Modeling the Innovation-Pipeline

Andreas Jost
DaimlerChrysler Research & Technology
IT for Engineering and Processes - Digital Engineering Competence Center
Wilhelm-Runge-Strasse 11 - 89013 Ulm - Germany
phone: + 49 731 505 2364 - fax: + 49 731 505 4400
mail: andreas.jost@daimlerchrysler.com

Tobias Lorenz
System Dynamics Group Bergen, Universitaet Stuttgart
Nordbahnhofstr. 179, 70191 Stuttgart - Germany
mail: space56@freenet.de

Gerald Mischke
DaimlerChrysler Research & Technology, Project Controlling
Mercedesstr. 137 - 70327 Stuttgart - Germany
phone: + 49 711 1720742 - fax: + 49 711 1734946
mail: gerald.mischke@daimlerchrysler.com

ABSTRACT

To generate innovative products regularely is a key success factor in established industries. **Major companies frequently outpace each other with innovations and product offensives. But what are the effects of such initiatives? And how can companies organize their innovation pipelines in order to successfully manage such ventures?**

The process in which innovations are developed and integrated into marketable products is highly complex and can be organized in various ways. An important distinction introduced by this paper is to separate between product development processes and processes for innovation generation. In established industries the first ones regularly initiate product development projects and strive to meet certain launch periods. The latter are problem-solution oriented and driven by the search for new, innovative concepts. They are characterized by risk and a high degree of uncertainty regarding success und completion time.

Both processes connect and interact in various ways. Nevertheless there are two general and contrasting alternatives. They can either be organized as processes which are tightly coupled and integrated by associating innovative ideas early with new product projects, or rather independently, integrating innovative components into product concepts in later phases of the product development process. In this paper we refer to these alternatives as *Integrated Innovation Pipeline*[1] and *Shelf-System Innovation Pipeline*. Both show distinct characteristics and requirements.

[1] An innovation pipeline in this context is interpreted as a (timely) structured flow of innovations and product projects

Being aware, that in reality innovation pipelines often represent a mix between these polarizing alternatives, it is essential to understand the basic dynamics of each alternative, in order to explore policies in a mixed environment.

This paper introduces a work-in-progress-model of such innovation pipelines oriented at the typical structures in the automotive industry. In comparison to classical views (mostly linear downstream approaches) the aim was to broaden the perspective by including typical delays and non-linearities of such innovation pipelines. This was achieved by developing a system dynamics model that pins down the structural elements and relations. **The intent of the developed model is to explore the dynamics and characteristics of alternatives in structure, organization and policy within typical automotive innovation pipelines.** The presented work also adds a new perspective and approach to the study of *multi-project product development* within the field of System Dynamics. It is the result of a five month process of modeling and exploration in close interaction with internal and external experts in the field of innovation and product development.

INTRODUCTION

Product development processes are without any doubt innovative processes. However in order to capture the characteristics of automotive innovation pipelines this paper distinguishes between the *innovation process* and the *product development process*.. Further on both concepts are combined in order to develop a comprehensive model of their interaction: The so called *Innovation-Pipeline*.

THE PROCESS OF INNOVATION GENERATION

Classical views of the innovation process[2] typically refer to a sequence of activities represented in a downstream process. Commonly, these are described as an arrangement of around four phases (e.g. *Idea generation*, *Idea formulation*, *Problem solving*, and *Utilization)*. Please note Figure 1. An innovation process is typically characterized by a

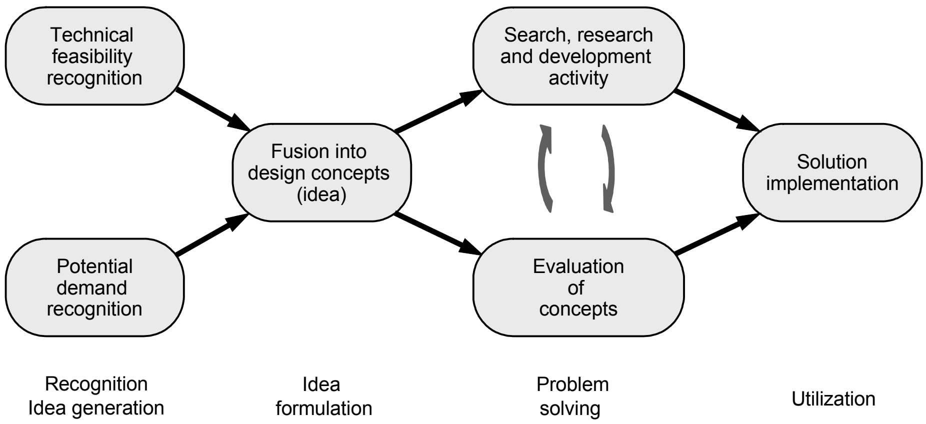

Fig 1: A classical view of the innovation process (adapted and enhanced from Myers/ Marquis (1969))

[2] Compare Myers/ Marquis (1969), Gebert (1979), Stern (2003) and various others.

high number of ideas (projects) in the early phases, combined with mechanisms to develop, evaluate and select the most promising ideas in the course of the following phases.

Numerous ideas are often generated in parallel. Further on in the process, the non-applicable ones are sorted out and valuable ideas are carried further through the more resource-intensive phases of development and evaluation. Outcomes of the innovation process are innovative solutions/concepts, more or less ready for application. The utilization stage refers to the introduction of a novelty as a product or process. Figure 2 provides an alternative illustration indicating the funnel characteristic of such processes.

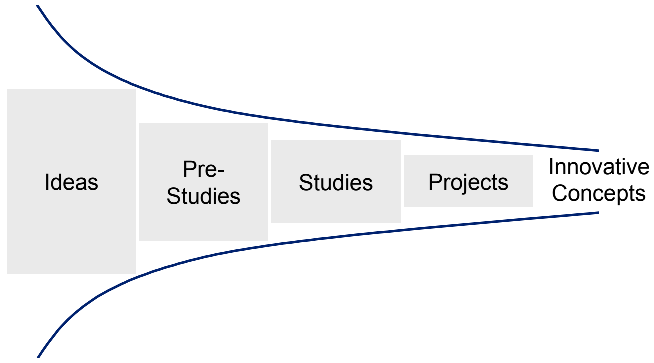

Fig 2: Process of Innovation Generation

In many cases, innovative concepts are not to be introduced separately but need to be integrated into existing products (for example, new car safety systems needs to be integrated into a new vehicle for utilization). At this point the link to the product development process becomes apparent.

THE PRODUCT DEVELOPMENT PROCESS

In the automotive industry, new products are developed in a project-type form, following a *product development process*. This process can be described as a downstream phase model composed of several stages. In the following example (see Figure 3) five phases are distinguished: Concept, Pre-development, Development, Production and Sales. Product projects follow through such processes in cycles. Typically, as soon as a new model is launched into the market, the subsequent development project for its next generation vehicle is already in preparation.

Fig 3: Product development process

As mentioned, product development processes are innovative processes. However, they differ in various ways from the classical view of typical innovation processes as described above.

In the automotive industry *product development processes* are planned and managed towards an indicated launch period. Therefore, they depend to some degree on operational security and the limitation of risks and experimentation. In other words: If a new and innovative concept is not available in a certain quality on time, product development is forced to use proven concepts.

Contrarily, *innovation processes* (interpreted in the classical view) are driven from the other end. Initiated by the identification of a potential demand (e.g. a technical problem) and the recognition of potential in technology, the focus lies on the development of innovative concepts. Typically such processes show a high degree of risk and experimentation. If and when an innovative solution is finally found is highly uncertain.

As described above, at one point the innovation process and the product development process have to meet. Product development projects frequently need to integrate available innovations generated by innovation processes into the product concepts within the product development process. Depending on the definition applied, new automotive vehicles sometimes integrate several dozens of innovative concepts, though the border between innovative concepts and improved traditional concepts is rather vague.

There are various ways innovation processes and product development processes interact. Nevertheless there are two general and contrasting alternatives. They can either be organized as processes which are tightly coupled and integrated by associating innovative ideas early with new product projects, or rather independently, integrating innovative components into product concepts in later phases of the product development process. In this paper we refer to these alternatives as *Integrated Innovation Pipeline* and *Shelf-System Innovation Pipeline*. Both are described in the following. Being aware that in reality, innovation pipelines often represent a mix between the two different alternatives, the approach described aims at the understanding of the basic dynamics of each alternative as a basis for the understanding of a mixed environment.

MODELING APPROACH

The model is based on a dual-pipeline approach which represents the typical structure of a product development process based on a feedback system incorporating investments and resources. It explicitly defines a structure for further analysis and policy testing.

The first pipeline represents the classical innovation process characterized by its high degree of uncertainty and the sorting out of conceptual ideas through iterative development and evaluation activities. This part of the pipeline represents highly innovative activities with high risk, which solutions (yet) cannot be expected for a certain launch date. In Figure 4 this pipeline is represented by the industrial research phase. The second pipeline represents the product development process, which managed towards an intended launch period of new product lines. In this process product development projects are initiated regularly and carried through subsequent maturation stages. In terms of innovations, projects need is to pick up available innovations and integrate them into product concepts. The product pipeline includes all activities of conception and integration of classical and innovative concepts into a product.

INTEGRATED INNOVATION PIPELINE

In the *Integrated Innovation Pipeline* view, innovative ideas are picked up early in the product development process and integrated and developed tightly coupled along the conception of the new product. Figure 4 illustrates this idea. The innovation process as described above is referred to as the industrial research phase, which is then followed by the product development phases of concept, pre-development, serial development and production. Each phase requires corresponding resources.

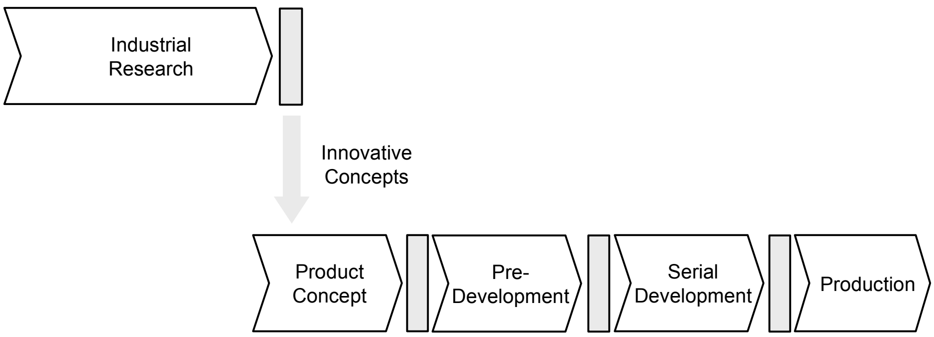

Fig 4: Structural model - Integrated Innovation Pipeline

SHELF-SYSTEM INNOVATION PIPELINE

The *Shelf-System Innovation Pipeline* represents an alternative to the structure described above. It is associated with the idea to extend the first pipeline in order to pick up generated innovative ideas and develop them (independently from certain product projects) towards a higher degree of maturity e.g. into innovative modules or components. These would then be made available in the so called *Shelf-System*. The Shelf-System represents a stock of mature concepts and tested modules which are available to be integrated on demand into a product project at significantly later stages. The entire construct (referred to as *Shelf-System Innovation Pipeline*) is illustrated in Figure 5. The introduction of parallel and independent stages in the innovation pipeline leads to corresponding resource requirements.

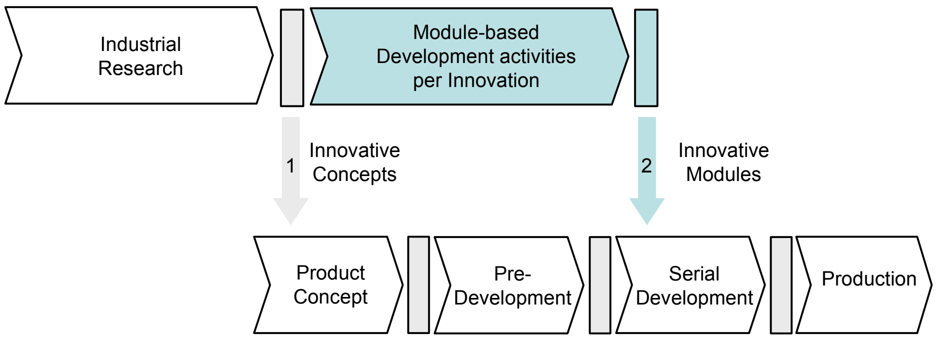

Fig 5: Extended structural model - Shelf-System Innovation Pipeline

MOTIVATION FOR SYSTEM DYNAMICS

This study investigates problems characterized by elements (Feedback, Non-linearities and Delays) which have always been an explicit strength of the System Dynamics methodology. In the following these effects are explained in more detail.

FEEDBACK

Major feedback is generated by the fact that the resources, which are attained via the market introduction of innovative products, are again invested into the innovation pipeline to contribute to the development of further innovative products. A macro feedback influencing the various aspects of the *Innovation Pipeline* is a reinforcing one.

NON-LINEARITIES

Several non-linearities have been identified while structuring the problem:

- The effect of the innovational content of a product on its attractiveness.
- The resource backflow generated by innovative products in the market.
- The impact of varying resource availability per phase on project duration and pipeline throughput.

Furthermore, the main allocation of the resources is typically executed on a yearly basis, which can also be regarded as nonlinear. The non-linearities governing the impact of the resources and the impact of the innovation content are caused by the concept of diminishing marginal returns. The marginal result of the invested resources into the R&D sections decreases. Similar applies to the marginal success of the innovational content of a given product on the market.

DELAYS

Delays are obvious in innovation pipelines, as phase durations regularly add up to several years from the first concept to the production of a new product. Further delays are brought in by market cycles and the generation of resource backflow. Therefore, innovation pipelines are confronted with significant time delays that need to be considered in the discussion of alternative structures and management policies. One of the main themes of this paper is that these delays are often misunderstood, underestimated or even outside the range of consideration.

LITERATURE REVIEW

The review of previous work related to the focus of this paper identified several publications applying System Dynamics to questions of R&D and product development. Milestones have been the works of Roberts (1964), Cooper (1980), Abdel-Hamid (1988), Ford (1995) and Milling (1996). More recent papers have been published by Ford/Sterman (1998), Repenning (2000), Lyneis/Cooper/Els (2001), Hilmola/Helo/Ojala (2003), Milling (2002) and Black/Repenning (2001).

The focus of the majority of the previous work has been on the development of single-project-models as opposed to multi-project-models. Repenning, for example, explicitly states, that "while interest in managing R&D function (as opposed to specific projects) is on the rise, there are few formal models focused on understanding multi-project development environments."[3]

The approach presented in this study suggests a model motivated by current, practical questions. In contrast to previous models that focus on resource allocation (comp. Repenning (2001)), the focus is on organizational structure and the incorporation of feedback from attained resources on possible investments into the innovation pipeline.

The presented model focuses on a structural approach oriented at organisational structures found in the automotive industry. It differs from previous approaches which focus on a project and activity based perspective (comp. Ford (1995)) and attempt to incorporate "all the significant structures developed for other systems and which apply to projects into a single model"[4] into a multi-project perspective. By the integration of the identified feedback the presented model may be considered as related to the approach presented in Milling (2002). Main driving factors in the model are available and invested "resources" which represent human as well as financial resources. The diffusion part of the presented model is simply computed via table functions, but may be extended to a sector of its own

[3] Repenning (2000), p. 174
[4] Ford (1995), p. 27

(e.g. related to classical approaches developed by Bass (1969) or more recently by Maier (1998)).

The aim of the presented model is to provide a tool for strategic analysis and policy testing in organisation and structure of innovation pipelines. Some of the presented ideas may be related to the concepts developed by Powell/Schwaninger/Trimble (2001) as well as to the work of Zahn/Dillerup/Schmid (1998) regarding the choice of production systems.

MODELING APPROACH

In the following the modeling approach is introduced by the illustration of the dominating feedback loop and the definition of the model boundaries. After that, conceptual model is explained as a basis for a better understanding of the explicit model structure.

DOMINATING FEEDBACK LOOP

A straight forward access to the central hypothesis of the described model is provided through the description of the main feedback loop. Investments in research and development activities lead to an increased throughput of the innovation pipeline resulting in an increased number of innovations in products. This, in return, increases the attractiveness of the products, resulting in more units sold. Units sold again contribute to the generated resources, also increasing possible investments in R&D (comp. figure 6).

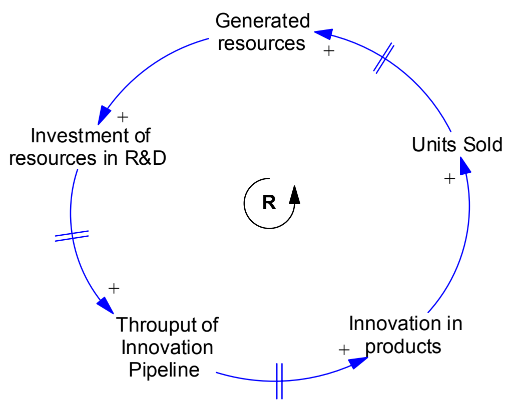

Fig 6: Main feedback loop

MODEL BOUNDARIES

The model boundaries have been drawn narrowly to keep a clear focus on the problem and its characteristics (See Figure 7). Exogenous parameters and model inputs are the average market potential and the average number of innovations per product. Both variables could be explained by demographic changes or changes in the consumer behavior, but are simply assumed to be static in this model. Also exogenous and static are the average resources required per project and the attained resources per unit introduced into the market cycle. In practice R&D ratios are, according to interviews, rather stable over time. In the model, therefore, they are assumed to be a constant fraction of the generated resource backflow. Endogenously modeled are the effects of the two major feedbacks conceptualized in this problem context: the influence of the resources on the throughput of the innovation pipeline and the effect of innovations per product on the resource generation when introduced into a market cycle.

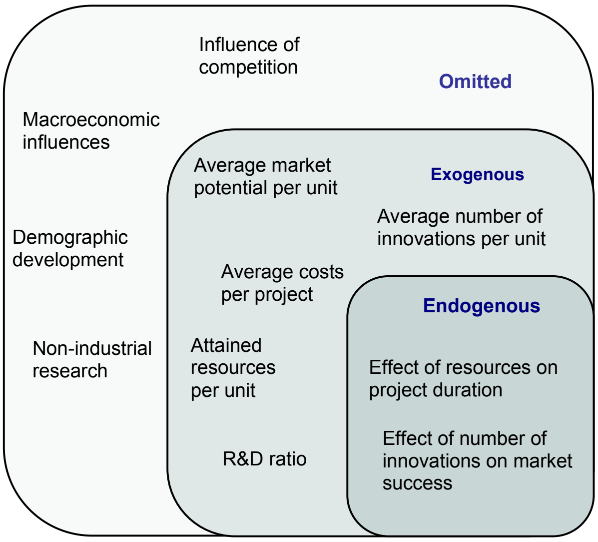

Fig 7: Model boundaries

The influence of the competition has been omitted although it would have given the problem additional and differing dynamics. Nevertheless, this advantage would be bought with the loss of the specific focus. Furthermore, the dynamics of research competition have already been studied and might be implemented. Non-industrial research, as well as macroeconomic and demographic development, is not implemented in this study, but might be included through time series at a later stage.

Central Assumptions

A major assumption in structuring the problem and developing a model is based on the identification of key drivers of successful innovation processes such as the abstract notion of resources, which include work as well as capital. The specific effects of and on individuals in development processes as researched by Ford (1995) are not accounted for, because the focus lies on the comparison of two different organizations of the R&D section, whereas human interaction is assumed to be similar. Additionally, the market success is simplified by a function dependent on the number of innovations in a product.

The policies governing the distribution of the attained resources in this model are assumed to be partly revenue-based and partly requirement-based. For example, the total amount of resources, which are spent in the R&D sections, are defined as a fixed fraction of revenue (the so-called R&D ratio, here assumed to be 5 %) while the distribution of the resources within the R&D sections is realized in regard to the requirements. This means that the total required resources are calculated first, then (for each section) the fraction of its requirements to the total requirements is computed. Finally, the resulting fraction times the actual number of available resources is distributed to that section:

$$\frac{\text{Required resources}}{\text{Total required resources}} \text{ x } \text{Available resources}$$

CONCEPTUAL MODEL

In accordance to the identified organizational elements as described above, the model is organized into four sections. The three main parts are concerned with the development of innovative concepts, product development and resources attainment. An explicit section is devoted to the two structural and organisational options. Figure 8 explicates the various aspects of each of the four sections.

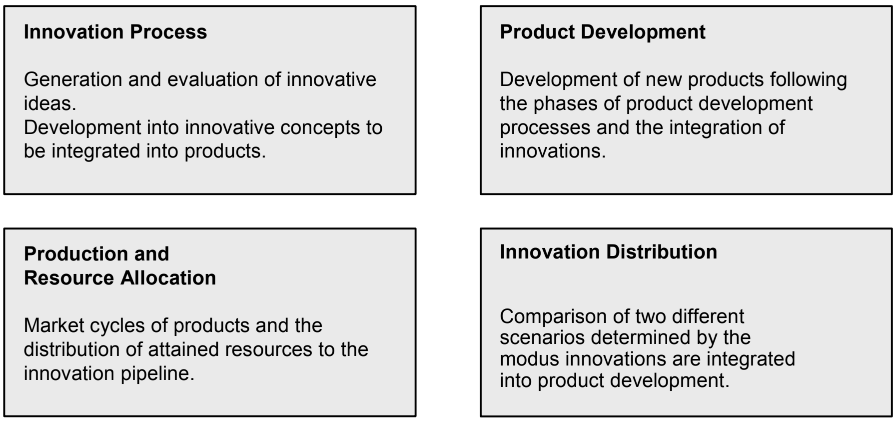

Fig 8: Conceptual model

EXPLICIT MODEL STRUCTURE

The aforementioned sections are linked and interrelated in various ways. Figure 9 illustrates the main path. In the following all four sections are described in detail.

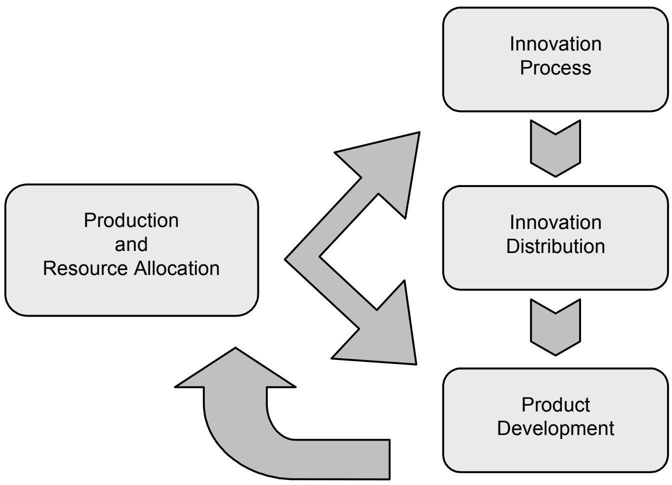

Fig 9: Interrelation of the model sections

INNOVATION PROCESS

The innovation process is represented as an aging-chain. It is designed to regulate the relation between the number of resources and the time needed to complete a given project. The number and completion time of the innovation projects in every stage is influenced by the available resources. The structure, simplified for better understanding, displays the organizational alternatives characterized by different outflows: Innovative concepts can either be taken out of the research stage or developed into innovative modules and made available in the shelf-system. The time needed is treated as an average time span around which the actual development durations are distributed. Innovations within each phase are assumed to be uniform and interchangeable.

PRODUCT DEVELOPMENT

The product development structure is also formed by an aging chain. In contrast to the innovation process every project is represented by an individual subscript. Maturation time is realized as a pipeline delay. This approach was taken in order to accommodate the characteristic of fewer risks and operational planning towards a certain launch period.
The balancing feedback, as introduced before, is also active in this section. For the model, it was assumed that every eight time units a new product development project is launched. Nevertheless, starting dates as well as duration depend on the availability of sufficient resources.

Production and Resource Allocation

In this section of the model, market cycles are simulated. Any product being introduced into the market by the production stage initiates a market cycle which generates new resources. This is a highly non-linear process. The sales distribution of product units is assumed to follow the course of a typical model cycle which is characterized by two peaks: the first is caused by the new product reaching full production capacity and market demand; the second (local) peak is caused by the so called model-upgrade. This curve has been discussed with the interviewed experts and incorporated through a table function depending on the time elapsed since production start (See Figure 10).

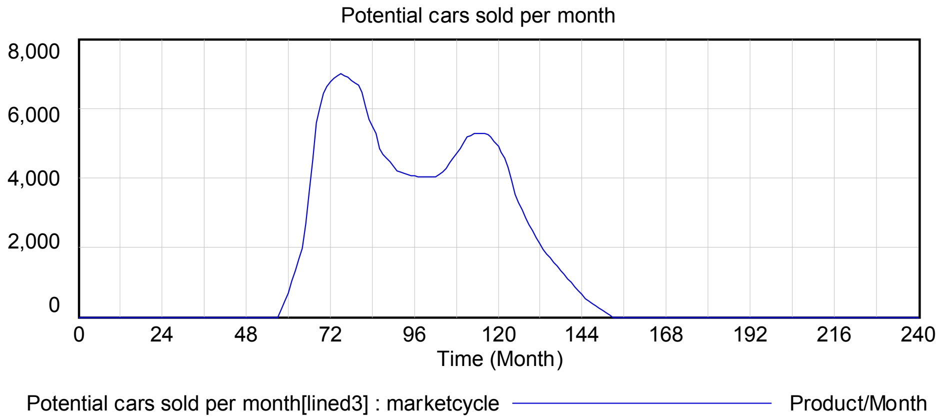

Fig 10: Typical market cycle of a product line

The output of this variable is the percentage of the total sales over the entire market cycle per time unit. It is then multiplied with the market potential and the effect of the innovational content within a given product line. This is assumed to be S-shaped, i.e. an innovation sensitive part is framed by a phase where a product with relatively few innovations still sells quite reasonable and a phase where (above a certain number) further innovations do not increase market success significantly anymore. Through this approach, generated resources of a given product line correspond to its respective innovational content. In this section it proves particularly useful, that each product project is described by an individual subscript. Each subscript can be associated with a specific number of innovations. The individual market success of a product line is then summed up in total product units per time unit.

Another nonlinear process is the redistribution of the attained resources. Similar to industrial practice it is calculated on a yearly basis. In this study five percent of the total units in a year multiplied by the conversion factor of units into resources are reallocated to the innovation pipeline for the next twelve time units.

INNOVATION DISTRIBUTION

As stated above, in the Integrated Innovation Pipeline a product project picks up innovations early whereas in the Shelf-System alternative these innovations are developed further and kept available to be integrated into product concepts at a later stage. Both alternatives are realized via IF THEN ELSE functions. In order to capture the innovational content of products, the number of available innovations is considered as an inflow of a stock. In the market cycle this might be interpreted as the innovational content of a given product line.

In order to calculate the standard innovation distribution, the influence of uncertainty is also considered. This takes into account that innovations are still in early stages of development. Throughout further development of the final product, there still is a potential loss of component projects due to incompatibility or problems discovered within the integration procedures. The functions for the contributing inflows of the innovation distribution are:

Integrated Innovation Pipeline:
IF THEN ELSE(Concept Start[line]=1, "Components:Development"*Percentage of used innovations, 0)

Shelf-System Innovation Pipeline:
IF THEN ELSE(PreDeveloping[line]=1, "Components: ShelfSystem",0)

See Figures 11-13 on the following pages for a structural overview of the individual sections. Figure 14 indicates the alternative ways innovations are picked up by product projects, integrated and developed referred to as the Integrated Innovation Pipeline and the Shelf-System Innovation Pipeline.

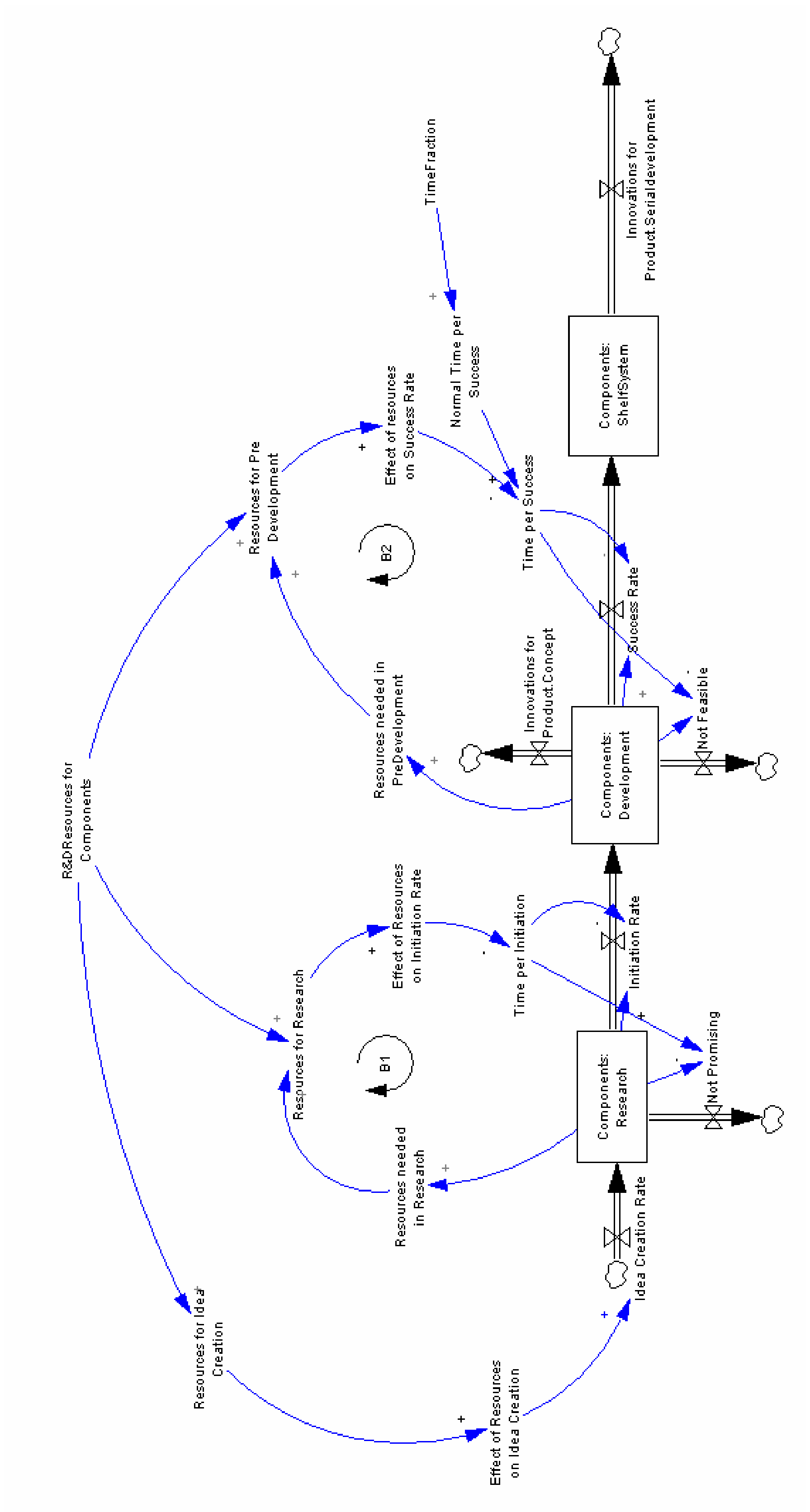

Fig 11: Innovation process (For better understanding the sketch is simplified, shadow variables and constants are hidden)

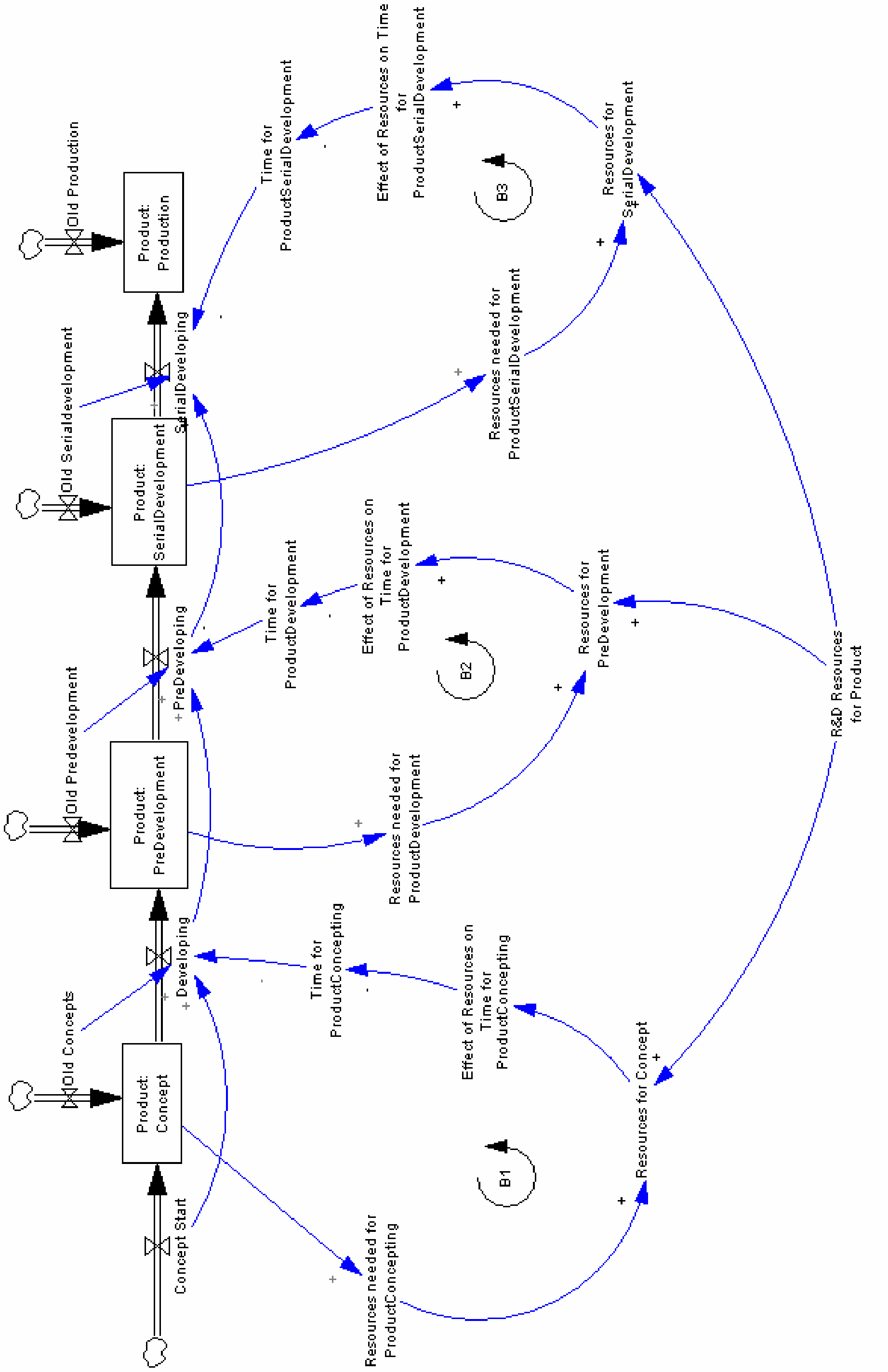

Fig 12: Product development (For better understanding the sketch is simplified, shadow variables and constants are hidden)

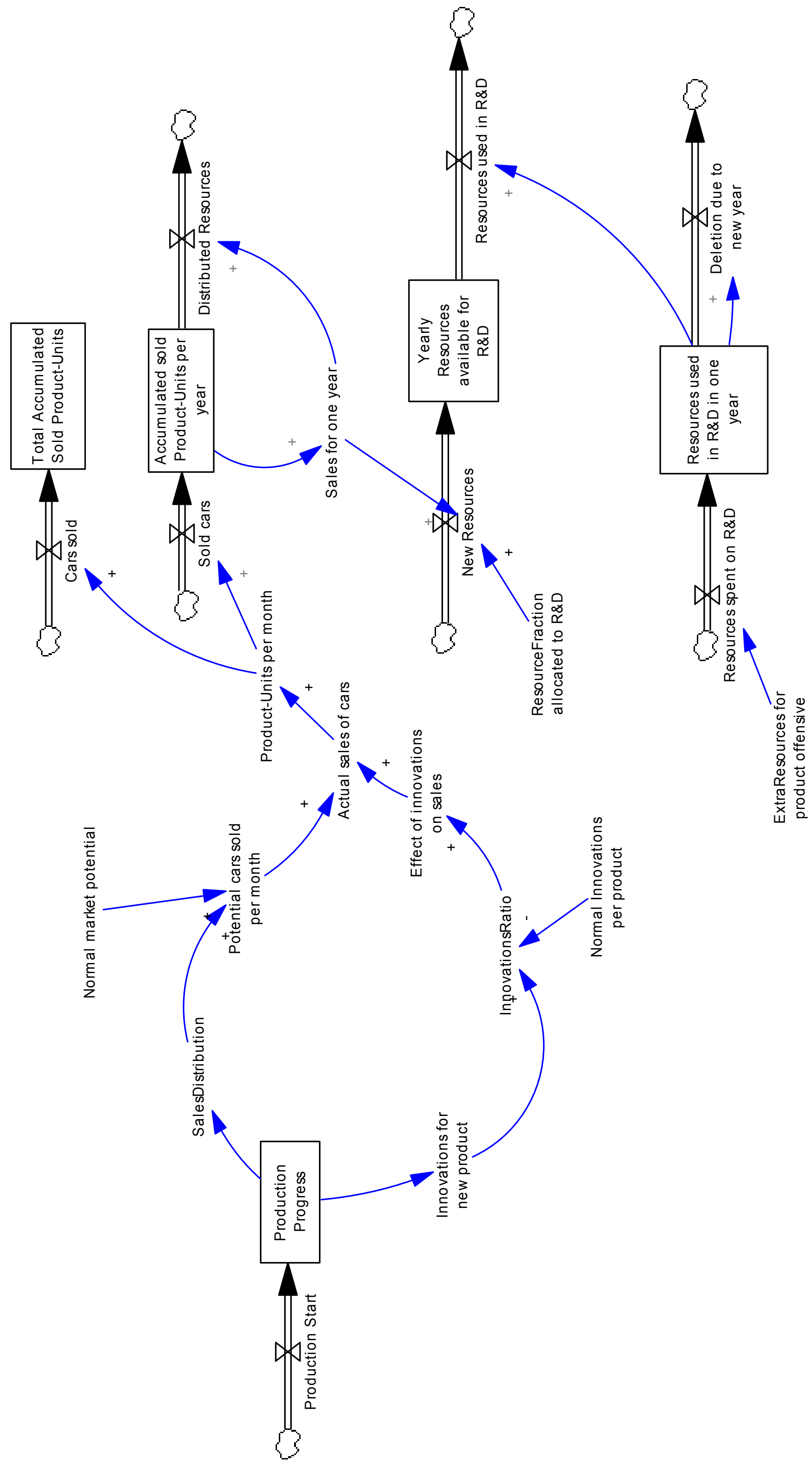

Fig 13: Production and resource allocation (For better understanding the sketch is simplified, shadow variables and constants are hidden)

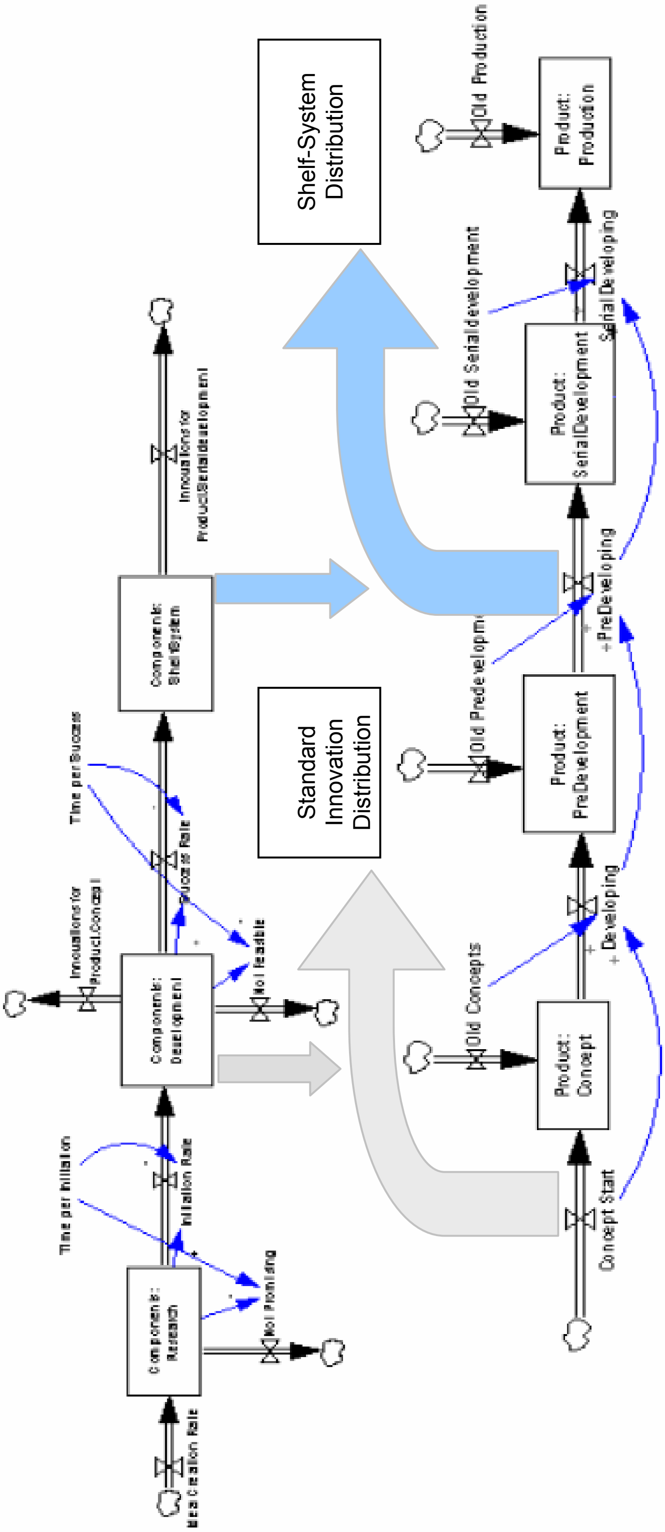

Fig 14: Integrated innovation pipeline vs. shelf-system innovation pipeline

DISCUSSION AND BEHAVIOR

In order to explore the behavior of the developed model various scenarios have been investigated and simulated. Many of them are related to current industrial questions. In the following section the scenarios *steady state*, *response to changes in market conditions* and *response to product offensives* are introduced and selected *model insights* are presented.

STEADY STATE

The steady state of both alternative model structures is calibrated to comparable runs and a steady flow of projects. This includes an equal number of total resources available, regular project launches (new launches every eight time units) and a constant number of innovations per product. Through precise calibration of key variables, a relatively stable condition could be reached (see Figure 15). The term *base* refers to the integrated organization of the innovation pipeline; the abbreviation *shelf* refers to the shelf-system alternative. **The constant oscillations are caused by the number of products on the market (each in a different stage within the market cycle) and the summarized distribution of product units over time.**

The steady state was calibrated to enable a comparison between the two alternative model structures in a series of scenarios. In order to assure a constant project flow in the time period under investigation, an even project distribution and a constant market pull were assumed and sufficient resources were generated.

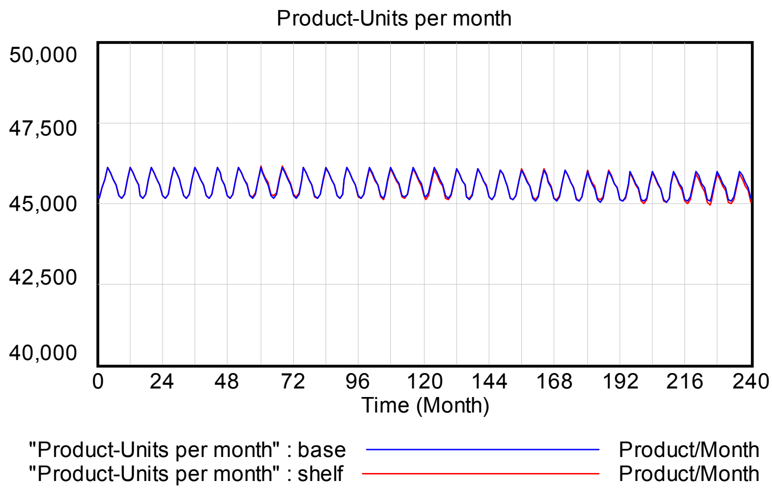

Fig 15: Steady state

The graphs of both runs in Figure 15 are difficult to separate, as the parameters are calibrated to provide an equal run for both alternative model structures. This calibration sets the basis for further comparison with selected scenarios.

A major problem in constructing and calibrating the model was caused by the high sensitivity of both structural alternatives to initial values and changes in decision rules/policies. Although the model is partly initialized with formulas, the remaining parameters are extremely sensitive while generating a somewhat fragile steady state. **In this aspect the model confirms the repeated statements of experts that innovation pipelines of this character are highly sensitive to changes in values and policies. One of the major problems is that a steady state, as described above, is not achieved in industrial innovation pipelines, causing significant problems by the fluctuation of resources and throughput.**

RESPONSE TO CHANGES IN MARKET CONDITIONS

The first scenario which was investigated is the response of the alternative pipeline structures to a sudden change in market conditions. The underlying idea was to test the reaction to a change in customer preferences caused by an external effect. This was simulated through the implementation of two step-functions causing an abrupt increase/decrease in the number of required innovations to meet a certain market potential. The results of these experiments indicate a noticeable faster response of the shelf-system version compared to the integrated (base) system (see Figure 16).

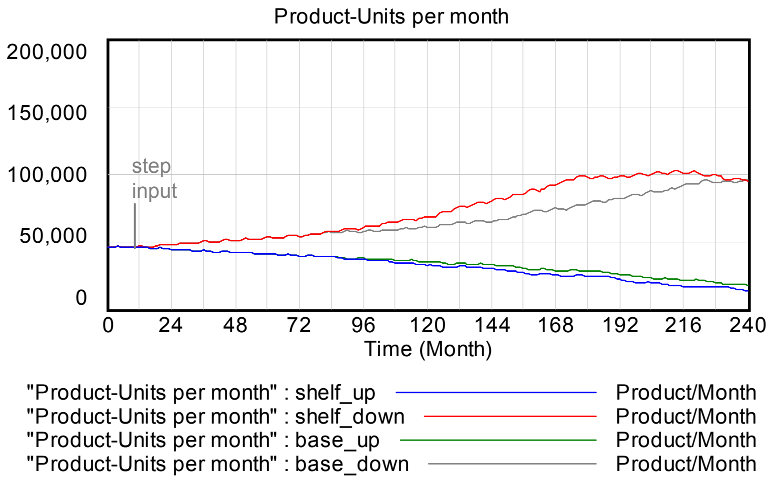

Fig 16: Response to sudden change in market reaction to innovational content

The figure above shows four graphs, two for each pipeline organization. In the “up” cases, a step function increases the number of required innovations to reach a certain market success. In the “down” cases, the respective innovations required are decreased. Therefore, in the latter case, similar market success is easier to attain compared to the steady state run. This leads to a higher resource backflow and, therefore, to more resources, which are available for R&D and so finally to a higher innovational content in products, leading to even higher market success. The opposite argument takes place for an increase in required

innovations. The faster response of the shelf-system structure (although incorporating positive as well as negative response) can be considered as a gain in flexibility providing potential advantages (compare Zahn/Dillerup/Schmid (1998) and the concept of flexibility as a strategic resource). The departure from the steady state follows an s-shape which is due to the nonlinear relationship between the number of innovations in a product and the respective market success. Above or below a certain number, additional or fewer innovations do not change the total number of products sold anymore and a new stable state is reached.
First model tests indicate some advantages of the shelf-system structure compared to the structure of the integrated innovation pipeline caused by its flexibility and the faster response time. Figure 15 suggests that advantages of the shelf-system exceed the disadvantages in case of a downturn. This is, nevertheless, to be attributed to the nonlinear relationship between the number of innovations and the products sold. Further tests and comparison with empirical groundwork may show whether this can also be accounted for in reality. Nevertheless, interviews with experts indicate that the model is considered to behave quite realistically.

RESPONSE TO A PRODUCT OFFENSIVE

The second scenario investigates the model's response to the initiation of a so-called product offensive. A product offensive refers to additional initiation of product development projects in order to extend a given product portfolio. This case was simulated by an increase in projects launched in the product pipeline. In addition to starting a product project every eight months, an additional one is launched at time period 12 (between the first and the second regular one). Figure 17 shows the response for the product units per month.

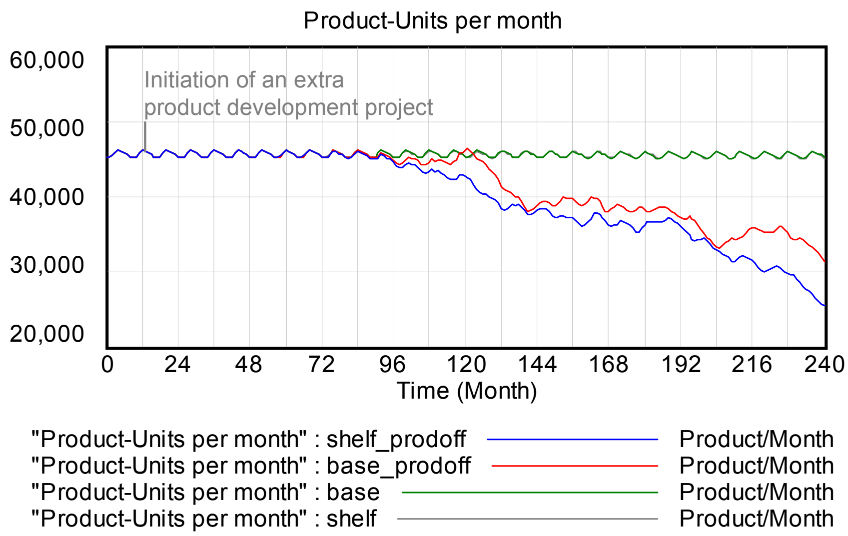

Fig 17: Product offensive with no extra resources or gains in resource efficiency and a high sensitivity to innovational content

The attributes "shelf" and "base" mark the steady state runs, "shelf_prodoff" and "base_prodoff" the scenario runs of the product offensive. The displayed parameters "Product-Units per month" show a clear downward trend which is caused by the implemented requirement-based resource allocation policy and the initial high sensitivity to the innovational content in the final products. With an increase above the normal number of product projects, the resource requirements in the product pipeline rise (see Figure 18), whereas the resources requirements in the innovation pipeline remain equal. **With no extra resources or gains in resource efficiency, this causes the resources distributed to this part of the innovation pipeline to rise, leaving fewer resources for the other parts of the pipeline sectors.** This includes the sectors for innovation generation, finally (and with time delay) leading to a decrease in available innovations. The decrease in the number of innovations is not noticeable in the innovational content of a product line until the new product projects reach production and are launched into the market. Due to the sensitivity of the market to the innovational content, a decrease in units sold per month is observable leading to a further downward trend. The additional superimposed fluctuations in Figure 16 confirm a pipeline behavior described in Braun (1994). Through product offensives, innovation pipelines tend to develop oscillatory behavior caused by parallel (or close by) initiation of extra product cycles and varying resource requirements. In addition, resource shortage and strains within the organizational stages associated with the innovation pipeline are believed to cause additional problems, such as the effect of fire-fighting (compare Repenning (2001)) or the 90%-syndrome (compare Ford/Sterman (2003)). As a first approach to capture such organizational problems also compare Jost/Sauer (2004) and the concept of *Business Syndromes*.

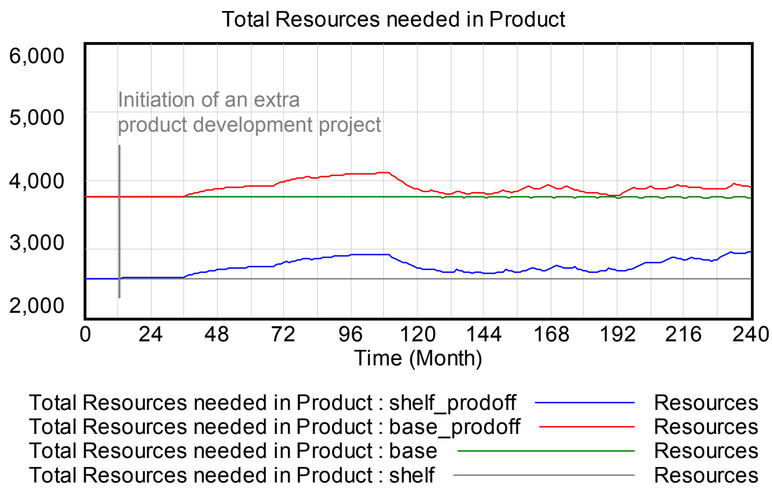

Fig 18: Changes in resource requirements in the product pipeline caused by the initiation of an extra product development project

In a further analysis step the required additional resources, which would be sufficient to fund the product offensive, are derived based on Figure 17. Therefore, a table function is introduced, which adds extra resources for the time the additional product project runs through the innovation pipeline. This was simply realized by comparison of available and required resources and the development of an according table function.
Results show, that product-units per month continue to show an oscillatory downward trend (see Figure 19), which is accorded to the sensitivity to the initial conditions and the high sensitivity of the market demand to the innovational content. The innovation pipeline in its steady state still represents a quite sensitive and unstable equilibrium.

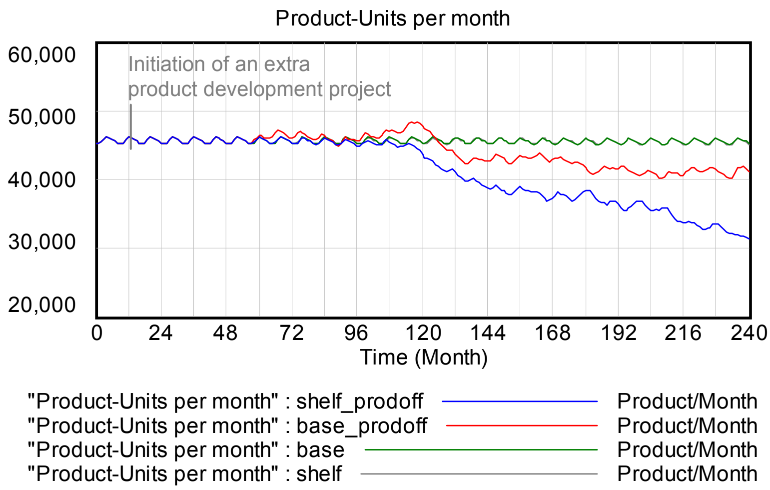

Fig 19: Response to a product offensive with high innovation sensitivity and sufficient resources provided

However, the results indicate, that the initial sensitivity to the innovational content may be too high. In a further simulation step this sensitivity is reduced by changing the nonlinear relationship governing the market response through offsets in the market cycles depending on the innovational content of a given product line. In the simulation run with a market response which is less sensitive to changes in the number of innovations (implemented as a linear relation with a relatively small slope), **the effect of a product offensive shows an increase in products-units per time followed by an oscillation with a frequency of approx. 48 time units (see Figure 20). This ongoing fluctuation (caused by the initiation of an extra project in spite of providing sufficient extra resources) is a major factor to be considered when planning product offensives.** It is considered to be a major challenge in industrial practice and supports findings of Braun (1994) and Le Corre/ Mischke (2004). Causes are sought in the typical market cycles of products combined with changes in resource distribution and throughput of both pipelines. **To sensitize, that these effects might occur through the initiation of product offensives and to develop strategies how to reduce and mange such fluctuations are of major interest for**

industrial practice. The developed model provides an important basis for further analysis and opens a new range of possibilities to support this process.

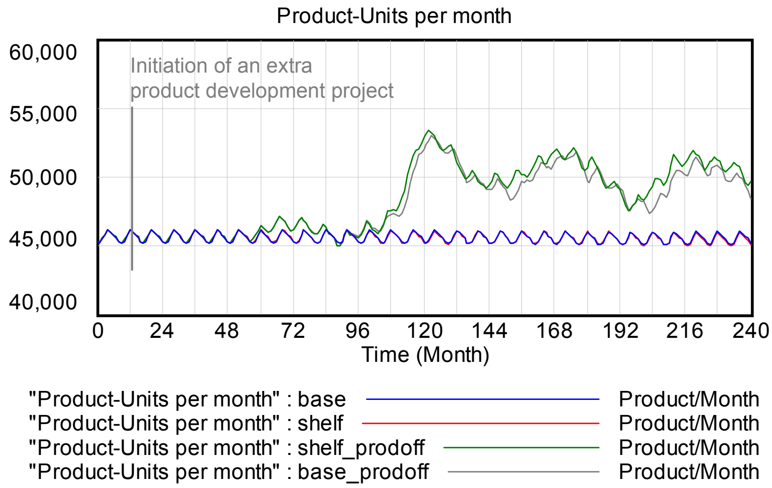

Fig 20: Response to a product offensive with sufficient resources provided and less sensitivity to the number of innovations

CONCLUSIONS, MODEL INSIGHTS AND FURTHER RESEARCH

The developed model represents a combination of two different pipeline concepts. The first incorporates the characteristics of a funnel, which filters numerous inputs (ideas) through deeper investigation and development activates. A substantial percentage of the creative, but not feasible ideas are sorted out on the way. The second pipeline depends on a high degree of operational security and a smaller percentage of non-usable output is tolerated.
Whereas the first pipeline needs to cope with very high degree of uncertainty, the latter is based on operational security and managed towards indicated deadlines. In both pipelines the required resources per project and stage rise enormously throughout the subsequent stages. Where this is (to some extent) balanced by the decreasing number of projects in the innovation pipeline, the overall required resources clearly mirror this behavior in the product pipeline. These effects are regularly underestimated in practice. Furthermore (as the first stages of the pipeline are less resource intensive) these effects become crucial with a considerable time delay which again is regularly underestimated in practice. Once the resource intensive stages are reached it becomes extremely difficult to cancel and/or delay product projects in practice. **The developed model contributes to the development of effective polices in the question of how to plan and manage product offensives. It takes into account the effects of product initiatives, the resulting resource requirements in the innovation pipeline and the consequences in the innovational content of a product.**

Another factor that needs to be considered is the inertia of resource shifts and changes. Whereas in the current model changes in resource allocation are assumed to be immediate and smooth, in reality the shift and allocation of resources (particularly human resources such as experienced product designers and engineers) involves (next to costs) considerable time delays. The same applies to the reduction of resources which is (particularly in case of human resources) an extremely sensitive undertaking. **Fluctuations in resource requirements should be minimized whenever innovation pipelines have to be modified in throughput, structure or organization. The developed model can provide a significant support in the investigation of resource effects and the development of innovative polices.**

The comparison of the two alternative pipeline structures in the steady state run indicates different model dynamics through variations in resource allocation and risk distribution. **The Shelf-System structure is generally observed to provide advantages in response time, flexibility and risk reduction within the innovation pipeline.** This advantage is achieved by shifting resources to an additional innovation-based maturation stage. In the model, these effects are taken in account through the allocation of resources to the additional stage and the alternation of filter mechanisms. **However, advantages gained through flexibility are believed to be counteracted by a decrease in product homogeneity.** This is due to modularisation and standardisation efforts which are needed to assure the integration of innovative modules at later stages in the product pipeline. Yet, these effects have not been implemented in the model and are subject for further research. To broaden the empirical foundation is also believed to lead to additional leverage points for sustainable policy development.

It can be summarized that the developed model was able to explicate major elements of the complexity of automotive innovation pipelines. It is believed that the result can be transfered to other industries with similar character. Innovation pipelines in established industries need to continuously generate successful product innovations. These product innovations represent a combination (“system product”) of proven (traditional) concepts and new, innovative concepts. By taking an integrated, dual pipeline approach, the developed model was able to incorporate these effects. Furthermore, through the integration of the dominating feedbacks it was possible to take into account system inherent limits to resources and resource distribution. In combination with the delays of the individual pipeline stages the model explicates the system inherent “inertness” within such innovation pipelines. Also the model confirms and reproduces effects suggested by Braun (1994), Repenning (2001) and Le Corre/Mischke (2004) successfully. Nevertheless, the authors recommend confirming the developed outcomes through further analysis and empirical data. Also, additional effects which have not been implemented yet need to be considered. Particular issues worthy of further research are:

- Limiting effects to the dominating loops through market reaction and saturation. The governing positive feedback loop might be weakened by a counteracting negative feedback loop.

- The effect of alternative options in resource provision for short term initiatives has not been considered in detail. This option might be of interest in order to increase pipeline throughput in product innovation through a worse-before-better strategy and smoothen out the reinforcing behavior.

- Competition within the market has not been considered within the presented model. The increased development efforts of one company could induce reactions of competitors, causing the character (and number) of innovations a customer expects in a given product to rise. This effect would weaken the dominating loop.

- Also certain decreases in product homogeneity due to module based innovations might be observed in the final “system-product”. These effects, in addition to the efforts needed for modularization and standardization, are worthy of further investigation.

REFERENCES

Abdel-Hamid. 1988. The economics of software quality assurance: A simulation-based case study. *MIS Quarterly* **12(3)**: 395-411.

Bass. 1969. A New Product Growth Model for Consumer Durables. *Management Science* **15**: 215-227.

Black, Repenning. 2001. Why firefighting is never enough: preserving high-quality product development. *SD Review* **17(1)**: 33-62.

Braun. 1994. *The Innovation War*. Prentice Hall: PTR New York

Cooper. 1980. Naval ship production: a claim settled and a framework built. *Interfaces* **10(6)**: 20-36.

Ford. 1995. *The dynamics of project management.* MIT: 27.

Ford, Sterman. 1998. Dynamic modelling of product development processes. *SD Review* **14(1)**: 31-68.

Ford D, Sterman J. Overcoming the 90% Syndrome: Iteration Management in Concurrent Development Projects. *Concurrent Engineering Research and Applications* **111 (3)**: 177-186.

Hilmola, Helo, Ojala. 2003. The value of product development lead time in software startup. *SD Review* **19(1)**: 75-82.

Jost, Sauer. 2004. *Business Syndromes*. Proceedings GWS-Conference 2004: Lüneburg.

Le Corre, Mischke. 2004. *The Innovation Game: A New Approach to Innovation Management and R&D*. Springer: New York.

Lyneis, Cooper, Els. 2001. Strategic management of complex projects: a case study using system dynamics. *SD Review* **17(3)**: 237-260.

Maier: 1998. New product diffusion models in innovation management- a system dynamics perspective. *SD Review* **14(4)**: 285-305.

Milling. 1996. Modelling Innovation Processes for Decision Support and Management Simulation. *SD Review* **12(3)**: 211-234.

Milling. 2002. Understanding and managing innovation processes. *SD Review* **18(1)**: 73-86.

Myers, Marquis. 1969. *Successful industrial innovations: A Study of Factors Underlying Innovation in Selected Firms.* National Science Foundation NSF: Washington DC. 69-17.

Powell, Schwaninger, Trimble. 2001. Measurement and control of business processes. *SD Review* **17(1)**: 63-91.

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

Roberts. 1964. *The Dynamics of Research and Development*. New York.

Stern, Jaberg, 2003. Erfolgreiches Innovationsmanagement: Erfolgsfaktoren - Grundmuster - Fallbeispiele. Wiesbaden. Gabler.

Zahn, Dillerup, Schmid. 1998. Strategic evaluation of flexible assembly systems on the basis of hard and soft decision criteria. *SD Review* **14(4)**: 263-284.