).

Strategic decision making in the production area

In the course of these developments, in recent years the way in which problems are approached in the production area within the manufacturing industry has gained increasing importance for strategic planning. In connection with this, the demand for a long term strategic flexibility of production systems is placed into the foreground. Therefore a company, when planning its production system, should not limit itself purely to investment decisions based on hard criteria and short term effects. It has become essential even in the field of production that strategic thinking and planning be considered much than before.

There are, however, considerable difficulties associated with the strategic decision making process within the planning of flexible production systems. Especially when evaluating investment projects with a high complexity, decision makers have to consider (Zahn et al. 1996)

- a high number of hard and soft decision criteria,
- the interdependencies within the production system and between production and other functional areas,
- high capital investments (in the sense of quasi irreversible commitments),
- time-consuming and costly implementation processes,
- long time horizons,
- the necessity of organizational changes and
- the impacts on the company's competitiveness.

System Dynamics models have a great potential helping to solve such problems. They have frequently proved invaluable in managing complex strategic problems, especially those in which decisions in production strategies needed to be made. Therefore it becomes obvious that System Dynamics models can contribute much to an improvement of decision-making processes in strategic planning in the production area.

A research project dealing with flexible production systems

For this reason, System Dynamics models form the basis of the instruments to support strategic production management discussed in this paper. These instruments were developed and perfected during extensive interdisciplinary research into flexible production systems

which was carried out at the University of Stuttgart. This project was supported by the Deutsche Forschungsgemeinschaft (DFG), began in 1982 and was completed in 1999. During the course of the project, the Department of Strategic Management developed several System Dynamics models in co-operation with various companies. The main objective of the models was to support strategic production management with special regard to both long term profitability of the systems and the achievement of sustainable competitive advantage. They have been developed to find a better understanding for these issues and to cope with them more effectively, with specific reference to long-term decisions, the lacking of objective assessment criteria and the high complexity of the problems.

During the study, more than a dozen System Dynamics simulation models were developed. The models were created at various intervals spread throughout the full course of the 17-year project. While the department co-operated with companies in different branches of industry, the main focus lay on the mechanical and electrical engineering industries as well as suppliers to the automobile industry. The study concentrated on small and medium sized businesses as well as on large conglomerates. However, since the individual projects usually focussed on specific business lines and their production systems, the size of the companies themselves only played a minor role in the creation and application of the models.

A large number of more theoretical and conceptual System Dynamics models were developed as a basis for research and to accompany the sometimes very extensive activities involved in the creation of models and their application in practice; while these were of great importance for the success of the projects, they cannot all be taken into account in this paper.

Basic structures of System Dynamics production models

The starting point of the research was the development of a concept to deal with the flexibility issues in the field of production (Zahn et al. 1987, Foschiani 1989). Within this concept, flexibility is reflected by various product performance criteria, such as price, delivery time, and quality. These criteria are influenced by several parameters, such as production equipment, human resources, and logistics.

Based on these considerations, figure 1 illustrates the fundamental feedback mechanisms of a production system (Zahn et al. 1987, Foschiani 1989, Zahn/Greschner 1993, Foschiani 1995). The given structures are based on the hypothesis that the firm's need for flexibility arises from the gap between product performance supplied by the production system and the demand (resp. the expected demand) within the market. This supply-demand gap - estimated in terms of delivery time, price and quality - forces the firm to invest in order to adjust its production and to reduce the gap. These investments cause changes in the parameters of the production systems, e.g. the physical resources, the human resources and the logistics. As a result of the changed parameters, the firm's supply will be improved and the demand-supply gap will be reduced. This in turn influences the profitability as well as the market share. These are the central decision-making criteria involved in this concept, which ultimately represent the basis of all managerial decisions within the company and the production area.

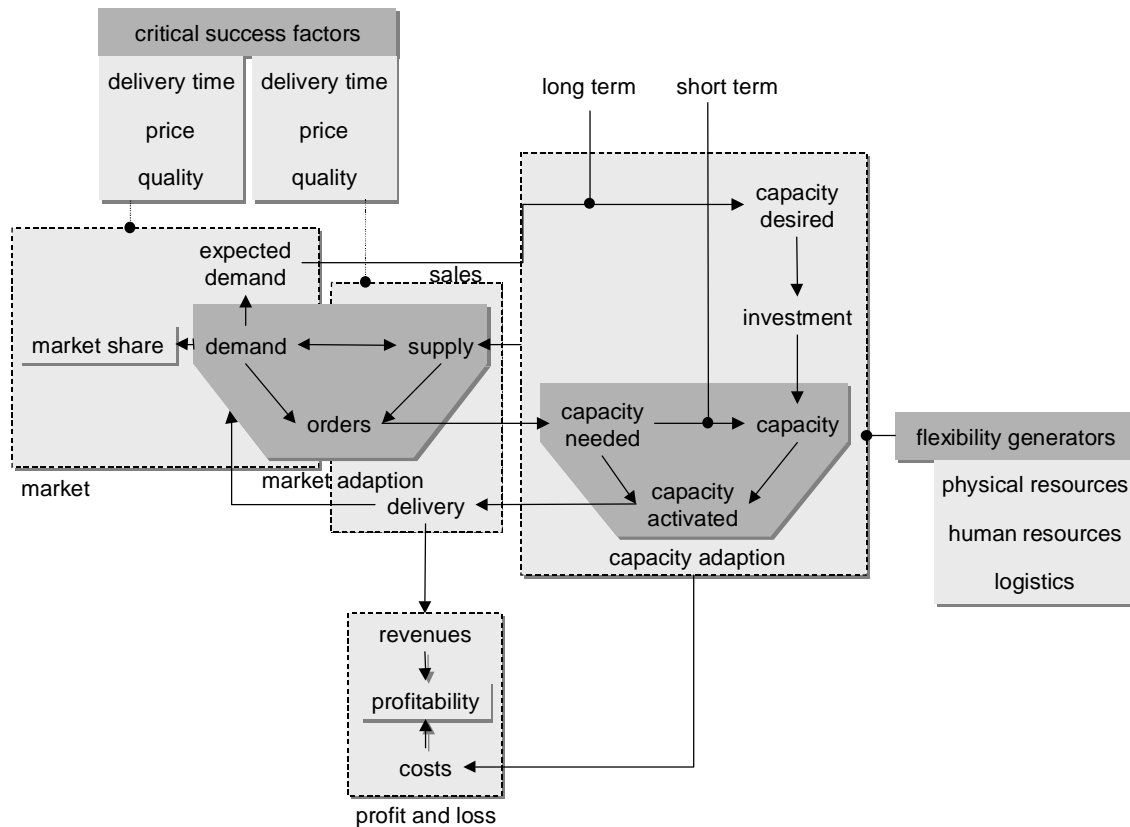


Figure 1. Basic structures of System Dynamics production models

A four-phase modeling concept

With this theoretical basis, the early system dynamics production models which had been developed in the research project were following the traditional System Dynamics approach. The individual tasks were the creation of a causal loop diagram, a flow diagram and a quantitative simulation model. Then, during the course of the research, the instruments were greatly enhanced in some areas and finely tuned in others. The intention was firstly – using a four-phase model – to add transparency to the model creation process and facilitate a gradual better understanding of the problems. Secondly, the development and use of a modular system intended to increase the efficiency of the modeling process itself.

The first step was the development of a step-by-step modeling concept combined with a simulation toolkit. Within this concept (see figure 2) the simulation model is generated in four different phases (Zahn/Greschner 1993, Foschiani 1995, Zahn/Greschner 1995):

In the first phase the user works with a generic model based on empirical studies and theoretical insights. Since problem cases of the same area of application usually show similar basic structures, the identification of such structures makes it possible to create a generic model. In this model the fundamental cause-effect relations of strategic management in the production area are shown by causal diagrams and a hypertext system. With the help of this model, the user generates a basic understanding of the problem and knowledge about dynamics in the production area.

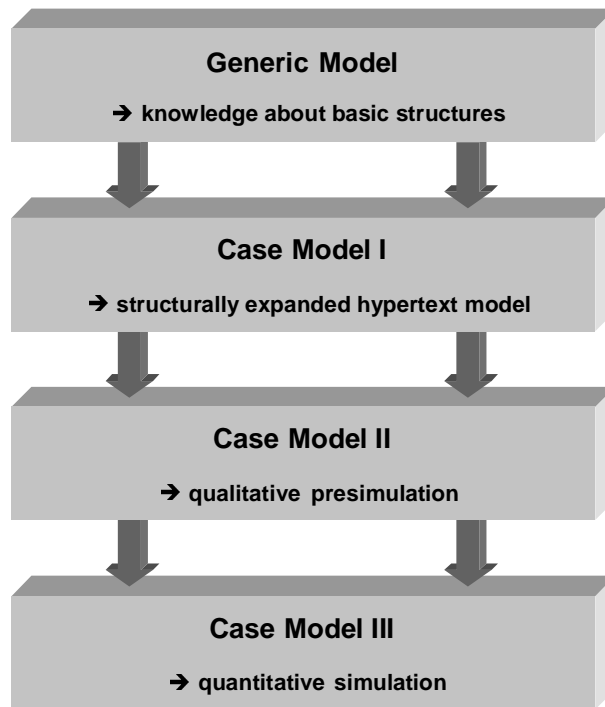


Figure 2. A four-phase modeling concept

During the second phase the user creates his concrete model from the existing generic structures. The toolkit makes all functions available to develop an appropriate model for a specific problem. The output of this phase is not a functioning simulation model but an expanded hypertext system.

In the next step the user determines the relationships of the model elements on a qualitative level. The qualitative specification of the relations includes setting the direction, the delay and the strength of the relationship. Model structures specified in this way allow a qualitative presimulation with several functions such as structure analysis, policy analysis, sensitivity analysis and deviation analysis.

The last step of this concept includes the development of a System Dynamics model - with all the usual user-friendly functions of these models which are available to the user - by defining the quantitative functions. During the work with this System Dynamics model, the user is able to return to the models built in the first three stages and use the available analysis schemes to better understand the results of the quantitative simulation.

A modular system to develop production models

Even in the four-phase model the quantitative System Dynamics simulation model forms the heart of the instrument developed to support strategic decision making in production management. While the models of the first three stages lead to a better understanding and structuring of the problem and essentially only allow to afford a static view on a qualitative level, the quantitative simulation model makes possible the examination of dynamic developments of the mapped system on a very high level of knowledge and information. It allows a detailed consideration of all relevant structural elements and, by simulating alternative

system constellations, to demonstrate the consequences of alternative decisions in production, and show resulting scenarios as well as the scope of the further action.

To allow this kind of analysis, a detailed mapping of the production system and related parameters is necessary. This usually requires considerable effort and an extensive methodological knowledge. For this reason, a modular system was developed, in which all areas of the production system and its environment are represented as different modules. The model is created by selecting, combining and quantitatively specifying the modules required to solve the problems in question. It is for example possible to select and combine a certain market form (polypoly, oligopoly, monopoly), the constellations of the production system (number and structure of the workstations) as well as the logistics (chain of workstations). The aim of the modular concept was to reduce the efforts required for model creation, to shorten the development period, and to minimize the required knowledge of methodological details.

A longitudinal analysis of models and decision making

Since all the System Dynamics models developed and used in the course of this research study are based on identical problems, they allow a comparative analysis. The most important question of this longitudinal analysis is how the different models have developed as far as parameters such as model size, aggregation level and system boundaries are concerned. Also of interest is the development of the modeling process with regard to the time frame and participating staff. In addition, this paper intends to show whether the described characteristics of models and modeling process influence the kind of decisions made and the level at which they are made when supported by the System Dynamics models.

The number of the models and applications used of course rule out any claim to universal validity of the project results. Such a claim has never been the purpose of the study. On the contrary, the intention is to identify trends – shown up in a very specific research area – which may possibly be applied to other areas as well. Figure 3 shows the parameters and the decision making processes of selected models developed in the research project and put to use in practical applications.

Looking at the size of the models (determined by the number of the model equations), a definite trend towards the use of larger models is obvious. The number of model equations has increased more than sevenfold from the first model to the later ones. This development has mainly been made possible by the fast improving performance of the hardware and software used in the project. Also the later models profited from the knowledge and experience accumulated during the course of the project. Not least for these reasons the modeling efforts for the various models did not increase in proportion to their size but much slower. Yet a closer look shows a distinctly higher expense in these cases, reflected in the much longer creation processes and the larger number of staff involved in the projects.

As shown in figure 3, the system boundaries of the individual models remained more or less unchanged during the course of the project. In addition to taking the production system as their core, nearly all models also consider the production environment – e.g. the companies' markets. Thus the vast increase in model sizes must be mainly caused by changes in the aggregation level. In fact, a detailed analysis of the System Dynamics models shows that the aggregation level has been reduced in all model segments. This means that the environment

factors are affected by this development as well (for example in the later models the markets were possibly included not as a whole but in segments); however, the most significant changes occurred in the parts of the model that represent the production and assembly systems themselves. While in the early models these systems were included as production on the whole, this was done in much more detail in the later models, even down to the individual workstations or workplaces.

	Model Size	Aggregation Level	System Boundaries	Problems / Decisions
Model 1	100 %	High: total production system and markets	Production system and markets	<ul style="list-style-type: none"> • Increase of market share by entering new business lines and markets
Model 2	250 %	Relatively high: total production system and markets	Production system and markets	<ul style="list-style-type: none"> • Finding a practicable degree of flexibility which is technically possible and makes economic sense • Creation and assessment of alternative strategies for shorter delivery times
Model 3	270 %	Relatively high: total production system and markets	Production system and markets	<ul style="list-style-type: none"> • Finding a practicable degree of flexibility which is technically possible and makes economic sense • Increase of market share by streamlining production program
Model 4	110 %	High: total production and logistics system	Focus only on production and logistics system	<ul style="list-style-type: none"> • Creation and assessment of alternative logistics systems in the production
Model 6	560 %	Low: individual workstations, workplaces and market segments	Production system and markets	<ul style="list-style-type: none"> • Assessment of alternative assembly systems with different levels of automation
Model 8	660 %	Low: individual workstations, workplaces and market segments	Production system and markets	<ul style="list-style-type: none"> • Assessment of alternative assembly systems with different levels of automation • Assessment of alternative strategies concerning production capacity
Model 9	650 %	Low: individual workstations, workplaces and market segments	Production system and markets	<ul style="list-style-type: none"> • Assessment of alternative production and logistics systems with different levels of automation
Model 10	750 %	Low: individual workstations, workplaces, workers and market segments	Production system and markets	<ul style="list-style-type: none"> • Assessment of alternative assembly systems with different levels of automation • Creation and assessment of alternative logistics concepts in the assembly area • Assessment of alternative working time concepts and shift models and schedules
Model 12	740 %	Low: individual workstations, workplaces and market segments	Production system and markets	<ul style="list-style-type: none"> • Assessment of the effects of changes in order structure • Assessment of the effects of production segmentation strategies • Assessment of the effects of the implementation of production planning and control systems

Figure 3. The evolution of System Dynamics production models

The attempt to design the System Dynamics models with an increasing level of detail and to work on a low aggregation level especially in the production-relevant parts of the model had a considerable effect on qualifications and the number of personnel involved in the model creation process. During the first practical projects, almost exclusively high-level managers participated in the model development, first and foremost directors and production managers; as the models became more and more detailed, more and more staff from middle management and specialists from the different production areas were involved. Their expert knowledge finally allowed a mapping of the systems on a relatively low aggregation level. The intensive co-operation with these experts often caused the top managers, who did not possess this specialized knowledge, to leave the model development process during its early stages.

Another consequence of the trend towards larger and more specific models was the increasingly central role of the methods experts. With the first models, which were relatively small and clearly arranged, the participants from the companies were able to follow the whole process right through to validation and application of the models; this was usually no longer possible with the larger and more complex models of the second and third generation. Only the System Dynamics experts with their extensive methodological knowledge were usually in a position to understand the models in all their stages and work with them. The experts from the different management levels and departments of the companies contributed to those models mainly in the first stages of development only, i.e., where problem structuring and the creation of rough causal diagrams were concerned. A further problem was the fact that more and more time was needed for the design of the large quantitative simulation models; this again caused long time intervals between problem definition and the generation of the simulated results. As a consequence, many representatives of the companies who participated mostly in the early modeling stages became less and less involved as the project wore on.

A detailed analysis of the decisions supported by the System Dynamics models and taken on the basis of their results indicates an overall trend towards more operative decisions. For example, the first model of the research project, created in co-operation with practical applications, dealt with increasing the market share by widening the range of variants and by possibly branching into new lines of business and new markets. Such decisions have undoubtedly strategic character. Later models such as model No. 10 were focussed on more operative questions. With this model, for example, individual assembly lines and their various degrees of automation or possible reorganization of working time were analyzed. However, it must be noted that even in such projects not only the more operative decisions but also the strategic considerations played an important role.

There are many reasons behind the reported trend. Of great importance is the shift from the participation of top management to that of line management which occurred in proportion to the increase of the size and level of detail of the models. Without doubt this caused some focal shift from general strategic questions to more functional and operative issues. It must also be taken into account that only the larger and more detailed models offered the possibility for dealing with such specific functional details. It is possible that the very existence of these highly performant models actually caused the demand for support of functional decision making and thus shifted the focus of the models and the decisions. Last but not least it must be mentioned that it was especially the technical parts of the interdisciplinary research project that turned towards the more operative problems. This had of course an effect on approach and focal point of the project part described here.

Conclusion

The paper shows the development of several generations of System Dynamics based models to support decision making, evolving in the course of an interdisciplinary research project over 17 years. It becomes clear that the performance of these instruments were improved greatly by the creation of a four-phase model, but also by using a modular modeling concept. It is further demonstrated that the models became larger and more specific during the study, which had a significant effect on participation in the modeling process as well as on the formulation of the problems and the resulting decision making process. For example, a shift became obvious from decisions on competitive strategy towards decisions which were more functionally oriented, even though the underlying issues in all practical applications remained more or less unchanged during the whole project. The conclusions drawn from the research project described here are presently being integrated in a follow-up research project dealing with similar problems. This project is returning to supporting strategic decision-making with smaller models on a higher aggregation level.

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