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System Dynamics as a tool for strategic decision making within enterprises

Diploma Thesis

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Für meine Familie

Foreword and acknowledgment

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Abstract

Formulation and execution of strategies are very important activities in the field of management. During strategic decision making processes a variety of different aspects have to be taken into account. This huge amount of influences and their relationships establish a complex and dynamic system. Managing this complexity is one of the greatest success factors for companies, as purposeful planning and optimized use of resources are possible. System Dynamics (SD) was founded in the field of management and is dealing with complex and dynamic systems for many years. Despite the big advantages of this method, there are only few implementations in enterprises yet. Reasons behind are, that each model is created for a specific purpose and consists of a high error risk. This work deals with the term strategic management, explains the method System Dynamics, and illustrates some applications of this technique, especially within enterprises. As a part of a cooperation project with the University of Skopje, a SD model for a pharmaceutical company is created and implemented in the simulation software. First of all this model provides a better understanding of the existing feedback processes and moreover a simulation allows managers to test their strategic decisions within a virtual environment.

Kurzfassung

Die Formulierung von Strategien and deren Umsetzung sind wichtige Aufgabenbereiche im Management. Speziell auf der strategischen Unternehmensebene müssen viele unterschiedliche Faktoren bei einer Entscheidungsfindung berücksichtigt werden. Diese Vielzahl von Einflussgrößen und vor allem deren Wirkbeziehungen erschaffen meist ein sehr komplexes System. Ein großer Erfolgsfaktor für Unternehmen liegt genau in dieser Komplexitätsbewältigung, da diese eine zielgerichtete Planung und einen optimierten Ressourceneinsatz ermöglicht. System Dynamics (SD) hat seinen Ursprung im Bereich des Managements und beschäftigt sich seit vielen Jahren mit dynamischen und komplexen Systemen. Trotz der großen Vorteile wird diese Methode jedoch relativ selten in der Industrie verwendet. Ursachen dafür liegen meist in der zweckgebundenen Erstellung von Modellen und Simulationen und einem hohen Fehlerrisiko. Im Verlauf dieser Arbeit wird der Begriff strategisches Management genauer erläutert, sowie die Methode System Dynamics beschrieben und einige Anwendungen im Bereich der Unternehmensführung aufgezeigt. Als Teil eines Kooperations-Projekts mit der Universität in Skopje wird ein SD-Modell einer pharmazeutischen Industrie erstellt. In Zusammenarbeit mit einer Pharmazeutikfirma wird dieses Modell an die reale Situation angepasst und in eine Simulationssoftware implementiert. Einerseits verbessert dieses Modell das Verständnis von Wirkzusammenhängen, andererseits ermöglicht die Simulation den Managern, ihre Entscheidungen in einer virtuellen Umgebung zu testen.

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1 Introduction

Managers try to increase the performance of their company, by making the correct decisions at the right time. They need a lot of knowledge and experience to understand the relationship between a huge amount of different factors. Forrester (1961) stated, that management is in transition from art to profession more than 60 years ago, but nowadays the decision process is still based on experience and instinctive feeling. There is a variety of techniques supporting managers to create ideas or evaluate different strategies, but none of them provides a better understanding of the underlying structure of feedback processes and interconnections of different systems. Especially in the field of strategic management the company is dealing with many environmental aspects. System Dynamics (SD) is a technique, that is accurate to capture dynamic and complex systems, and provides a very good tool for a better understanding of these systems. Managing is known as a set of different actions, especially planning and controlling, which are adequately supported by SD implementations. Good planning is grounded on an as accurately as possible forecasting and suitable models are needed.

The SD society is constantly growing and a lot of scientists are working in many different areas, reaching from social studies up to climatic researches. Despite the big advantages of SD only very few companies are aware of this technique and implementations are rare. This diploma thesis examines some implementations in enterprises and explains reasons for this method.

The Institute for Engineering and Business Informatics is currently cooperating with the University of Skopje, Macedonia, to create a hybrid model (combination of operational and strategic simulation tools), which should help managers in the strategic decision making process. Management is basically divided into different dimensions, such as the normative, strategic and operational level (Bleicher, 1999). While strategic management is focusing on the alignment and orientation of activities, the operational level implements these objectives by operations that focus on skills and resources. At the operational level, e.g. manufacturing, the processes are well known and a lot of data is available and therefore the abstraction level is very low. Due to the lack of data and the high abstraction level at the macro level, simulation techniques that are useful in micro levels, are not suitable any more. The field of strategic management is characterized by feedback processes and a high abstraction level. SD is able to capture global causal dependencies, but is not appropriate to illustrate discrete events, that are common in the operational level. A combination of SD in the strategic and Discrete Event Simulation (DES) in the operational segment should combine the advantages of both techniques.

The development of a SD model for the strategic level was one of the major reasons for this diploma thesis. During project meetings a reference company was chosen and interviews with managers were arranged. Based on these interviews and literature research a basic model of the industry should be created. To secure consistency and allow verification and validation, the strategic SD model should contain a simple production model as well. Despite the fact, that the strategic model will be used in combination with the operational model, it should assist the strategic decision making process as good as possible alone.

Every model is as good as it fits to its purpose and therefore some goals were set. The reference company is dealing with the pharmaceutical market and many regulations create impacts. Their premium product is actually creating an adequate profit, but they think it is possible to increase the sales volume even further. Currently few sales representatives are consulting physicians to obtain their satisfaction for this product. Constraints in the manufacturing, supply chain or distribution are not limiting the present service but they exist. The major question is, how to raise sales volume by concerning the boundaries?

The market of the reference product is not subjected to big changes, but limited. Based on this limitation, the profit is limited too and extensive investments would lead to a negative response. All these constraints, relationships and feedback processes make it almost impossible to capture without a suitable technique. The SD model is supposed to structure this system and to provide a good understanding of the dynamics that arise from the feedback loops and delays. A simulation should forecast the company's performance and allows managers to test their decisions in a virtual abstraction of the industry.

2 Strategic Management

The term management derives from the verb *manage* and is based on the Italian word *maneggiare*, which means to guide something by hand. Forrester (1961) once quoted, that managing a company would be more difficult, than doing tasks of the mathematician, the physicist, or the engineer, due to the wider scope of the systems and many more significant factors that have to be taken into account. Non linear relationships between values and event triggered behavior make it even more challenging. Figure 1 illustrates major factors that have to be considered by managers (Williamson et al., 2003).

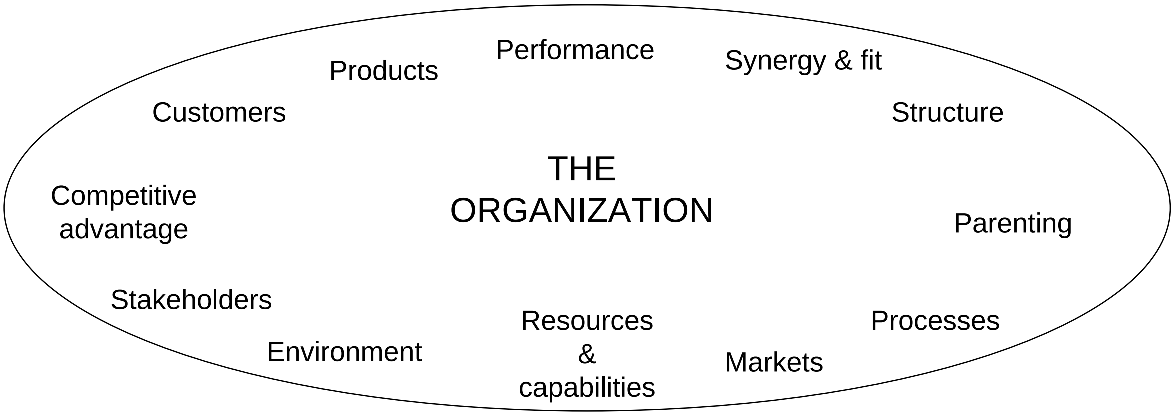


Figure 1: Variables that have to be taken into account by managers, adopted from Williamson et al. (2003)

Nearly everything needs to be managed and many different activities have to be done. The basic concept includes planning, organizing, staffing, coordinating, controlling, and evaluation (Orcullo, 2007). This research is focusing on industrial management and especially on the strategic segment. The following distinction of management levels is based on the *St. Galler Management-Concept* and the work of Bleicher (1999).

The *St. Galler Management-Concept* provides a logical deviation between different levels of management within a concept of integrated management. Bleicher (1999) claimed, that this segmentation does not state the boundaries for responsibility. Figure 2 shows a holistic approach of integrated management and the different dimensions and modules.

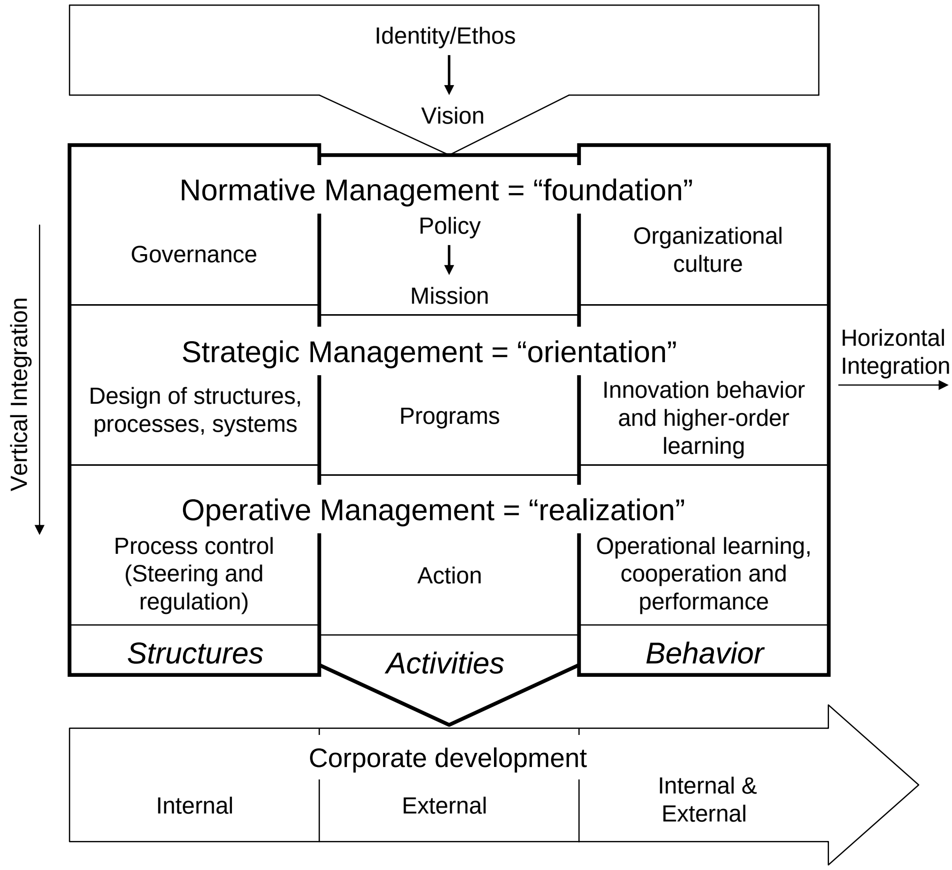


Figure 2: Management levels and a holistic approach of integrated management, adopted from Bleicher (1999)

These dimensions can not be viewed separately, because there are many feedback processes between them. Based on Bleichers concept, the three dimensions are explained bellow.

- **Normative Management**
  Normative Management is dealing with the generic policy of companies. Goals and actions within this level of management are focusing on the viability and the ability to develop. Company policy is based on the vision and borne by corporate culture and corporate governance.

- **Strategic Management**
  Strategic Management is focusing on the construction, maintenance, and exploita-

tion of success potentials, by considering the available and assigned resources. Existing knowledge in market, technology, social structures, and processes are subscribed as potentials of success. The ability to gain new success potentials arise from the development of new, prospectively suitable, skills. While activities are established in the normative segment, the strategic management is focusing on the alignment and orientation of activities.

- **Operative Management**
  Both previous dimensions are executed in operational level. The major function of the operative management is to implement the normative and strategic objectives by operations that focus on skills and resources.

Bleichers explanation of strategic management is very common, but Nag et al. (2007) stated, that there are many various definitions and perceptions of this term. A part of their research is based on questioning a sample of 57 different scholars who are recent authors in major journals. They identified some frequently named variables but no dominant theoretical definition and claimed that the big success of strategic management is a result of this attitude, because multiply research orientations, of many members, who hail from a wide variety of disciplinary, provides a big advantage. In addition Nag et al. (2007) established a suitable definition of strategic management:

> *"The field of strategic management deals with the major intended and emergent initiatives taken by general managers on behalf of owners, involving utilization of resources to enhance the performance of firms in their external environments."* (Nag et al., 2007)

Orcullo (2007) claimed, that the need of strategic management is constantly growing, due to the profit motive and the nature of competition. These and many additional reasons drive business organizations to plan well and apply the principles of strategic management.

2.1 Characteristics of Strategic Decisions

Basically each decision is made to secure the viability of a company. Zäpfel and Brunner (1984) claim that a strategy should put a company in a position within the environment, which ensures its positive development. Decisions are daily business for managers and basically they are described as selection of possible actions, even if the decision means to do nothing (Beintner, 2010). Hence, each decision considering the assignment or usage of resources is finally agreed to be strategic. The basic questions in the strategic company management consists of *"What"* and *"How"* (Lyneis et al., 2001).

Kunath (2009) stated, that as a result of the irreversibility of each strategic decision, it has to be based on a accurate operations research. He also mentions the term *strategic complexity*, which arise from the number of competition relevant strategic factors and their time dependent behavior. Handling this complexity is one of the major factors of success.

Amongst others, Micheal E. Porter and his work about competitive advantages characterize the field of strategic management. Porter (2010) asserted in the beginning of his work, that competition sets the course for success or failure. Kunath (2009) claimed, that competitive advantage serves as a fundamental approach of the value based strategic planning. Porter was focusing on the market (market-based view) and stated, that factors of success are established in the competition. This approach was very popular in the 1980s and as mentioned before one of the fundamental concepts for the field of strategic management.

Porters five-forces model explains the structure and the arising intensity of competitive rivalry within industries by five different elements. Suppliers and buyers create an impact due to their bargaining power, while substitutes or new entrants create threats. The fifth force is determined as the rivalry within the industry. The main influence on the competitive position arises from the competition strategy of the company. Porter (2010) mentioned three different strategies that could lead to competitive advantages.

- cost leadership
- differentiation
- focus
  - cost focus
  - differentiation focus

Kunath (2009) stated, that the market-based view provides a very good tool for analyzing and strategy formulation, but does not support forecasting or evaluation in the strategic management process. In addition to the market-based view, Kunath used the resources-based approach to explain the relationships of existing resources and success factors. These capabilities are divided into tangible - physical, financial, and IT-based - and intangible - structural, assets, and human - resources. Especially intangible resources have great potential for success, because they are not as easy imitable as tangible resources.

2.2 Evaluation of Strategic Decisions

As mentioned above, strategic decisions should secure the viability and of course trigger an increase in performance. Success contains quantitative and qualitative factors (Huber, 1985). While quantitative factors - such as turnover, cash-flow or profitability - indicate previous success, qualitative factors - such as customer relationship or image - are hard to measure. Huber (1985) was analyzing companies, which have shown outstanding quantitative results, to show characteristics of successful strategic management decisions. He assumed that qualitative attributes and manners would lead to long term quantitative success.

Huber (1985) was not able to measure qualitative factors and due to his assumption of their long term quantitative impact, he tried to compare companies by their cash-flow statement. After having recognized, that measuring only one value seems to be inadequate, he stated three characteristics of success in the narrower sense:

- high long-term profitability
- solid market position
- leading competitive position

As mentioned above, measurable values does not necessarily provide information about the current situation and unmeasurable factors need to be quantified first. A control system, containing strategic and financial controls, ensures that business strategies meet goals (Barringer and Bluedorn, 1999). While firms register financial values regularly, strategic controls - such as customer satisfaction criteria, success in meeting targets, and many more - should be implemented as well. Barringer and Bluedorn (1999) stated, that both controls can be present simultaneously in a firm and therefore they created the following hypothesis. They presume a positive feedback between the degree of emphasis on strategic control and corporate entrepreneurship intensity and a negative feedback at the degree of emphasis on financial controls and administration. Due to their research they could establish the positive feedback.

3 System Dynamics

System Dynamics (SD) is known as a method to analyze, model and simulate dynamic and complex systems. To distinguish between these applications, SD is separated in two main areas, depending on the objectives and the purpose of usage. Forrester (1987) mentioned the ultimate success of SD investigations within a clear initial identification and therefore these models should organize, clarify and unify knowledge. Wolstenholme (1997) gave a short specification of the term System Dynamics and the fundamental concept behind. His description, stated below, is one of the most used explanations:

- *"What: A rigorous way to help thinking, visualizing, sharing, and communication of the future evolution of complex organizations and issues over time,*
- *"Why: for the purpose of solving problems and creating more robust designs, which minimizes the likelihood of unpleasant surprises and unintended consequences,*
- *"How: by creating operational maps and simulation models which externalize mental models and capture the interrelationships of physical and behavioral processes, organizational boundaries, policies, information feedback and time delays; and by using these architectures to test the holistic outcomes of alternative plans and ideas,*
- *"Within: a framework which respects and fosters the needs and values of awareness, openness, responsibility and equality of individuals and teams."*
  (Wolstenholme, 1997)

A big advantage of SD is the ability to accept the complexity, non-linearity and feedback loop structure of dynamic systems. These characteristics, especially in the field of social and physical systems, force the development and implementation of SD (Forrester, 1994).

As already noted, SD is divided in two areas of application, called quantitative and qualitative. While qualitative models are mainly used for identification and understanding of closed-loop relations, the quantitative models are used for simulations. Richmond (1993) defined the qualitative part as System Thinking and mentioned, that System

Thinkers use a diagramming language to depict feedback structures visually. The qualitative modeling does not involve simulation and is also known as the *soft* Operational Research (Coyle, 1998). Simulation - the quantitative part - is not always possible or even necessary. Different modeling techniques are used, depending on the field of application. Causal Loop Diagrams (CLD) are common in the qualitative modeling and provide a very good understanding of feedback loops (see Chapter 3.3). These diagrams provide the base for further quantitative models, if a simulation is desired. Stocks and Flows are used as fundamental elements of the quantitative models (see Chapter 3.4). Running different scenarios in a suitable simulation software promotes a good understanding of the time depending behavior of the modeled system. Peterson and Eberlein (1994) mentioned, that a qualitative model alone, could often fail, due to variable reasoning of the modeler. Sometimes mental concepts could lead to wrong assumptions and a simulation would show unexpected behavior.

3.1 History

System Dynamics was developed by Jay Wright Forrester during the mid 1950s. Forrester was currently a professor in the MIT Sloan School of Management that was formed a few years before. The very first beginning of SD was at a workshop with managers of General Electrics (Forrester, 1995). They had a big problem with human resources and Forrester asked them to write down hiring decisions concerning a fluctuating demand. This simple game should provide a better understanding of the problem. The concept at that time was based on Stocks and Flows and is nowadays still used for the quantitative models.

In the upcoming years, Forrester emerged the field of System Dynamics from the hand written phase to the computational phase. In 1958 Richard Bennett - a colleague of Forrester - created the first computer modeling language. It was called *SIMPLE* (Simulation of Industrial Management Problems with Lots of Equations) and Jack Pugh extended this early system dynamics compiler and developed *DYNAMO*. This modeling language was used as an industry standard for over thirty years.

After Forrester has published *Industrial Dynamics* in 1961, which is treated as the origin of SD, this method became popular in management science (Forrester, 1961). In cooperation with John Collins, a former mayor of Boston, the book *Urban Dynamics* was created and published in 1969 (Forrester, 1969). This research changed the house building policies in cities so far and created strong emotional reactions.

The success of *Urban Dynamics* established a contact to the Club of Rome in 1970 through a meeting on urban difficulties in Italy. After a meeting of the club in Bern, Switzerland, and a discussion about the world problems - renewable and nonrenewable resources, exponential growing population etc. - Forrester developed the first *WORLD* model, named *WORLD1*. The refined *WORLD2* model was published in the famous book *World Dynamics* in 1973 (Forrester, 1973). Nine months later *Limits of Growth* was published and the public attention rose enormously. The statement was, that by keeping the current attitude, such as the exponential growing population, pollution, industrialization, and exploitation of nonrenewable resources, the limits of growth are reached within one hundred years. As a result of the environmental destruction, the population will rapidly decline and could inexorably guide to an extinction (Meadows, D.H., Club of Rome and Potomac Associates, 1974).

Limits of Growth was based on the results of the *WORLD3* model and some changes were made in the following years. The first update was done in 1992 and the *WORLD3* model was fitted with current data (Meadows et al., 1992). The overall behavior of the system - an overshoot and collapse scenario (see Chapter 3.5.6) - did not change. In 2004 another update was made and the present attitude leads to the same scenario within the next thirty years. Only strict regulations could guide that model into equilibrium at about eight billion inhabitants (Meadows, D.H. and Randers, J. and Meadows, D.L., 2004).

3.2 System Thinking

Cavana and Maani (2000) described four different levels of thinking and built an analogy of an iceberg. At the tip the level of events is mentioned and represents the state where most people are satisfied and stop thinking. System Thinking is going downwards this iceberg to the underlying levels - Patterns, Systemic Structures and Mental Models.

Sterman (2000) demonstrated the popular event-oriented view, that leads to an event-oriented decision making. Figure 3 shows the basic approach of most problem solving scenarios.

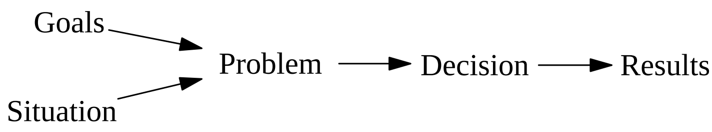


Figure 3: Event-oriented view of the world, adopted from Sterman (2000)

Sometimes the current situation will not be the same as we desire. This discrepancy creates a problem, which should be solved by taking actions. After implementation, we expect the desired state as a result. This one way thinking does not include any other systems and is based on the assumption that the environment or the current situation is not changing during the whole process. Sterman (2000) gave a short example, considering price reduction as a decision to increase sales volume. As a result the amount of sold products would reach the desired level and the problem seems to be solved. After the sales volume has had gone up, competitors start to cut prices too and the sales volume decreases again. This feedback is not mentioned by the event-oriented view. Not considering such side effects or the actions of others could lead to big problems. System Thinkers are aware of these facts, because they tend to think in a feedback view. Figure 4 demonstrates the basic approach of this method.

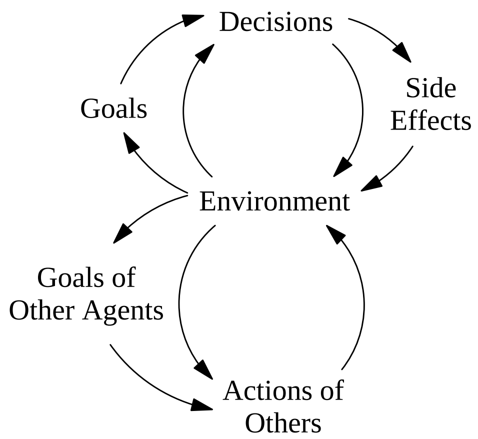


Figure 4: The feedback view, adopted from Sterman (2000)

Once a goal is set and a decision is made the result will change the current situation -

mentioned as environment - and this event could lead to new decisions or maybe different goals. To be aware of unexpected reactions of the environment, side effects should be mentioned as well. The term side effect is not necessarily correct, because an effect on surrounding systems can change their state of the situation enormous. A feedback to the observed system could be delayed and would change the situation in the future. As mentioned in the short example above, other agents are acting in this environment too and they also set actions to reach their goals.

Another example of the feedback thinking process is the basic learning process. Sterman (1994) claimed, that all learning depends on feedback and each decision we make, alters the real world. In consequence of information we gather from the current state, we revise our understanding and we bring the system closer to the desired level by implementing new decisions.

3.3 Causal Loop Diagrams

As mentioned in the beginning, the qualitative models in the field of System Dynamics provide a better understanding of dynamic and complex systems. The complexity of systems does not arise from single variables, but rather it is caused by the relationships between. These connections and the dynamics within the system are based on two different types of feedback (Sterman, 2000). Fundamental loops are either positive (re-enforcing) or negative (self-correcting) and establishes the basis of all Causal Loop Diagrams (CLD). These diagrams are frequently used in SD researches, but they are also common for many different applications, because they are easy to create and provide a lot of information with less time exposure.

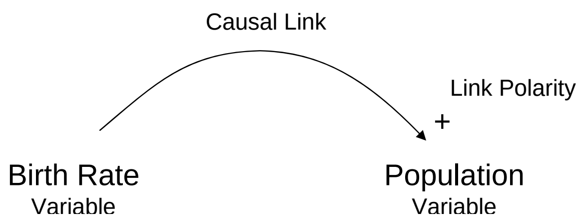
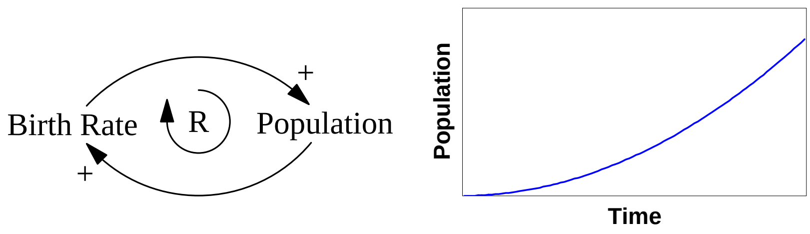
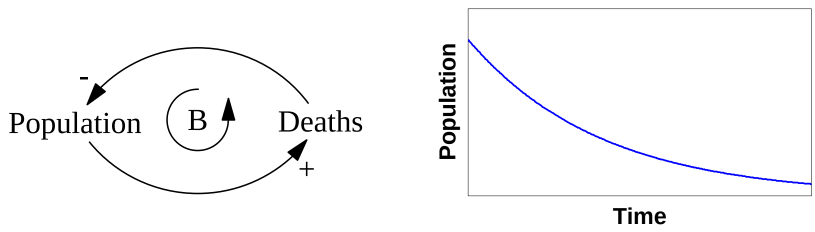


Figure 5: Causal Loop Diagram notation, adopted from Sterman (2000)

Figure 5 illustrates the fundamental notation of Causal Loop Diagrams. As a basic rule, each variable represents a noun and the linkage between the verbs. The arrows present the influence direction and are signed with a plus or a minus to signal the polarity. A plus denotes a positive (+) feedback, that means if variable A is increasing, variable B is increasing too ($\frac{\partial A}{\partial B} > 0$). The minus polarity is called a negative (-) feedback and signifies, that variable B decreases, when variable A increases ($\frac{\partial A}{\partial B} < 0$). Hence the figured example illustrates: If the *Birth Rate* is positive the *Population* is going to increase.



(a)



(b)

Figure 6: Fundamental structure and behavior of feedback loops: (a) positive feedback; (b) negative feedback; adopted from Sterman (2000)

Figure 7 shows a simple example of a Causal Loop Diagram. The main feedback loops are marked with an identifier and provide an information about the behavior. A positive feedback loop is self-reinforcing and marked with an R, in some cases a plus (+) or an avalanche symbol is used as well (see Figure 6(a)). These loops provide an endless exponential growth (see Chapter 3.5.1), but in reality nothing can grow forever. The regulation is done by negative feedback loops that are self-correcting. These loops are identified with a B, minus (-) or scale symbol (see Figure 6(b)). All systems consist of

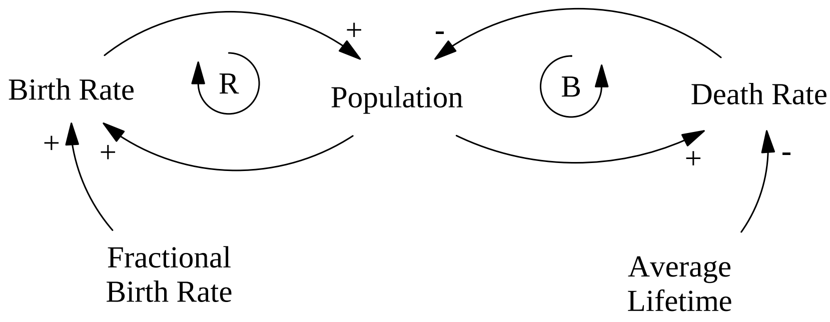


Figure 7: Example of a Causal Loop Diagram (Sterman, 2000)

these feedback loops only, no matter how complex they are. As figured in the example above, a positive loop will constantly increase the *Population*. Presuming a given amount of humans, the *Birth Rate* - people per year - will increase, if the *Birth Rate Fraction* raises. The *Population* will be affected by a second feedback, because people are going to die after a certain period of time. If this *average lifetime* advances, the *Death Rate* - people per year - shrinks.

Causal Loop Diagrams are not figuring stocks and flows, although they act similar sometimes. To explain the difference a short example is given. The population is mentioned as a stock, representing the amount of people on earth, and it is increased by births and decreased by deaths. As a result of a large population, the birth rate is high and if it increases, the birth rate will do so too. Births will always elevate population, while deaths will always lower it. If fewer people die, more of them will stay alive.

As mentioned above, theses qualitative models should provide a very good understanding of interactions and are widely used to represent interdependencies and feedback processes. Causal Loop Diagrams are commonly used in the early phase of System Dynamic projects to map mental models. They are not providing any information about the stock and flow structure of the system and therefore they are not suitable for a simulation.

3.4 Stock and Flow Diagrams

Stock and Flow Diagrams (SFD), compared to the Causal Loop Diagrams (CLD), depict a more detailed structure of the real system. In combination to the feedback processes they form the main concept of the System Dynamics theory (Sterman, 2000). Stocks are accumulations and represent the current state of the System anytime. They are increased by inflows and drained by outflows. Flows represent rates, which are adjustable by valves. The basic diagramming notation is illustrated in Figure 8.

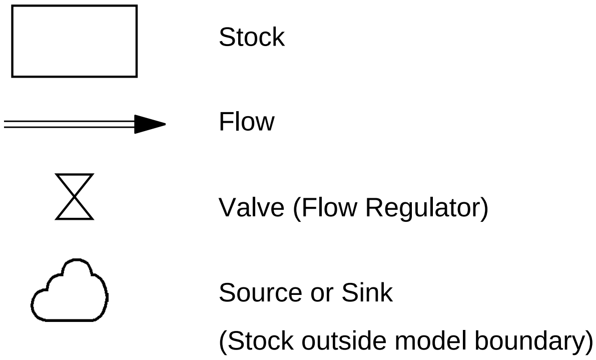


Figure 8: Stock and Flow Diagram notation, adopted from Sterman (2000)

Stocks are represented by rectangles and flows by arrows. Depending on the direction, a flow can be an outflow - pointing away from the stock - or an inflow - pointing in the stock. Integrated valves adjust the quantity of time-dependent in- or outflows. Clouds demonstrate stocks that are not included in the system boundary. In the majority of cases they are called sources or sinks.

Figure 9: Fundamental structure of Stock and Flow Diagrams, adopted from Sterman (2000)

Figure 9 illustrates the basic structure of a Stock and Flow model. The mathematical form can be represented as an integral (1) or differential equation (2).

$$Stock_{(t)} = \int_{t_o}^{t} \left(Inflow_{(s)} - Outflow_{(s)} \right) \, ds + Stock_{(t_0)} \tag{1}$$

$$\frac{d\,Stock}{dt} = Net\,Change\,in\,Stock = Inflow_{(t)} - Outflow_{(t)} \tag{2}$$

As mentioned above, the stocks represent the state of the system during simulation runs. By tracking their levels, figures are created and provide a good understanding of the system behavior. Many stocks that are representing real systems are mentioned as reservoirs. Like a bathtub, they can be filled and drained by the valves, but if there is no water inside, nothing can flow out of it.

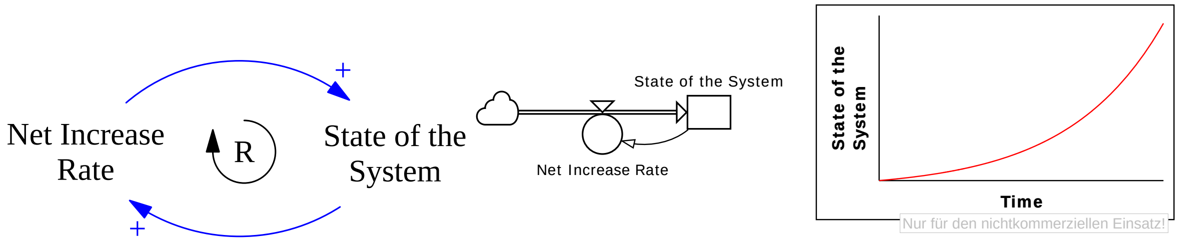
Depending on the simulation software more symbols are included in Stock and Flow Diagrams, especially Variables (Circles) and Constants (Diamonds) for the calculation of flows (see Chapter 4.2).

3.5 Basic behavior modes

According to the already mentioned characteristics, all dynamics of systems arise from the feedback loops, stocks and flows, and non-linearity due to decision making processes of acting agents within (Sterman, 2000). Sterman listed some fundamental modes of dynamic behavior. The most fundamental modes are described in this section. Identifying such basic archetypes is useful in very early phases of the modeling process, especially when creating qualitative models (Cavana and Maani, 2000). Senge (2006) extended these fundamental modes and published system archetypes which are very powerful in prescribing existing systems. These archetypes could be used as a diagnostic tool to establish a better understanding of organizational structures (Kim and Burchill, 1992).

3.5.1 Exponential growth

A positive feedback loop is self reinforcing and the exponential growth is the consequently reaction. Figure 10(a) shows the basic structure of a reinforcing loop using only two variables. This exponential growth can also be triggered by loops containing many different variables and negative feedback too. As long as the number of negative polarities is even, this response occurs. Figure 10(b) illustrates the basic stock and flow structure as well as the exponential growing behavior. According to the connection between *net increase rate* and the current *state of the system*, increasing one variable

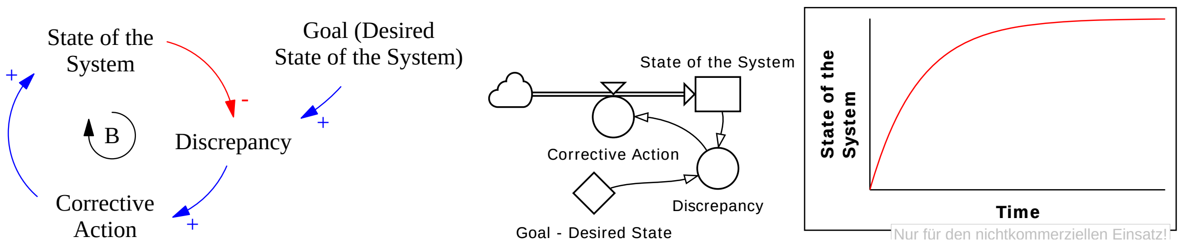


(a) (b)

Figure 10: Exponential Growth mode - (a) CLD (Sterman, 2000); (b) SFD structure and system behavior

rises the other. For example, the population is assumed to be the state of the system and the birth rate as net increase rate. The birth rate - measured in people per year - is depending on the actual amount of people. As a consequence of a constant average number of children per person the amount of births per year will increase, if there is more population. Each born child enhances the amount of people and leads to an exponential growing population.

3.5.2 Goal-seeking

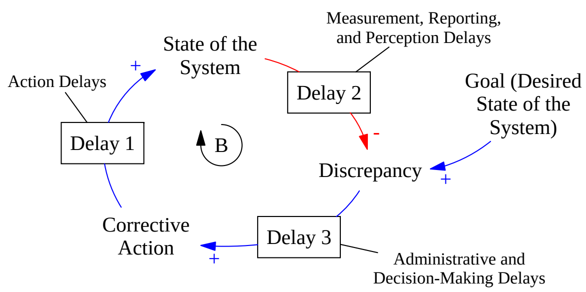


(a) (b)

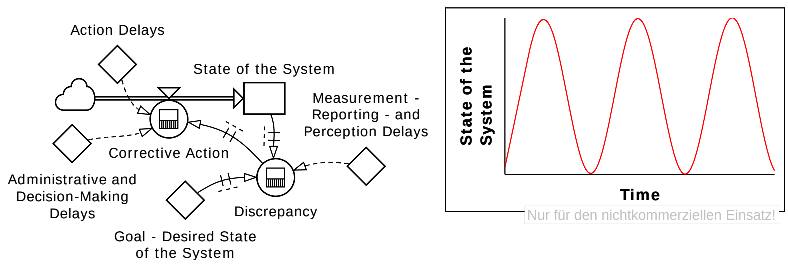
Figure 11: Goal Seeking mode - (a) CLD (Sterman, 2000); (b) SFD structure and system behavior

In the goal seeking mode the system tries to reach a desired value. Figure 11(a) shows the qualitative model of this system. A desired state of the system is set and compared to the current situation. Presuming the desired state is greater than the present state, the behavior is shown in Figure 11(b). The negative polarity within the feedback loop creates a self-correcting attitude and will guide the system in equilibrium. In the beginning the discrepancy between the desired and the current state of the system is huge and the corrective action is great. This leads to a very strong growth in the beginning. As a result of the rapidly increasing state of the system the discrepancy becomes smaller and thus the corrective action too.

3.5.3 Oscillation



(a)



(b)

Figure 12: Oscillation mode - (a) CLD (Sterman, 2000); (b) SFD structure and system behavior

The third fundamental mode arises from the time delays between variables. The structure, shown in Figure 12(a) is similar to the structure of the goal seeking mode. The current is compared to the desired state of the system and a discrepancy leads to corrective actions. As a consequence of perception, measurement, and reporting, a time delay occurs and the discrepancy is calculated with obsolete data. The corrective action is commonly based on decisions, made by agents within the system. Considering, that each administrative process takes a specific time, the decision for a corrective action, as well as the realization, and the impact on the system are delayed.

In the beginning the discrepancy is huge and strong corrective actions are set, similar to the goal seeking scenario. As a result of the delayed perception of the current state, the corrective action tends to be high and the desired state of the system will be exceeded. Corrective actions change and the current state needs to be narrowed to reach the goal. Due to the delays the desired level will be undershot and the adjustments have to be changed again. Depending on the delays, this action can stabilize over a certain period, oscillate in a constant frequency (see Figure 12(b)) or explode, which is known as the chaos-scenario. Delays are common in real systems and therefore oscillations are among most occurring modes of behavior.

3.5.4 S-shaped growth

The previous three modes are called the fundamental modes and based on a single feedback loop with or without delays. The upcoming behavior modes are more complex but very common in the real world. At first the S-shaped growth structure is shown in Figure 13(a). This system contains a reinforcing loop and a balancing loop that is going to stabilize it. The reinforcing loop is similar to the exponential growth in Section 3.5.1. A maximum capacity is added and if the current state of the system approaches the limit, the fractional net increase rate is shrinking. Hence the net increase rate will be zero, if the capacity is reached.

Figure 13(b) represents the stock and flow structure and the system behavior, which resembles an “S”. In the beginning an exponential growth occurs, according to the non active balancing loop. This loop will create a bigger impact, if the current state approaches the limit and the system will tend to equilibrium. This simplified behavior is very common in nature. Capacity is limited and as long as there is enough space available an exponential growth is possible. If the free space becomes less, the growth rate will be lowered. In reality the limit is exceeded, due to a late perception of overcrowding or other delays.

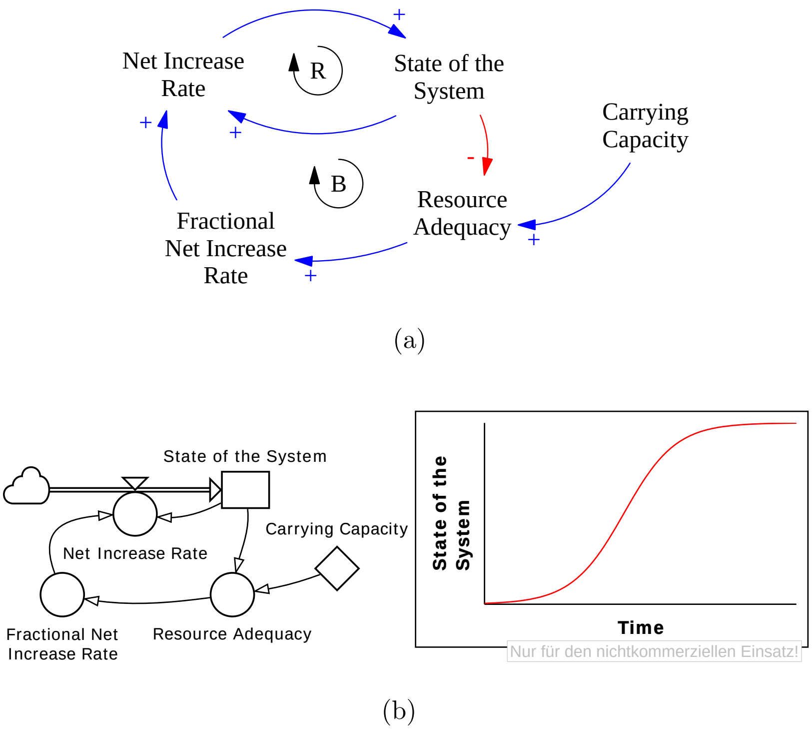


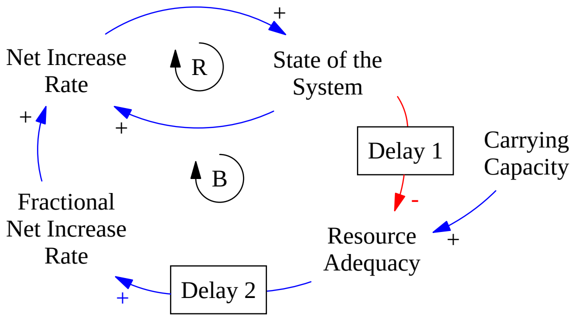
Figure 13: S-shaped Growth mode - (a) CLD (Sterman, 2000); (b) SFD structure and system behavior

3.5.5 S-shaped growth with overshoot

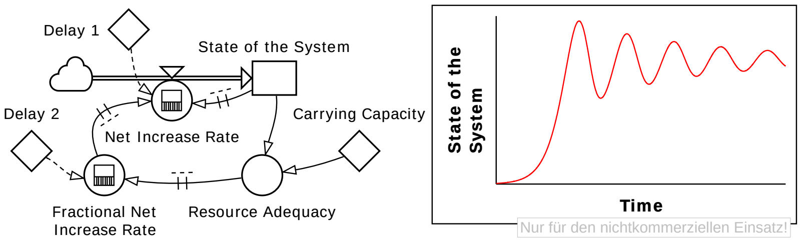
This behavior mode is similar to the basic S-shaped growth. As mentioned above, delays lead to a late recognition and slow down counteractions. In Figure 14(a) the delays are added. The system behavior shown in Figure 14(b) tends to be the same in the beginning, due to the fact, that the balancing loop is not active yet. After the overshoot, the system is oscillating around the carrying capacity and depending on the delays, it could stabilize, oscillate in a constant frequency, or explode.

3.5.6 Overshoot and collapse

A fundamental assumption within the S-shaped growth behavior mode is, that the carrying capacity is constant and does not change over time. In Figure 15(a) a second balancing loop is included, that erodes the capacity. In the beginning the behavior is



(a)

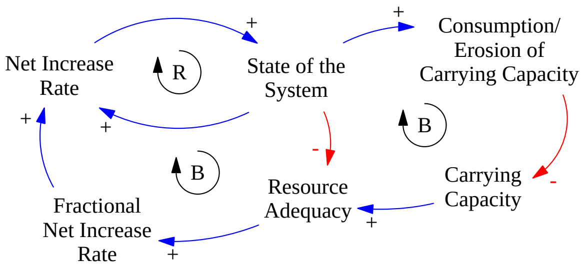


(b)

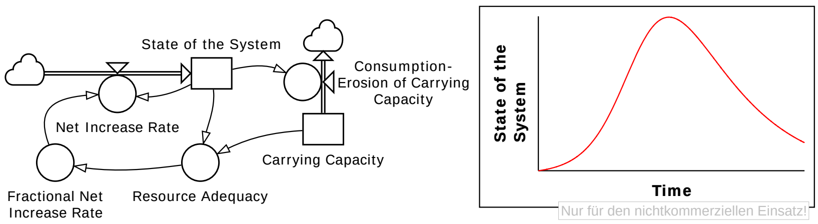
Figure 14: S-shaped Growth with Overshoot mode - (a) CLD (Sterman, 2000); (b) SFD structure and system behavior

similar to the S-shape growth, because both balancing loops are not active and an exponential growth is possible. Instead of only one regulation, that would guide the model in equilibrium, the second loop is starting to decrease the capacity. After a certain period the current state of the system is equal to the capacity and the net increase rate is zero. When the system reaches the maximum, the erosion is at its maximum and the carrying capacity shrinks very fast. As a consequence of the negative resource adequacy, the net increase rate will be negative too and the state of the system continues declining. This behavior is illustrated in Figure 15(b).

A basic example, considering the current population and the exploitation of non renewable resources should provide a better understanding. If the population continues the exponential growing behavior, the available non renewable resources will be shortened faster. Assuming, that every person consumed the same amount, the capacity will decrease and after a certain period not every person will be able to satisfy the individual



(a)



(b)

Figure 15: Overshoot and Collapse mode - (a) CLD (Sterman, 2000); (b) SFD structure and system behavior

requirements. As a result of the unfulfilled claims, less children are born and the exponential growth of the population will be weakened. But the exploitation of non renewable resources continues and a maximum will be reached. As a result of a very low birth rate - that is not exceeding the death rate any more - the population is going to decline. The shortage of resources will trigger a negative net birth rate and the population is declining even faster. This fundamental behavior mode is well known from the famous *WORLD* model, mentioned in Chapter 3.1.

3.6 Evaluation of Models

Each model is an abstraction of the real world and due to the different perceptions and understanding of relationships, the behavior of a model could vary from the real situation. Forrester mentioned, that the validity of a model should be judged by its suitability for the particular purpose it is created for. Models can be very useful for a specific application, but worse than useless for another purpose (Forrester, 1961). Forrester mentioned, that validity of a model should be examined relative to:

- *System boundaries*
  System boundaries should be chosen suitably for the related objectives. If the system boundary is set to far, the model will increase in complexity and may lead to confusion. If important issues are not mentioned inside the boundary, the model will be useless.

- *Interacting variables*
  Are all important variables and their connections properly mentioned within the model?

- *Values of parameters*
  Constant coefficients provide the state of the current situation and need to be declared within a plausible range. Sensitive parameters should be identified by model testing and values based on decision functions could be based on a statistical research.

The literature provides three main tasks in the modeling process. Forrester and Senge (1980) declared the basic notation as follows:

- Testing
  "By testing, we mean the comparison of a model to empirical reality for the purpose of corroborating or refuting the model."

- Validation
  "Validation is the process of establishing confidence in the soundness and usefulness of a model."

- Verification
  "Verifying structure means comparing structure of a model directly with structure of the real system that the model represents."

Sargent (2005) mentioned, that it is very costly and time consuming to reach an absolute validity over the complete application area of a model. Figure 16 depicts the relationship of costs for model validation as a function of the model confidence.

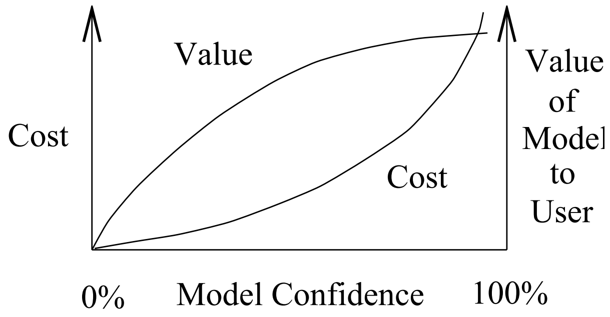


Figure 16: Costs and value to user as a function of the model confidence (Sargent, 2005)

Sargent also highlighted, that validation and verification is not a single action within the development process, but rather it is a concept that is usually part of the entire process. Figure 17 illustrates the modeling and simulation process and all usual testings within.

Starting in the real world, all available data has to be structured and unessential information needs to be sorted out. Data is also generated by concerning different facts, that are maybe extraneous. In the early phase a conceptual model is created and due to different perceptions, some relationships could be presumed deficiently. Further verifications are needed, until the simulation provides useful results. At last a validation has to be done by comparing the simulation results with the current real system.

Basically all validation techniques can be divided into subjectively or objectively approaches (Sargent, 2005). There are many techniques available, depending on the availability of data and time. In most cases a combination of different methods is used. Animation of shipped products, comparison to other models or historical data, and operational graphics methods are very common and provide a good understanding of the system behavior.

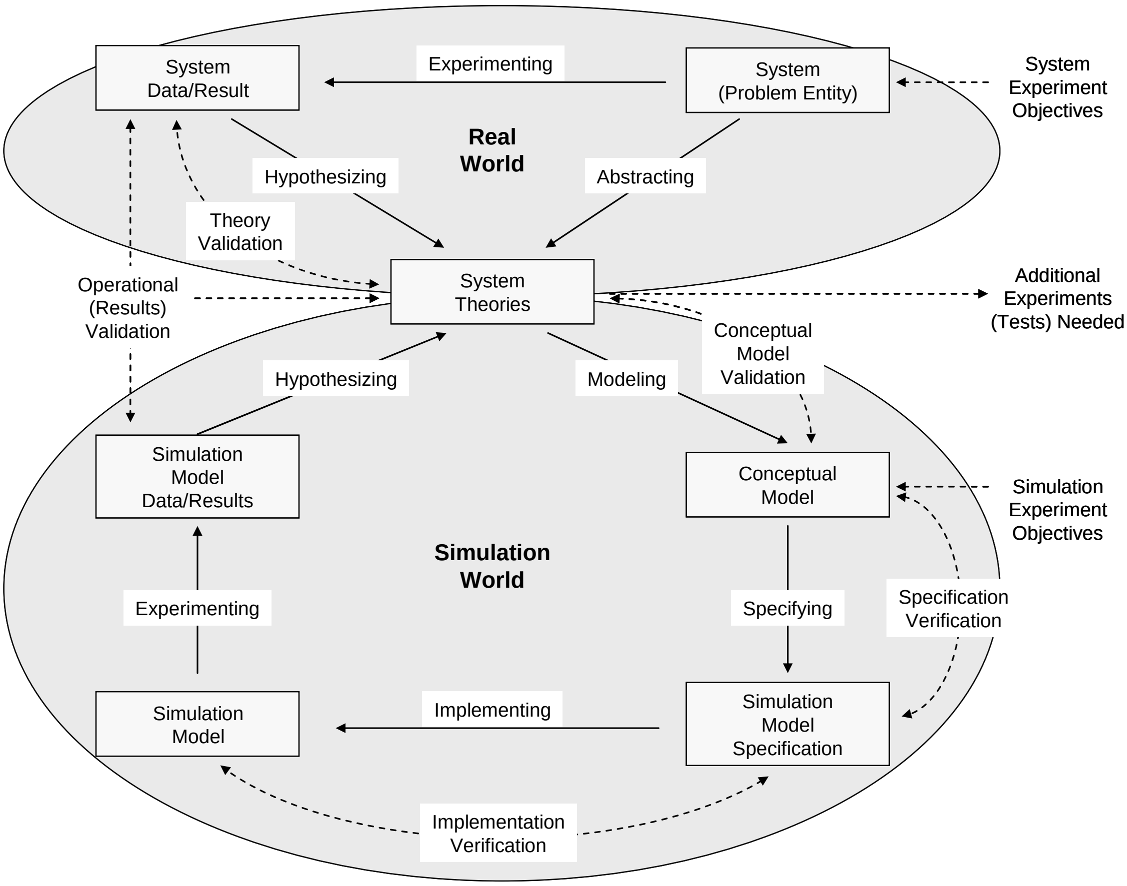


Figure 17: Real World and Simulation World relationships with Verification and Validation, adopted from Sargent (2005)

4 SD Applications and Alternatives

Despite the fact, that SD was developed to solve important problems on the top management level it is rarely used in enterprises yet (Bradl, 2003). Computer simulations are common in many kinds of engineering applications, such as wind-tunnels, fluid dynamics, finite elements and many more. In the field of strategic management only few computerized models assist decision making processes. Gary et al. (2008) published a research about the current state of SD implementations in the wide ranged field of management. They argued that the strategic field is very interested in understanding the dynamics that lead to big differences in firms performance and the linkage to managerial decision making. Hence they predicted big opportunities for System Dynamic researchers in the future.

According to the variety of companies, each SD model has to be created for a specific situation. Depending on the size of the project, high error rates and costs lead to big difficulties. Malone et al. (2009) argued, based on interviews with experts, that small professional system dynamics researches would burden $25,000 up to $100,000. More complex project trigger expenditures that reach into millions. They also mentioned, that only a few models were used after solving the original problem. As a result managers expect that the positive effect and the resulting advantages will cover all expenditures. Due to the high error risk and the probability that the whole project fails, the managers regard SD-Researches sceptically.

4.1 Applications within Enterprises

The SD-society is mainly focusing on theoretical research and implementations are not the big issue. Based on the early concepts of Forrester, social and economical studies are widely spread. More suitable approaches exist for the operational field of management and therefore SD researches are concentrating on more environmental or intangible aspects. Hidaka et al. (1999) used SD to transfer the basic Total Quality Management

(TQM) approach into a Causal Loop Diagram. They also declared, that this method provides a better understanding for managers. Kim and Burchill (1992) used SD-archetypes to generate a better understanding in the field of TQM implementations.

Ewaldt (2000) used SD to describe the effects of capacity limitations within multilevel production chains and showed the dynamics due to different delays within the manufacturing process. Nowadays companies are also very interested in sustainable manufacturing and the impact on the environment. To show these impacts - coming from reduction of pollution, the consumption of raw material, and waste - Kibira et al. (2009) created a modeling framework. More dynamic and complex behavior occur in the interconnection between production and process improvement. SD is also appropriate to manage this complexity and provides a better understanding of these dynamics. Morrison (2010) asserted, based on his research, that managers should focus on the creation of confidence and experience, rather than focusing on highest possible output or improvement rates.

The supply chain tend to be very complex in most cases and therefore a lot of studies are dealing with the dynamics that arise from this complexity. As a consequence of the popular bullwhip effect, retailer and supplier tend to make overhasty order decisions (Goncalves, 2010). A SD modeling framework of Georgiadis et al. (2005) addresses the supply chain of the food industry, but their approach is suitable for other fields of application too. A more detailed supply chain research deals with the closed-loop supply chains, concerning manufacturing and re-manufacturing, under different inventory policies (Bijulal and Venkateswaran, 2008). Much more studies are done in the field of supply chain management and the dynamics within are very good described. More complexity is located in the opposite direction. Market dynamics arise from a bulk of different aspects. Researches are dealing with many different issues and are always created for a specific kind of market. Wang and Cheong (2005) created a model, which abstracted the mobile commerce market. Yan (2009) dealt with the complexity in the project based industry and focused on the market competitor behavior. The variety of views towards the market creates very different purposes of market related researches. As already stated, each study has to be fitted to the initial objectives and therefore many of them describe the investigated market very good, but are nearly useless in a different one.

The use of SD in the strategic project management can trigger big advantages for managers. Managing the complexity of projects leads to an increase in performance. Lyneis et al. (2001) mentioned, that the use of SD is most effective when it is a part of a learning process, because further projects and decisions are based on the experience of previous studies. The decision making process is mainly based on the knowledge of the decision maker, hence Yim et al. (2004) used SD for improving the decision making performance in higher level strategic concerns. Beintner (2010) stated, that SD projects does not guarantee successful strategy formulation and combined the SD approach with the field of soft operation research to support the strategic decision making processes within enterprises.

The area of strategic planning is a part of the strategic management process and mainly based on forecasting system behavior. Lander (2005) provided a strategic planning tool for recycling management within enterprises, based on a study, concerning end of life vehicles.

The philosophy of using SD to assist managers is as old as SD itself and countless investigations were made in nearly every area. Forrester (2003) stated, that thus far model formulation has been rather unsuccessful. He quoted many reasons of failure and mentioned, that especially the structure of economically regenerative loops that make up our economic system are inadequately reflected.

4.2 Simulation Software

The first introduced software solution was based on the 1958 developed SIMPLE compiler and named DYNAMO (Forrester, 1995). Although DYNAMO was developed and used for continuous simulation, it was also an impulse for the development of discrete event simulations (Nance, 1993). DYNAMO was state-of-the-art for about 30 years, but as a consequence of the technological progress and particularly the diffusion of Windows, new software solutions were developed (Clark Jr. and Kurono, 1995). STELLA was introduced 1985 and provided a visual programming standard, that is used nowadays as well. There are many software packages providing similar basic features, but differ in the surface and handling, such as iThink®, ModelMaker®, Powersim® Studio, Vensim® and many more. In addition to the theoretical part, a qualitative and a quantitative model of a pharmaceutical industry was created. The following quantitative part of the case study (Chapter 5) is implemented in Powersim® Studio 8 and therefore this software package is explained in detail.

Powersim® Studio

Powersim® Studio is a registered trademark of Powersim Software AS© and available in different versions. Currently Version 9 is available, but the following case study is executed in PowerSim® Studio 8.

Powersim® Studio 8 provides a user interface, that allows modelers to draw simple stock and flow diagrams by a few clicks. The software solution does not support the creation of Causal Loop Diagrams, but enables many possibilities to adjust or display parameters. Different views allow a good segmentation, even if the model is huge, and therefore a good overview of the project is possible. In addition Powersim® Studio 8 enables continuous data exchange with spreadsheets or databases. As mentioned in Chapter 3.4 each software solution uses different additional symbols. The fundamental notations, used in this case study, are listed in Figure 18.

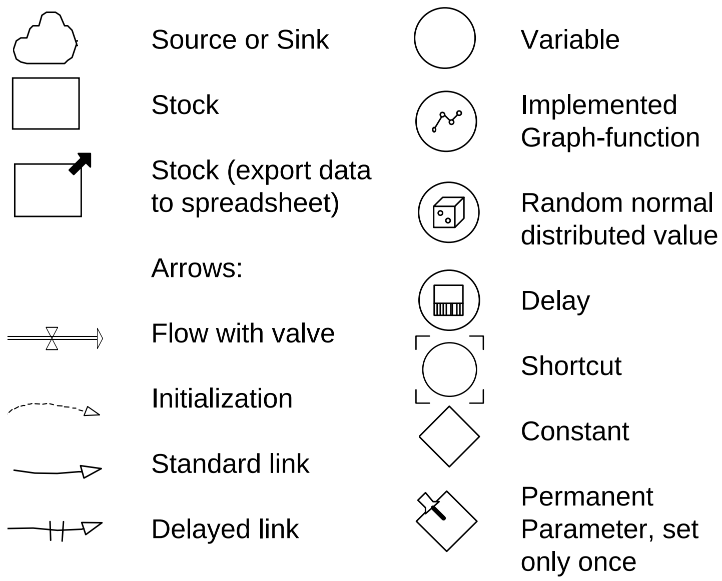


Figure 18: Fundamental notations of Powersim® Studio 8, which are used in the case study

In addition to the basic notations of Stock and Flow Diagrams - Stocks, Flows, Valves, Sources and Sinks - Constants and Variables are implemented. Arrows figure the linkage between entities, but does not provide further information about the polarity. Basically each variable is calculated by their linked variables, constants or stocks, and contains a specific unit. Dotted arrows sign an initialization of stocks by a constant, that is set in the beginning. Usually constants are adjustable during the simulation, based on the assumption that some conditions may change. If a constant should not be modified during the simulation, it is fixed as permanent and enables adjustments only before the simulation start.

An implemented graph function returns values for given inputs. If some values depend on statistical or empirical data, these functions will express the relationship between the variables. Normal distributed values, or delays are also commonly used in SD researches, especially in social or economic models. Delays occur in nearly every stage of system activity, because every action takes time. Basically delay functions let information, or material, wait before their effect is implied on another parameter. Powersim® Studio 8 contains different types of delay functions. Two of them are frequently used, such as the DELAYPPL and the DELAYINF. The DELAYPPL-Function can be seen as a conveyor belt, where nothing come out until a certain time expires. The DELAYINF-Function returns the n^{th}-order exponential delayed input. This attitude is common for a response to a step increase and the order of the delay is equal to the number of levels the flow runs through.

As mentioned above Powersim® Studio 8 provides different views for a better segmentation of models. Therefore shortcuts enable the additional use of a variable in more than one view. Stocks or Constants can also be used in more diagrams within the same project. A shortcut is always illustrated as a boxed symbol.

Powersim® Studio 8 is a very powerful software for continuous stock and flow simulation. It provides many additional features, such as optimization, event-handling and scenario control. The interface allows a very easy error handling and marks failure directly in the model. In addition to the automated failure analysis, objective and subjective tests has to be done. Therefore Malczynski (2011) provided two very useful checklists for model constructions and analysis.

4.3 Alternative Simulation Techniques

In General each model is used to map real problems in an abstracted world. This process is called abstraction. Afterward the model is optimized, analyzed, and the solution is transferred back into the real world, which is called implementation. The main distinction between different types of models is done in the way of solving. Analytical models are commonly depending on functions and analytically solved with simple solutions - e.g. spreadsheets. In many cases an analytical solution is not possible and problems need to be solved by simulations. The term simulation is also used to describe the execution of models.

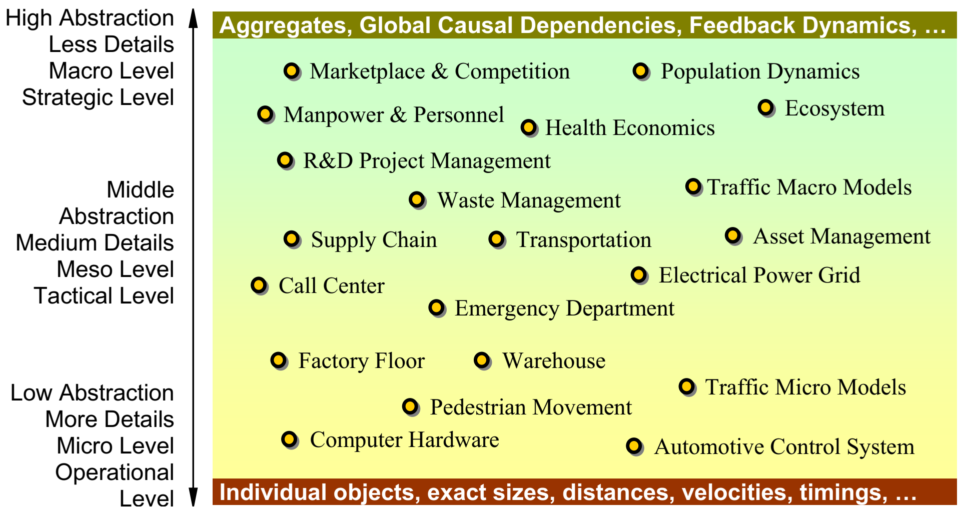


Figure 19: Applications of Simulation Modeling on Abstraction Level Scale (Borshchev and Filippov, 2004)

Borshchev and Filippov (2004) illustrated the typical range of problems that are subject of common simulation modeling techniques (see Figure 19). In addition to the System Dynamics (SD) approach two other simulation modeling techniques are very popular:

- Discrete Event (DE or DES)
- Agent Based (AB)

Beside these fundamental methods, Dynamic Systems (DS), which are known for modeling physical systems, are mentioned as well. Borshchev and Filippov (2004) explained the fields of applications of these techniques on the same scale (see Figure 20).

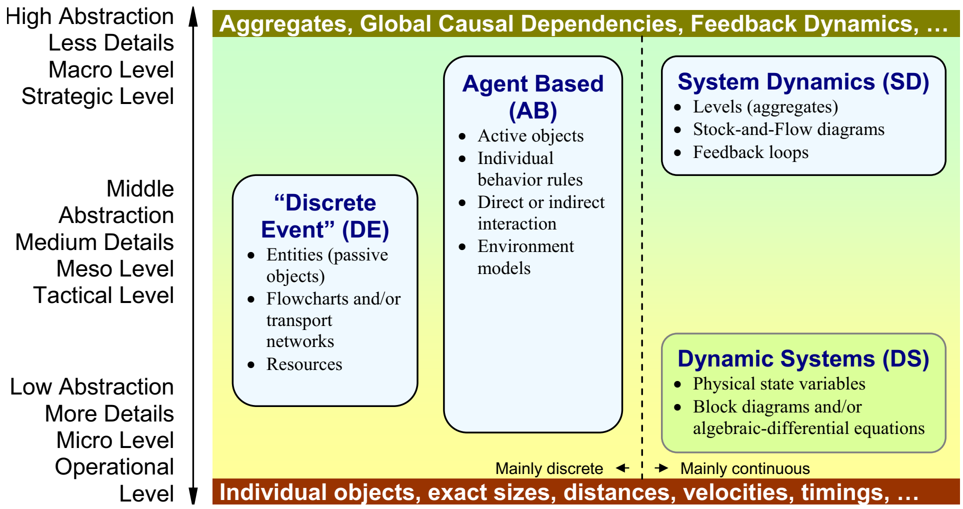


Figure 20: Approaches (Paradigms) in Simulation Modeling on Abstraction Level Scale (Borshchev and Filippov, 2004)

DS is not mentioned in the following description, because this method is not related to managerial issues. Depending on the abstraction, the DES approach is used in the lower and middle level. In the field of management DES is efficiently addressed to the micro or meso level, better known as the operational level. Similar to the AB method, DES calculates with discrete time steps, which means that after an event is processed the calculation advances to the next event.

While SD and DES are very traditional methods, the field of AB modeling is relatively new, because the computational power was not high enough until the 1990s (Kortelainen and Lattila, 2009). AB modeling is hard to categorize within the abstraction scale, because this classification depends on the type of modeled agents only. A categorical definition of entities, that are necessary to create an agent, does not exist (Schieritz and Milling, 2003).

Schieritz and Milling (2003) compared the SD approach to the AB method - in their obviously named research: *"modeling the Forrest, or modeling the trees"* - and the main differences are listed in Table 1.

Each technique has strengths and weaknesses and new approaches try to combine different methods to exploit their advantages. This diploma thesis is founded on the idea of combining SD and DES. Sophisticated researches are dealing with these combinations

	System Dynamics	Agent-based Simulation
Basic building block	Feedback loop	Agent
Unit of analysis	Structure	Rules
Level of modeling	Macro	Micro
Perspective	Top-down	Bottom-up
Adaptation	Change of dominant structure	Change of structure
Handling of time	Continuous	Discrete
Mathematical formulation	Integral equations	Logic
Origin of dynamics	Levels	Events

Table 1: System Dynamics versus Agent-based Simulation (Schieritz and Milling, 2003)

and some modelers are talking about the “holy grail” (Brailsford et al., 2010). SD is not dealing with stochastic behavior and shows big disadvantages by modeling individual variability. On the other hand, DES is not suitable for modeling high abstraction levels with few available data. Brailsford et al. (2010) mentioned, that it is possible to model these parts with DES too, but these approaches would be absurdly huge, slow in performance and very data intensive.

Another attempt towards this *Holy Grail* is the combination of SD and AB. Kortelainen and Lattila (2009) created a hybrid model to explain competition in a constantly developing market environment. Each of their four modeled entities - Customer needs, Product, Firm, and Technology - consists of an underlying SD model, which describes the agents development. Events trigger a communication between those agents and therefore a discontinuous sequence of simulation steps. Größler et al. (2003) combined SD and AB for a supply chain model. The manufacturer behavior is given by a SD model and creates orders, while the supplier is modeled as an agent and delivers goods in each simulation step.

Additionally the possibility of combining DES and AB should be mentioned as well. Their linkage is easier, because DES already consists of individual entities, which could become an agent. DES entities are treated as passive objects and thus it is possible to give them an extra individual behavior (Borshchev and Filippov, 2004).

5 Case Study: Pharmaceutical Industry

The goal of this diploma thesis, in addition to the theoretical part, is to create a model of a pharmaceutical company and to show the advantages of implementing System Dynamics as a tool for strategic decision making within enterprises. A reference company was chosen, to fit the model to the most likely scenario. Beside the data collecting, also important relationships were mentioned during interviews with managers. The following model is mainly based on a reference product, because of the diversity in the field of pharmaceutical products. The first chapters introduce the company and the product and give a short overview about the study area. A mental model provides the basic fragmentation of the system. Causal Loop Diagrams create a better understanding of the existing feedback processes. On the one hand these diagrams should help managers going through the decision process, because correlations of subsystems and the interaction within them are illustrated. On the other hand these models serve as the basis for a simulation. In Chapter 5.3 each subsystem is explained in detail and finally all of them are connected to an entire model.

5.1 Company and Product

5.1.1 Fitofarm

Fitofarm was founded in 1989 and is located in Skopje, Macedonia. Regarding the European and International standards, they are producing pharmaceutical and cosmetic products, as well as food supplements, medical devices and consumer products for general use in their newly constructed facility. Beside the national market in Macedonia, Fitofarm is presenting its own portfolio in many neighboring countries, like Bulgaria, Turkey, Montenegro, Albania, Armenia, Azerbaijan, Bosnia and Herzegovina and Kosovo (Fitofarm, 2012). The production is mainly automated, packaging and distribution is done manually. New production machines guarantee high production capacity. During a visitation some bottlenecks were figured out, especially in the dispatch warehouse.

Currently the manufacturing is done in a single shift and the maximum utilization is not reached yet, so the bottleneck does not limit the actual production.

Regarding the international standards the new facility contains a state of the art laboratory. After manufacturing a special product batch, a sample out of it is brought to the laboratory. Laboratory assistants check the products and after passing all tests, the whole batch will be shipped to the dispatch warehouse. Depending on the product, the revision could take up to one day.

Actually Fitofarm employs 61 workers and five of them are sales representatives. At least two of them are currently advising doctors to secure the sales quantity for their premium product (see Chapter 5.1.2). Doctors will prescribe this particular medicine more likely to the patient, when the sales representatives advise the doctor as often as possible. If the doctors prescribe this product, the patient will go to the pharmacy to get this particular medicine. Most pharmacies have their own inventory management system and if they run out of stock, they will send an order to the wholesaler. The wholesaler uses his own inventory management system and places orders depending on the inventory level at the reference company. Fitofarm tries to fulfill orders mainly out of their inventory. To be aware of downtime and unexpected high orders, a safety stock, that last at least a couple of weeks, is desired.

At the moment Fitofarm does not spend a lot of money for advertising. Only a certain amount is used to support sales representatives with advertising specialties. It is hardly possible to distinguish between marketing and customer relationship in this particularly situation. Due to the fact, that there is no direct connection to the customer it seems to be more like a marketing concept. In further use, there is no differentiation between both denotations. Marketing and customer relationship is basically the advice to the doctors, done by the sales representatives. Advertising investments are mentioned as expenses that lead to even better advise efficiency.

Fitofarm is currently comparing sales quantity with the number of advices per doctor each month. They are not aware of the impact that occurs by changing the amount of sales representatives. Assuming that more sales force leads to a better result is true, but due to the fact of higher labor costs, it does not make any sense to increase the number of sales representatives more than a specified amount. The potential market is not that big and the effect of market saturation is limiting the profit. Further raise of the sales force leads to a linear growth in labor costs, but only a small increase in revenues.

Despite the fact, that activities in understanding market behaviors are not the main issue of the company, a lot of data and relationships were mentioned by the managers during interviews. System Dynamics seems to be a very good method, to connect their existing knowledge with market models. In further use, the simulation should provide a good forecasting, especially for market behavior for product launches.

5.1.2 Reference Product

Gamalon® is a premium product of Fitofarm and considering the amount of available data and the well known market, it is chosen as the reference product for this model. To declare Gamalon® as a premium product is not based on a portfolio analysis, but rather on the issues of high price and low production costs and therefore a good contribution margin. Many other Fitofarm products are sold much more often, but the margin is usually very small. Gamalon® is considered as a food supplement and is used for many different treatments. In order to obtain the drug, a prescription is required. Because the sale is highly dependent on the opinion of the doctors, a connection to the sale force can be established. In the field of only available on prescription drugs, the price is regulated by the government and prevent an aggressive market. The product quality is no issue as well, because all competitors use the same raw material and due to the strong regulations, each product has to reach a very high quality standard.

5.2 Model Overview

5.2.1 Mental model

Models are commonly used in management and should be a substitute, representing the real system. Forrester (1961) classified models basically in physical and abstract models. Depending on the linkage to time, they are static or dynamic. He also mentioned that managers are dealing continuously with mental models, that are not necessarily correct, but rather they are substitutes of the reality in our thinking. There is no real framework for creating a mental model. Doyle and Ford (1998) named some definitions and demonstrated the big difference in perception. Mental models are also very common in the field of System Dynamics. Sometimes the Causal Loop Diagram is used to map a mental model as well, but in this chapter the first approach is based on the statement of Vosniadou and Brewer (1992). They see the main purpose of creating mental models by answering questions, solving problems and dealing with other situations. Especially for the understanding of interconnections between different areas and the flows within, a mental model of the industry is figured below.

At first, the system has to be bounded. The company is dealing with many environmental aspects, but not all of them can be taken into consideration. Figure 21 shows the mentioned areas in the company's surrounding. The basic flows within the systems are also figured. These flows consider information, products, money as well as human resources.

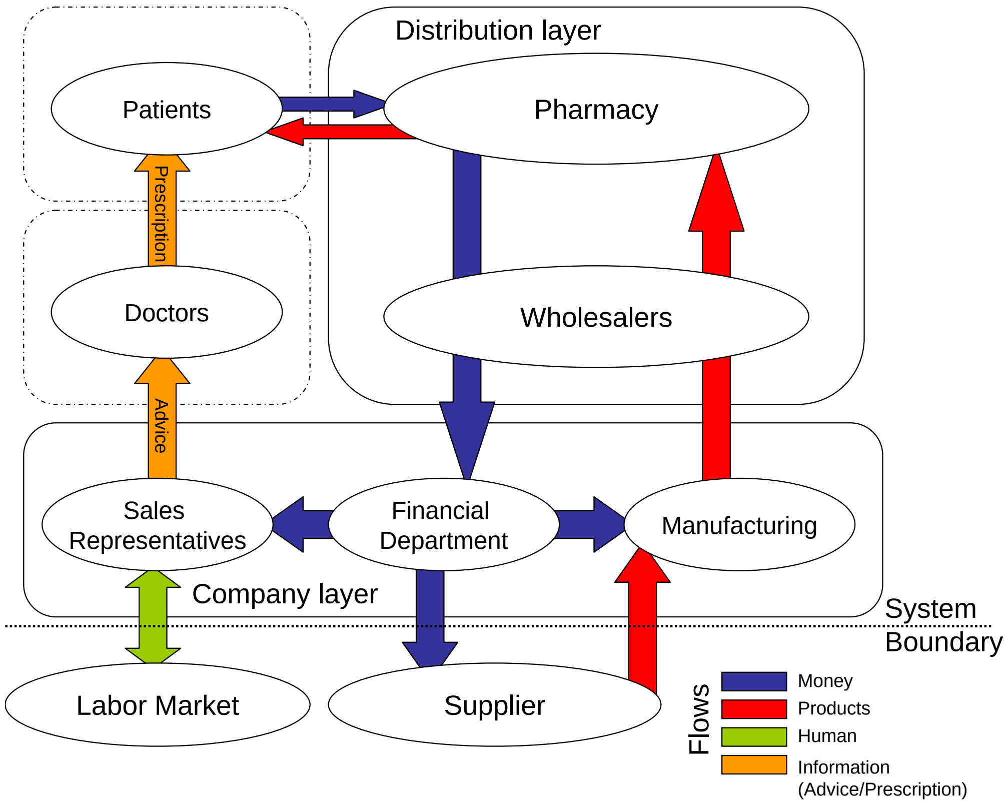


Figure 21: Mental model of the pharmaceutical industry, including the basic flows

In the next step, the scope of the model is defined. Fitofarm produces a variety of products and their sales representatives advise doctors for different products. This model should only mention the reference product (see Chapter 5.1.2). All flows within the model are specified for this particular product. Especially the salary of the sales representatives is mentioned as a proportionate amount. At the moment there are two employees responsible for advising doctors on the reference product.

The company layer is divided into three segments. The *staff segment* is deals with the human resources, including the sales force. Other employees - e.g. in administration, production, etc. - are not considered in this model. The current situation provides enough personnel to fulfill all orders and the managers are aware of the fact, that increasing the sales quantity would require more staff. The possibility of manufacturing in more shifts was considered, but these arrangements are not taken into account in this case study.

The *financial segment* is focusing on the basic profit calculation policies and provides the main monetary numbers for the managers. Administration, packaging and operational expenditures, are not separated and mentioned within the unit costs for each product. There are no mass effects - e.g. the degression of unit costs - due to the small market and the currently high automation level of the company. Revenues are dependent on the sales quantity and the product price. Because the product price is set by the government, the only way to increase the revenues is to raise the sales volume. Expenditures are linked to the amount of sales representatives and the production costs. In addition, investments in advertising can trigger higher expenditures as well, but as mentioned above, this is not intended.

The *production segment* provides the product supply, to fulfill all incoming orders. The distribution of the product contains three different levels. The basic production level includes the manufacturing, the verification in the lab and afterward the storing in the dispatch warehouse - figured in the company layer. The second level compromises the shipment to and storing at the wholesalers and at last the product reaches the pharmacy, where it is received by the patient.

5.2.2 Basic structure

Cavana and Maani (2000) provided a methodological framework, to structure the modeling process and explained the phases of system thinking and modeling methodology. At first the problem needs to be structured, which is already done by the mental model in Chapter 5.2.1. After defining the boundaries and scope of the project, it has to be modeled with Causal Loop Diagrams. Based on their research, the modeling process contains several steps. They stated that not every phase requires every step and their approach should be treated as a guideline for modeling. The following list should give a short overview about the basic steps that are used in this study.

1. Identify main (key) variables.
2. Develop causal loop diagrams (influence diagrams) to illustrate the relationships among the variables.
3. Identify system archetypes that would describe high-level causal patterns.

The next phase is named the dynamic modeling process. Further steps are mentioned as well, like the implementation and the scenario planning. An implementation is not the basic objective of this study, therefore the dynamic modeling process is the last step in this research.

In cooperation with the managers it was possible to figure out some key variables. During meetings they highlighted some issues, that are very important for the company. These values are treated as key variables within the model and each variable represents a subsystems within the model.

The main key variables - in alphabetical order - are:

- **doctors prescribing the product**
  The amount of doctors that are prescribing the particular product.
- **orders**
  The amount of orders placed at the company.
- **profit**
  The profit calculated by opposing revenues to costs.

- **total sales representatives**
  The amount of productive sales representatives.
- **treated patients**
  The number of patients, treated with the reference product.

Figure 22 shows the relations of the key variables. Despite the fact, that there are more connections within the model, this basic approach connects only key variables and explains the idea behind.

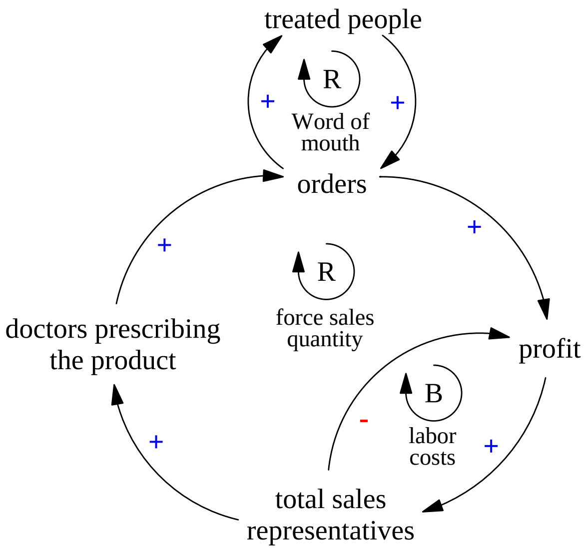


Figure 22: Interconnection of the key variables

Starting with the amount of sales representatives a direct connection is drawn to the doctors that are prescribing the reference product. By increasing the sales force, the amount of *prescribers* raises and therefore the number of prescriptions increases as well. Assuming that every prescription represents an order, the key variable is named orders. There is also a positive correlation to the profit, as there is a positive profit margin. An increasing profit would result in hiring new sales representatives. This behavior is called a reinforcing loop and the system would explode. Additionally the amount of treated patients is increasing, which leads to the word of mouth effect and a hype cycle. This loop accelerates the exponential growth of the system behavior. Because of an existing market restriction - not displayed in Figure 22 - the amount of doctors that are prescribing the product is limited. The number of orders is limited as well, as there are not endless potential patients available. A constant growth in labor costs creates a balancing loop that stops the exponential growth and guide the model to stabilization.

To build the model from scratch is very hard, because the available data of the company's environment is limited and an intensive study of market behavior is not possible within a short period of time. After an extensive literature research many already exiting models were found, which are providing a very good basis in each segment. The goal is to adopt, modify and combine these parts to an entire model.

Bass (1969) developed a model for the diffusion of innovations, John Sterman adopted the model for System Dynamics and named it the Bass Diffusion Model (Sterman, 2000). This model is widely used for describing market behavior, especially the adoption of new products, and describes the empirical adoption curve of new products very well (Bass et al., 1994). The publication of the Bass model was voted for one of the most influential works and has become very important in forecasting Business to Business (B2B) products (Bass, 2004). The Bass Diffusion Model is widely-used in many fields of applications. Sandberg (2011) explained the diffusion of democracy by using it and Paich et al. (2011) already implemented a Bass Diffusion model to describe the adoption of pharmaceuticals according to a study of pharmaceutical market behavior. It seems to be appropriate to use it for this case study as well.

A very good production model, concerning backlogs and inventory forecasting, from Sterman (2000), is a suitable abstraction of the real situation. According to the idea of simplification, an assumption is made within the supply chain. The distribution of the product consists of several steps, which lead to the bullwhip effect. This concept was developed by Forrester and is also known as the Forrester effect (Goncalves, 2010). High oscillations in inventory and orders will decrease the effectiveness of each participant within the supply chain. The necessity of safety stocks and therefore high inventory costs and a poor production utilization lead to an inefficient result of the whole system. The bullwhip effect is strongly dependent on the interconnection of the supply chain and the behavior of each participant. Lee et al. (1997) named causes of this effect and explained how to counteract it.

Due to the fact, that there are many different ways of distribution and a lot of individual participants, the supply chain is not modeled in each single step. Pharmacies tend to order from different wholesalers and many of them are connected as well. Sometimes goods are shipped from one warehouse to another, or a product ordered at a specific wholesaler is brought by a different one. All actions within the supply chain result in a very complex structure and makes it even impossible to model. The bullwhip effect could trigger great problems, but in this case, the supply chain is not that long and the potential market not that big. Price fluctuations are not occurring and a good demand forecasting is already implemented. The exclusion of the supply chain should not make the simulation untruthful, because guessing the connections of the supply chain and the scope of them would distort the model even more

In order to mention the existing bottleneck in the supply chain, the production capacity is limited. Assuming the restriction at this level provides the same effect, as it currently occurs in the distribution path. Therefore the dispatch warehouse of the production subsystem will be treated as the whole supply chain without any further delays. Based on these assumptions the model is divided into five parts.

- **Labor pool**
  considers the amount of sales representatives, hiring and quitting of employees.

- **Doctors**
  considers the adoption of the product by physicians.

- **Patients**
  considers the potential market, the prescription of the product to patients and the current treated patients.

- **Production**
  considers the production layer, order fulfillment, inventory adjustments, production starts and order forecasting.

- **Finances**
  considers the profit calculation based on a simple Cash-Flow statement.

According to this segmentation, the entire model contains five subsystems. The financial unit consists of variables that derive from different segments, but this part is excluded, to keep the entire model clear. The fundamental feedback processes are illustrated in Figure 23 and provide a good insight of the system.

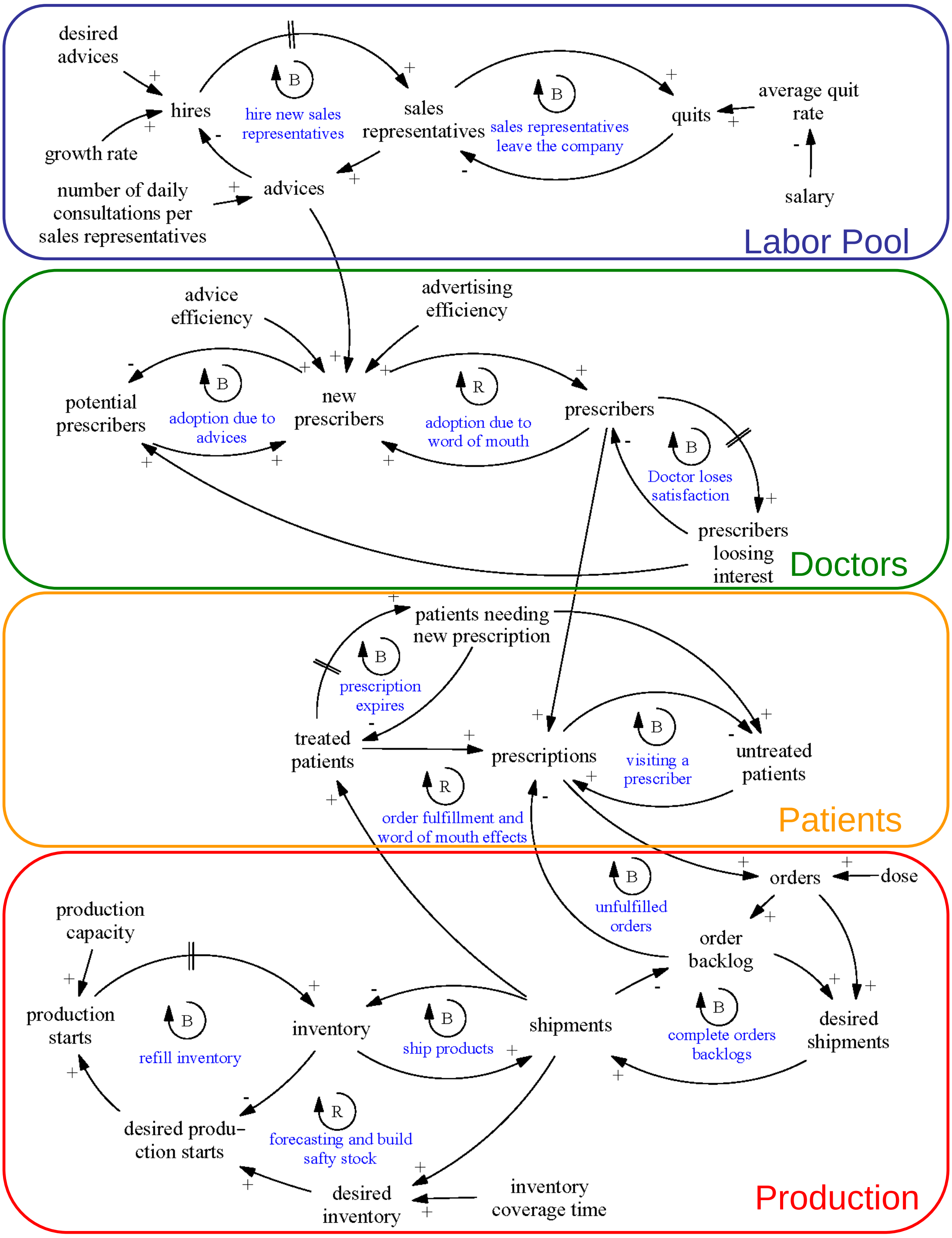


Figure 23: Pharmaceutical Industry (CLD)

Figure 22 on page 41 has shown the connections between the key variables and this notation is basically the same in the entire CLD model. The positive linkage from profit to sales force is missing in this CLD, because the hiring decision is not primarily based on the financial statement. As long as the production is not limited by the constraint, the revenues will rise due to a higher sales volume. According to the market saturation, a further increase of sales force will still advance revenues, but decrease the profit. To prevent a focus on the sales volume, the profit is chosen as a financial reference value. The financial background for hiring decisions is basically established by comparing the profit development from different simulation runs. In reality the primary reason for hiring new staff is the discrepancy between current and desired advice frequency and therefore this is the single cause in the model.

5.3 Sub-models

In the following chapters each subsystem is explained in detail. A short explanation describes the basic approach of each segment and a Causal Loop Diagram (CLD) provides an overview of the relevant connections. The implementation within the simulation software - Powersim® Studio 8 - is done by Stock and Flow Diagrams (SFD). All used variables, abbreviations, units and equations are described, as well as assumptions that were made, to gain useful rates. Every subsystem contains across system variables. Their destinations and impacts on other systems are explained in each section.

All assumptions within this model are made in coordination with managers of the reference company and are primarily based on already existing or implemented System Dynamic researches.

5.3.1 Labor pool

Sales representatives are the most important factor for the product turnover. They visit doctors and advise them, hoping that they will prescribe a particular medicine. Assuming that there is unlimited production capacity and no bottleneck within the distribution, the sale force is the major impulse for sales quantity. These circumstances lead the company to focus as much as possible on the labor pool.

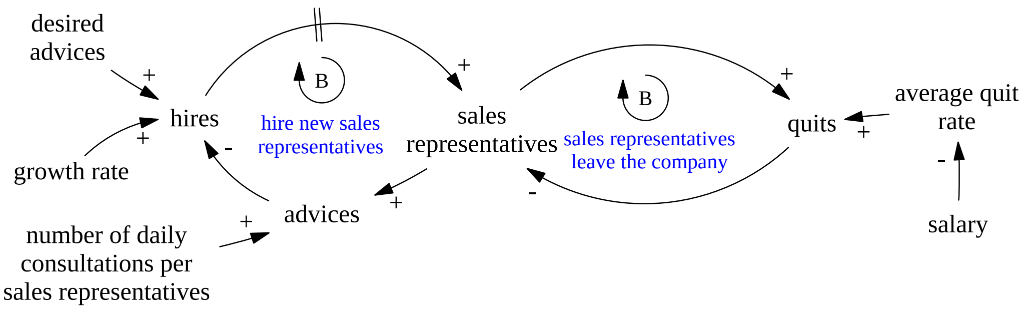


Figure 24: Labor pool subsystem (CLD)

As shown in Figure 24 the amount of sales representatives is increased by hiring and decreased by quits. From the perspective of the labor market, this type of job is considered as a transitory work. Job advertisements are well answered, but the employee is not willing to stay more than a certain time with the company. Higher educated sales representatives are more likely to leave the company earlier than others, due to much better offers in more specific fields of application. The reference company intends to hire well educated sales representatives and is aware of the fact, that they are not that long with the company.

Each sales representative is expected to visit a certain amount of doctors per day. This goal is set by the sales department and should be reached by each sales representative, whether the employee is experienced or not. Depending on this amount, an advice frequency is calculated (see Equation 3). The decision to hire or not is based on the deviation of actual and target advice frequency.

$$f_{advice} = \frac{total\, amount\, of\, sales\, representatives * advices\, per\, day}{total\, number\, of\, doctors} \tag{3}$$

If the company desires to hire new staff, they will not do it abruptly. A maximum growth rate is implemented to prevent high oscillations in labor pool. Due to the delay between hires and the actual amount of sales representatives, which is representing the non productive time in the early phase, the real amount of staff is not the same as the productive staff.

Basically sales representatives could be released too, but in fact of this transitory work cognition it is enough to stop hiring. Within a certain period of time, sales representatives leave the company and the labor pool is stabilizing.

Stock and Flow Diagram

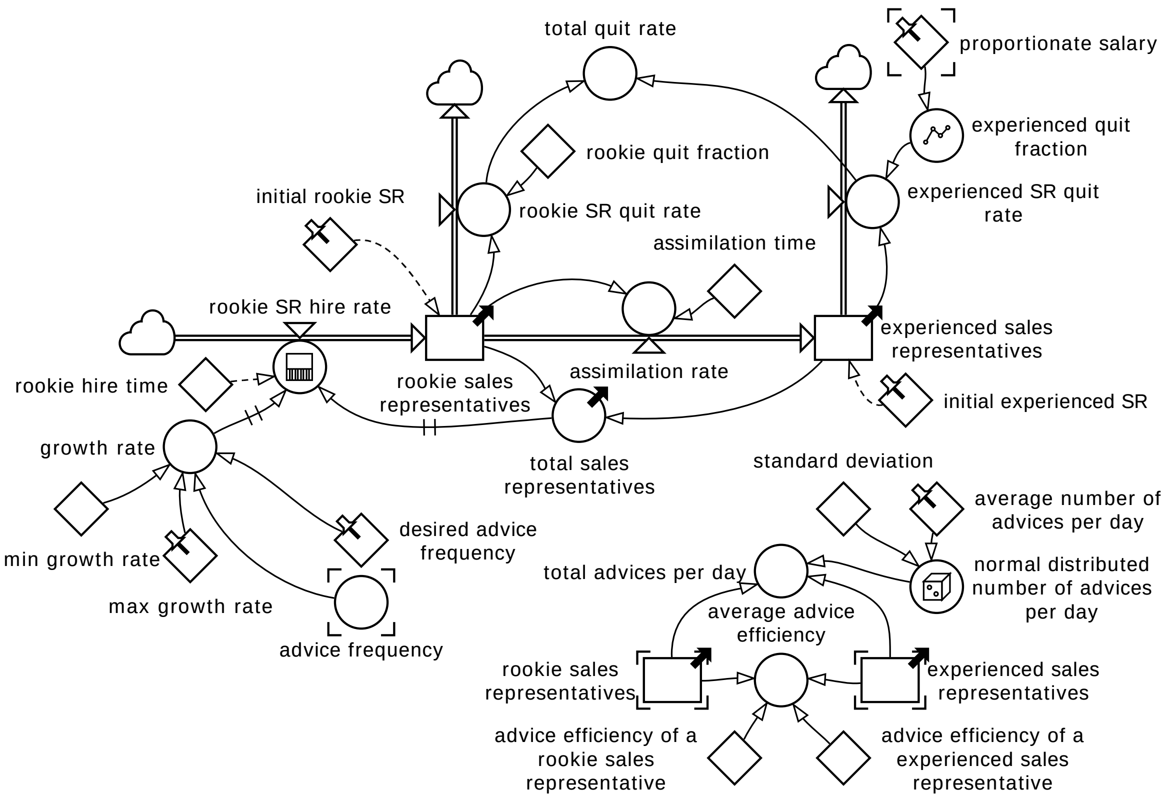


Figure 25: Labor pool subsystem (SFD), modified from Sterman (2000)

variable name	abbreviation	value	unit
advice efficiency of a experienced SR	$eff_{advice_{exp}}$	100	%
advice efficiency of a rookie SR	$eff_{advice_{rookie}}$	75	%
advice frequency	f_{advice}	inbound	$\frac{1}{month}$
assimilation rate	$rate_{assimilation}$	-	$\frac{salesmen}{year}$
assimilation time	$t_{assimilation}$	2	$year$

Continued on next page

variable name	abbreviation	value	unit
average advice efficiency	$eff_{advice_{avg}}$	-	%
average number of advices per day	$advices_{per\,day_{avg}}$	initial	$\frac{doctors}{day*salesman}$
desired advice frequency	$f_{advice_{desired}}$	initial	$\frac{1}{month}$
experienced quit fraction	$frac_{quit_{exp}}$	-	$\frac{1}{year}$
experienced SR	SR_{exp}	-	$salesmen$
experienced SR quit rate	$rate_{quit_{exp}}$	-	$\frac{salesmen}{year}$
growth rate	$rate_{growth}$	-	$\frac{1}{year}$
initial experienced SR	$SR_{exp_{initial}}$	initial	$salesmen$
initial rookie SR	$SR_{rookie_{initial}}$	initial	$salesmen$
maximum growth rate	$rate_{max\,growth}$	initial	$\frac{1}{year}$
minimum growth rate	$rate_{min\,growth}$	0	$\frac{1}{year}$
number of advices per day	$advices_{per\,day}$	-	$\frac{doctors}{day*salesman}$
proportionate salary	$salary_{proportionate}$	inbound	$\frac{Euro}{month}$
rookie hire time	t_{hire}	3	$month$
rookie quit fraction	$frac_{quit_{rookie}}$	0.25	$\frac{1}{year}$
rookie SR	SR_{rookie}	-	$salesmen$
rookie SR hire rate	$rate_{quit_{rookie}}$	-	$\frac{salesmen}{year}$
total advices per day	$advices_{per\,day_{total}}$	-	$\frac{doctors}{day}$
total quit rate	$rate_{quit_{total}}$	-	$\frac{salesmen}{year}$
total SR	SR_{total}	-	$salesmen$

Table 2: Variables used in the labor pool subsystem

Figure 25 shows the Stock and Flow Diagram of the labor pool subsystem. All used variables, abbreviations, values, and units of the labor pool segment are mentioned in Table 2.

The sales representatives are divided into two several stocks. The stock *rookie sale representatives* (SR_{rookie}) is representing new hired employees that are already productive, while the stock *experienced sale representatives* (SR_{exp}) mentions workers that are with the company for a longer period and incorporated. The reference company is not willing to hire experienced sales representatives, because well educated and experienced workers are very expensive and rare on the labor market. The only possibility to increase the staff is to hire inexperienced workers, so called Rookies. The basic model is known as the promotion chain and learning curve from Sterman (2000) and is modified for this issue. 5 The amount of rookie sales representatives is increased by hiring and decreased by getting experienced and quitting. The steady amount of job-seekers allows the company to hire without delay, if necessary. As mentioned above, the company does not hire all at once. They are going to follow a certain *growth rate* ($rate_{growth}$). By choosing the *desired advice frequency* ($f_{advice_{desired}}$) the company is going to hire, with *maximum growth rate* ($rate_{max\,growth}$), until the current sale force is able to fulfill the requirements (see Equation 6). This $rate_{max\,growth}$ is adjustable and on that account, it is a lever for the managers. If there is no necessity to hire new staff, they company will use the *minimum growth rate* ($rate_{min\,growth}$). If the $rate_{min\,growth}$ is assumed negative, the inflow will turn into an outflow, representing dismissals. As stated above, releasing staff is not intended, so the $rate_{min\,growth}$ is set to zero.

$$rate_{growth} = IF\,(f_{advice} < f_{advice_{desired}}, rate_{max\,growth}, rate_{min\,growth}) \qquad (4)$$

The rate of hired rookies is also depending on the actual amount of *total sales representatives* (SR_{total}) and specified in the variable *rookie hire rate* ($rate_{hire}$). To hire a huge amount of new rookies while the actual staff is low would not make sense. The proportion of already trained staff and new staff should be mentioned, due to the fact, that all the new employees have to be trained on the job as well.

$$SR_{total} = SR_{rookie} + SR_{exp} \qquad (5)$$

After hiring a new employee it takes at least 3 month to become a productive sales representative. Therefore the inflow of rookies is delayed by the *rookie hire time* (t_{hire}). This delay is modeled as a pipeline-delay (see Equation 6) and as a result each hiring decision will increase the sales force after this period. The initial hire rate is given by $rate_{hire_{initial}}$ and is depending on the simulation scenario.

$$rate_{hire} = DELAYPPL(SR_{total} * rate_{growth}, t_{hire}, rate_{hire_{initial}}) \qquad (6)$$

After 2 years the rookie sales representative becomes an experienced sales representative. This *assimilation time* ($t_{assimilation}$) was named by the managers of the reference company. After this period they treat the employee as an experienced one and give him new instructions. The amount of rookies becoming experienced each month is reflected in the variable *assimilation rate* ($rate_{assimilation}$).

$$rate_{assimilation} = \frac{SR_{rookie}}{t_{assimilation}} \tag{7}$$

Well trained sales representatives are used to visit conferences and exhibitions too. As a result, they are not consulting as many doctors per day, but the managers pointed out, that the effectiveness could be modeled the same way. Instead of visiting a certain amount of doctors each day he will probably advice at least the same amount of doctors at a conference. The main difference between a rookie and an experienced sales representative is the effectiveness of the advice. The *advice efficiency* of an experienced employee is 100% and of an rookie at about 75%. The calculation of the *average advice efficiency* ($eff_{advice_{avg}}$) is shown in Equation 8 and used in Chapter 5.3.2.

$$eff_{advice_{avg}} = \frac{eff_{advice_{rookie}} * SR_{rookie} + eff_{advice_{exp}} * SR_{exp}}{SR_{rookie} + SR_{exp}} \tag{8}$$

With a certain probability a rookie sales representative will leave the company before he becomes an experienced one. This behavior is common in every business and mostly regardless of the salary. The outflow *rookie SR quit rate* ($rate_{quit_{rookie}}$) decreases the amount of rookies. Assumed that only one out of two rookies becomes an experienced sales representative the *rookie quit fraction* ($frac_{quit_{rookie}}$) is set to 0.25 $[\frac{1}{year}]$

$$rate_{quit_{rookie}} = SR_{rookie} * frac_{quit_{rookie}} \tag{9}$$

Equation 10 shows the accumulation of the rookie sales representatives.

$$SR_{rookie} = \int_{t_0}^{t} (rate_{hire} - rate_{quit_{rookie}} - rate_{assimilation})\, dt + SR_{rookie_{initial}} \tag{10}$$

Transitory work means, that only a very small amount of once hired staff stays with the company for a long time. According to the managers of the reference company the average period of employment is about five years. Therefore, after two years of being a rookie there are three years left for an average experienced sale representative. The *experienced quit fraction* is assumed to be 0.333 $[\frac{1}{year}]$. The number given by the managers of the reference company is mentioned as the initial value in this model and will be treated as a constant. As already mentioned, the *experienced SR quit rate* ($rate_{quit_{exp}}$) depends on the proportionate salary. To show another lever for managers, the quit rate is set as a function of the proportionate salary (see Figure 26). By increasing the average salary, the proportion of experienced and rookie sales representatives is changing and the average advice efficiency is increasing. Initially, this relationship was not recognized by the managers, on grounds of their method of calculation (see Chapter 5.1.1).

$$frac_{quit_{exp}} = f(salary_{proportionate}) \tag{11}$$

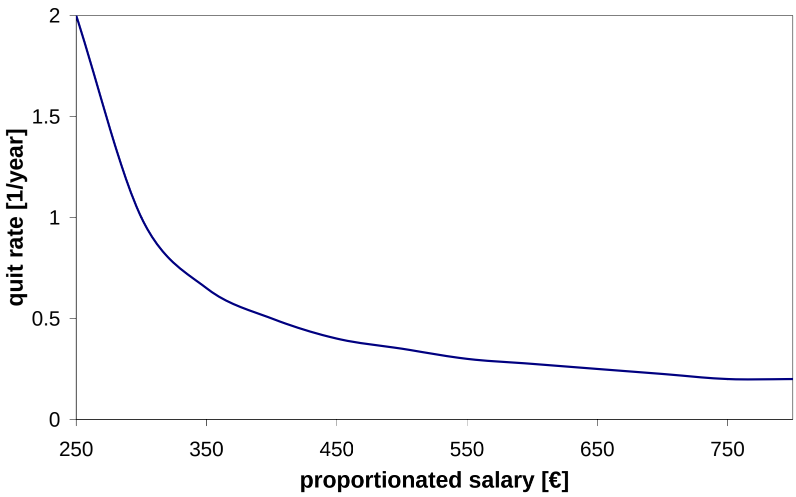


Figure 26: Quit fraction as a function of the proportionate salary

After declaring the inflow and outflow of the SR_{exp} stock, the initial amount of experienced sales representatives is set and depends on the start up scenario.

$$SR_{exp} = \int_{t_0}^{t} (rate_{assimilation} - rate_{quit_{exp}})\,dt + SR_{exp_{initial}} \tag{12}$$

Each sales representative whether he is experienced or not, should do a certain *number of advices per day* ($advices_{per\,day}$). This Goal is set by the sales department. Basically this target is reached and sometimes exceeded as well. In coordination with the reference company the effective number of advices is calculated, by considering a normal distribution.

$$advices_{per\,day} = NORMAL(avg\,advices_{per\,day}, standard\,deviation) \tag{13}$$

Multiplied by the total number of sales representatives the number of *total advices per day* ($advices_{per\,day_{total}}$) is calculated and transmitted to the doctor segment.

$$advices_{per\,day_{total}} = advices_{per\,day} * SR_{total} \tag{14}$$

As already pointed out in Equation 3 the advice frequency is computed f_{advice} and effects the hiring decisions function.

Across system variables

outbound variable	inbound variable	Section
average advice efficiency		5.3.2
	advice frequency	5.3.2
	proportionate salary	5.3.5
total advices per day		5.3.2

Table 3: Across systems variables of the labor pool subsystem

The amount of total sales representatives is treated as a key variable within the labor pool segment. In consequence of the constant amount of doctors within the study area, the advice frequency depends solely on this variable. The impact to the doctors segment occurs mainly from the advice efficiency and frequency. The across system variables of the labor pool subsystem are mentioned in Table 3

5.3.2 Doctors

The doctor segment is based on the diffusion model, once developed by Bass (1969) and already implemented in a model of the pharmaceutical market behavior by Paich et al. (2011). The Bass diffusion model is used to describe the adoption of new products or technologies in many different researches. As already mentioned in Chapter 5.2.2, the Bass Model is used for forecasting and provides great results. Paich et al. (2011) named the potential consumers prescribers and divided them into physicians that already adopted this medicine and those who have not. Their approach is adopted for this model and is modified in some parts, especially because the product type is completely different.

In Figure 27 all doctors within the study area are treated as potential prescribers. Depending on the actual satisfaction of the product they are divided into three categories.

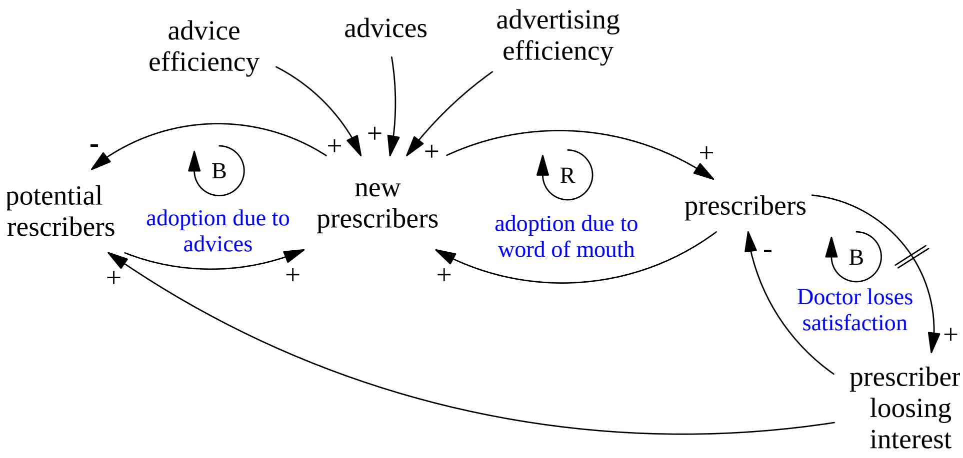


Figure 27: Doctors subsystem (CLD)

In the beginning all potential prescribers are unaware of the product or unsatisfied to prescribe it and resulting from external and internal influences they become aware of the product.

Advising the doctor is the most important external factor and the amount of new prescribers is strongly depending on the *advice frequency* f_{advice} and the *average advice efficiency* $eff_{advice_{avg}}$. Sometimes advertising leads doctors to prescribe this medicine as well. In the early phase only few doctors - Bass named them "early adopters" or "innovators" - will prescribe the medicine. After the product reached the market successfully, more doctors will prescribe the medicine and another feedback loop starts to change the system - Bass called them "imitators". This is known as the word of mouth effect. If more physicians are satisfied with the product, they will advice other doctors to prescribe it too. This reinforcing loop needs to be activated once and can lead to huge, sometimes unexpected success.

The managers of the reference company pointed out that competition could be very strong at this level. Every competitor sends sales representatives to obtain the doctor's attention for their own product. It is not the goal of System Dynamics to model the attitude of a single doctor, but to gain suitable rates, the behavior of an individual physician is very important. In coordination with the reference company it was possible to find a correlation between the probability to prescribe a medicine and the time that has passed since the last advise (see Figure 28). The function contains three segments, which are named Phase 1 to 3.

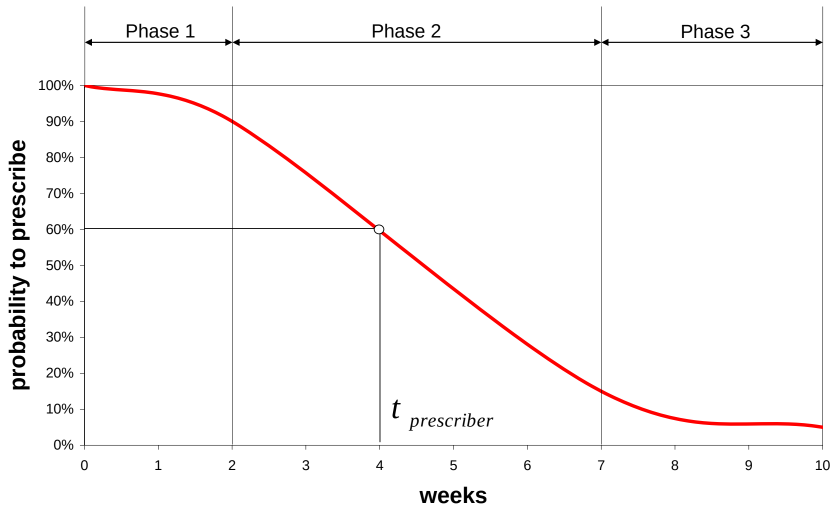


Figure 28: Probability to prescribe the medicine as a function of time passed since an advice

- **Phase 1** - shortly after advising
  Within the first two weeks, there is no significant decline. The doctor is aware of the product and prescribes it regularly.
- **Phase 2** - recently after advising
  After two weeks, he will probably forget about the product and a constant decline in satisfaction occurs.
- **Phase 3** - longer time after advising
  If the last advice happend longer than seven weeks before, the doctor will not prescribe that medicine any further. The last remaining prescriptions are results of some patients that are insisting on this particular drug.

$t_{prescriber}$ marks the time span of treating a doctor as prescriber. After this period he acts like an unaware doctor and has to be satisfied again.

Stock and Flow Diagram

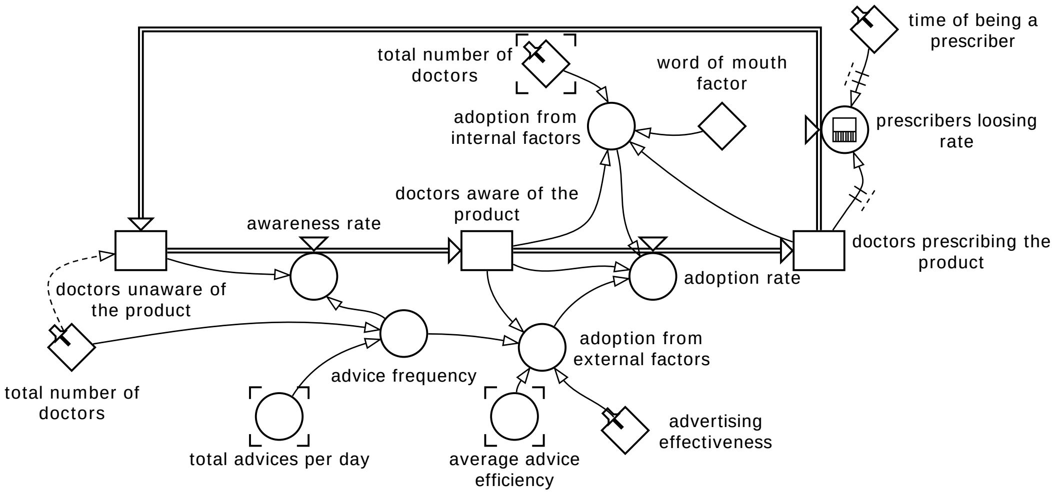


Figure 29: Doctors subsystem (SFD), modified from Paich et al. (2011)

Figure 29 presents the Stock and Flow Diagram of the doctor subsystem. All used variables, abbreviations, values, and units of the doctor segment are listed in Table 4.

variable name	abbreviation	value	unit
adoption from external factors	$adoption_{external}$	-	$\frac{doctors}{month}$
adoption from internal factors	$adoption_{internal}$	-	$\frac{doctors}{month}$
adoption rate	$rate_{adoption}$	-	$\frac{doctors}{month}$
advertising effectiveness	eff_{advert}	initial	$\frac{1}{day}$
advice frequency	f_{advice}	-	$\frac{1}{month}$
average advice efficiency	$eff_{advice_{avg}}$	inbound	%
awareness rate	$rate_{aware}$	-	$\frac{doctors}{month}$
doctors aware of the product	$doctors_{aware}$	-	$doctors$
doctors prescribing the product	$doctors_{prescribers}$	-	$doctors$
doctors unaware of the product	$doctors_{unaware}$	-	$doctors$
prescribers loosing rate	$rate_{loosing\,prescribers}$	-	$\frac{doctors}{month}$
time of being a prescriber	$t_{prescriber}$	initial	$weeks$
total advices per day	$advices_{per\,day}$	inbound	$\frac{doctors}{day}$

Continued on next page

variable name	abbreviation	value	unit
total number of doctors	$doctors_{total}$	initial	$doctors$
word of mouth factor	$factor_{word\,of\,mouth}$	0.05	$\frac{1}{day}$

Table 4: Variables used in the doctor subsystem

The constant *total number of doctors* ($doctors_{total}$) indicates the amount of all potential prescribing doctors inside the study area. It is also set as an initial value for the stock *unaware of the product* ($doctors_{unaware}$) and means that in the beginning, all doctors are unaware of the product. As already stated in Equation 3 the *advice frequency* (f_{advice}) is calculated. If the doctor is advised by a sales representatives he becomes aware of the product, but he will not prescribe it regularly. At least some of them will prescribe samples to patients which are searching for this particular product. They are called *doctors aware of the product* ($doctors_{aware}$) and increased by the inflow *awareness rate* ($rate_{aware}$).

$$rate_{aware} = doctors_{unaware} * f_{advice} \tag{15}$$

Only doctors already aware of the product are able to become *doctors prescribing the product* ($doctors_{prescribers}$). External and internal factors affect the adoption rate. The *average advice efficiency* ($eff_{advice_{avg}}$) (see Equation 8) and the *advertising effectiveness* (eff_{advert}) in combination with the *advice frequency* (f_{advice}) create *adoption from external factors* ($adoption_{external}$). The advertising effectiveness is also set as an initial number and should represent the impact of advertising to a doctor. As mentioned in Chapter 5.1.1, the company does not spend a lot of money in promotion, but to explain occurring effects and to compare it to the original solution, this option is added too.

$$adoption_{external} = doctors_{aware} * f_{advice} * eff_{advice_{avg}} + doctors_{aware} * eff_{advert} \tag{16}$$

As mentioned above, the word of mouth effect creates the *adoption from internal factors* ($adoption_{internal}$). The word of mouth factor figures the eventuality that an already prescribing physician advise another doctor, that is already aware of the product. This number represents the probability of a contact and the impact of a conversation. Based on the assumption, that doctors are meeting on conferences and sales representatives of the reference company are attending too, the standard equation - concerning two different values - used by Sterman (2000) is modified and figured with a several number.

$$adoption_{internal} = \frac{doctors_{prescribers}}{doctors_{total}} * doctors_{aware} * factor_{word\,of\,mouth} \tag{17}$$

The adoption rate is basically the sum of adoption resulting from internal and external factors, but in case of a market saturation - every doctor is a prescriber - it has to be secured that the amount of aware doctors will not turn negative. This assumption is done by the MIN-function in Equation 18. If the actual number of aware doctors is less than the calculated adoption rate, the batch of new physicians prescribing the product will be this remaining amount.

$$rate_{adoption} = MIN\left(adoption_{external} + adoption_{internal}, \frac{doctors_{aware}}{timestep}\right) \tag{18}$$

$$doctors_{aware} = \int_{t_0}^{t} (rate_{aware} - rate_{adoption})\; dt \tag{19}$$

After the *time of being a prescriber* ($t_{prescriber}$) (see Figure 28) the currently prescribing doctor loses interest and will not longer be treated as a prescriber. The *prescribers loosing rate* ($rate_{loosing\,prescribers}$) is draining the amount of prescribers and raise the amount of unaware doctors.

$$rate_{loosing\,prescribers} = DELAYPPL\left(\frac{doctors_{prescribers}}{t_{prescriber}}, t_{prescriber}\right) \tag{20}$$

$$doctors_{prescribers} = \int_{t_0}^{t} (rate_{adoption} - rate_{loosing\,prescribers}\, dt) \tag{21}$$

$$doctors_{unaware} = \int_{t_0}^{t} (rate_{loosing\,prescribers} - rate_{aware}\, dt + doctors_{unaware_{initial}}) \tag{22}$$

Resulting from the start conditions, the initial amount of $doctors_{unaware}$ is set to $doctors_{total}$ in the beginning and $doctors_{aware}$ and $doctors_{prescribers}$ are set to zero. Due to the fact, that there are no inflows and outflows across the system boundaries, the sum of all physicians within this systems will not change over the simulation period.

$$doctors_{unaware} + doctors_{aware} + doctors_{prescribers} \mathrel{\hat{=}} doctors_{total} \tag{23}$$

Across system variables

outbound variable	inbound variable	Section
advice frequency		5.3.1
	average advice efficiency	5.3.1
doctors prescribing the product		5.3.3
	total advices per day	5.3.1
total numbers of doctors		5.3.3

Table 5: Across systems variables of the doctor subsystem

The number of doctors prescribing the product creates the most important impact to the patient segment and is treated as a key variable within this subsystem. The across system variables of the doctor subsystem are mentioned in Table 5.

5.3.3 Patients

Generally the idea behind the patient segment is to use the Bass Diffusion Model (Bass, 1969) too, resulting from the complex behavior it needs to be modified in some parts. The Causal Loop Diagram in Figure 30 explains the relationship within this subsystem. According to the managers, the potential market of the reference product is very stable. Therefore, advertisement would not increase the potential market and a growth in treatments will not guide to a hype. During interviews a correlation to the over the counter products was mentioned, but this effect lays outside the system boundary and it is impossible to assume a acceptable correlation.

As mentioned above, the amount of prescribers creates the major impact on this subsystem. Figure 30 does not provide the implemented version, but explains the basics of the segment.

Patients tend to visit the doctor in a regular frequency, especially when they are untreated. With a certain probability they will visit a doctor that is currently prescribing the reference product and receive a prescription for it. In this version of the CLD, every prescription lead to a treated patient, through the word of mouth effect, more presently

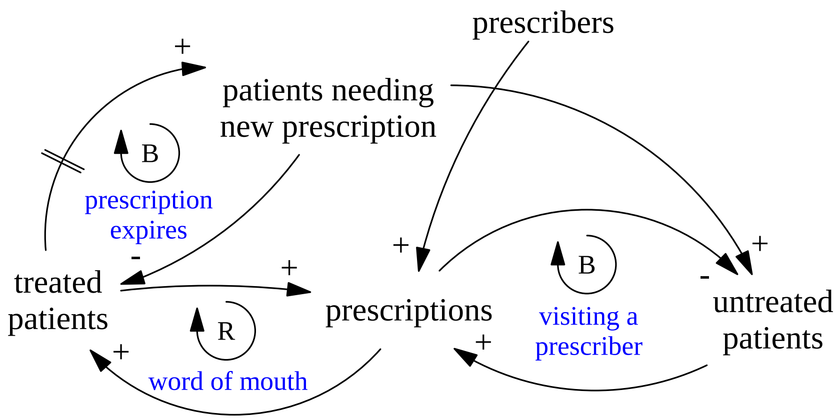


Figure 30: Patients subsystem (CLD)

treated people will augment the number of prescriptions. There are two different assumptions to be taken in consideration. On the one hand, a treated patient will suggest potential, but untreated patients to take this drug as well. This is the basic recommendation process. On the other hand, if a patient is already treated successfully with this particular medicine, he will probably ask for the same again. A single participant is influenced by many different aspects, but the System Dynamics approach is not focusing on each unit within the several stocks. Therefore, the common word of mouth approach is used and the adoption fraction is assumed higher than usual. So the amount of treated patients has a stronger impact on the number of new prescriptions. Every prescription last at least a few months and the patient has to renew it when this period expires. Hence he will be an untreated patient again.

The simplification in Figure 30 is made by assuming that every order will be fulfilled. In reality it is possible that the pharmacy run out of products, cause of many different aspects. The supply chain is not modeled in this study (see Chapter 5.2.2) but the limitation is mentioned in the Production segment (see Chapter 5.3.4). Due to that constraint, it is possible that the order fulfillment is not guaranteed and some patients will not get the product within a acceptable period. The detailed and implemented situation is shown in the following Stock and Flow Diagram as well as in the entire CLD (see Page 44).

Stock and Flow Diagram

Figure 31 demonstrates the Stock and Flow Diagram of the patient subsystem. All used variables, abbreviations, values and units of the patient segment are listed in Table 6.

The potential market is very stable and not subjected to large changes. The variable *initial potential patients* ($patients_{potential_{initial}}$) is set to 5000 and mentions all potential patients in the study area. There are no prescriptions or treatments in the beginning, so the initial values of *patients with a prescription* ($patients_{prescription}$) and *Fitofarm treated patients* ($patients_{treated}$) are set zero. Due to the fact, that there are no flows across the system boundaries, the sum of all patients within this systems does not change during the simulation period.

$$patients_{potential} + patients_{treated} + patients_{prescription} \hat{=} patients_{potential_{initial}} \tag{24}$$

variable name	abbreviation	value	unit
adoption fraction	$frac_{adoption}$	10	–
adoption from prescription	$adoption_{prescription}$	-	$\frac{people}{week}$
adoption from word of mouth	$adoption_{WoM}$	-	$\frac{people}{week}$
contact rate	$rate_{contact}$	1	$\frac{1}{month}$
doctors prescribing the product	$doctors_{prescribers}$	inbound	$doctors$
dose per person	$dose_{per\,person}$	initial	$\frac{medicine}{month*person}$
Fitofarm treated patients	$patients_{treated}$	-	$people$
fulfilled orders	$orders_{fulfilled}$	inbound	$\frac{medicine}{week}$
getting new prescription	$rate_{new\,prescription}$	-	$\frac{people}{week}$
initial potential patients	$patients_{potential_{initial}}$	initial	$people$
patients with a prescription	$patients_{prescription}$	-	$people$
potential patients	$patients_{potential}$	-	$people$
prescriptions	$rate_{prescriptions}$	-	$\frac{people}{week}$
time to get a new prescription	$t_{prescription}$	initial	$month$
total number of doctors	$doctors_{total}$	inbound	$doctors$
total population			
total population	$people_{total}$	initial	$people$

Continued on next page

variable name	abbreviation	value	unit
treatments	$rate_{treatments}$	-	$\frac{people}{week}$
unfulfilled orders	$orders_{unfulfilled}$	inbound	$\frac{medicine}{week}$
untreated patients	$rate_{untreated}$	-	$\frac{people}{week}$
visits per month	f_{visits}	initial	$\frac{1}{month}$

Table 6: Variables used in the patient subsystem

The variable *prescriptions* ($rate_{prescriptions}$) is the sum of *adoption from prescription* ($adoption_{prescription}$) and *adoption from word of mouth* ($adoption_{WoM}$). An untreated patient is visiting a doctor once per month in average, hoping to get the best treatment possible. If he is advised by a doctor that is currently prescribing this medicine he will get a prescription for it. Assuming that each doctor handles the same number of potential patients in average, this probability is calculated by comparing the actual amount of *doctors prescribing the product* ($doctors_{prescribers}$) and the *total number of doctors* ($doctors_{total}$). Multiplied with the *potential patients* ($patients_{potential}$) and the visit frequency *visits per month* (f_{visits}) the adoption from prescription is calculated.

$$adoption_{prescription} = \left(\frac{doctors_{prescribers}}{doctors_{total}} * patients_{potential} * f_{visits}\right) \quad (25)$$

As mentioned before, the actual amount of *Fitofarm treated patients* ($patients_{treated}$) creates a word of mouth effect and as a consequence more prescriptions. With a certain probability, successfully treated patients advise untreated patients to take the same medicine. Sterman (2000) named a variable *contact rate* ($rate_{contact}$), to implement the possibility of encounters. Because not every coincidence leads to an adoption, an *adoption fraction* ($frac_{adoption}$) is implemented too.

$$adoption_{WoM} = \left(rate_{contact} * frac_{adoption} * \frac{patients_{potential} * patients_{treated}}{people_{total}}\right) \quad (26)$$

If nearly everyone is treated with the product, the internal word of mouth feedback will lead to a negative number of potential patients. To prevent this market saturation effect, a MIN-function is implemented in Equation 27. If the adoption from prescription and word of mouth exceed the current potential market volume, only this available rest will

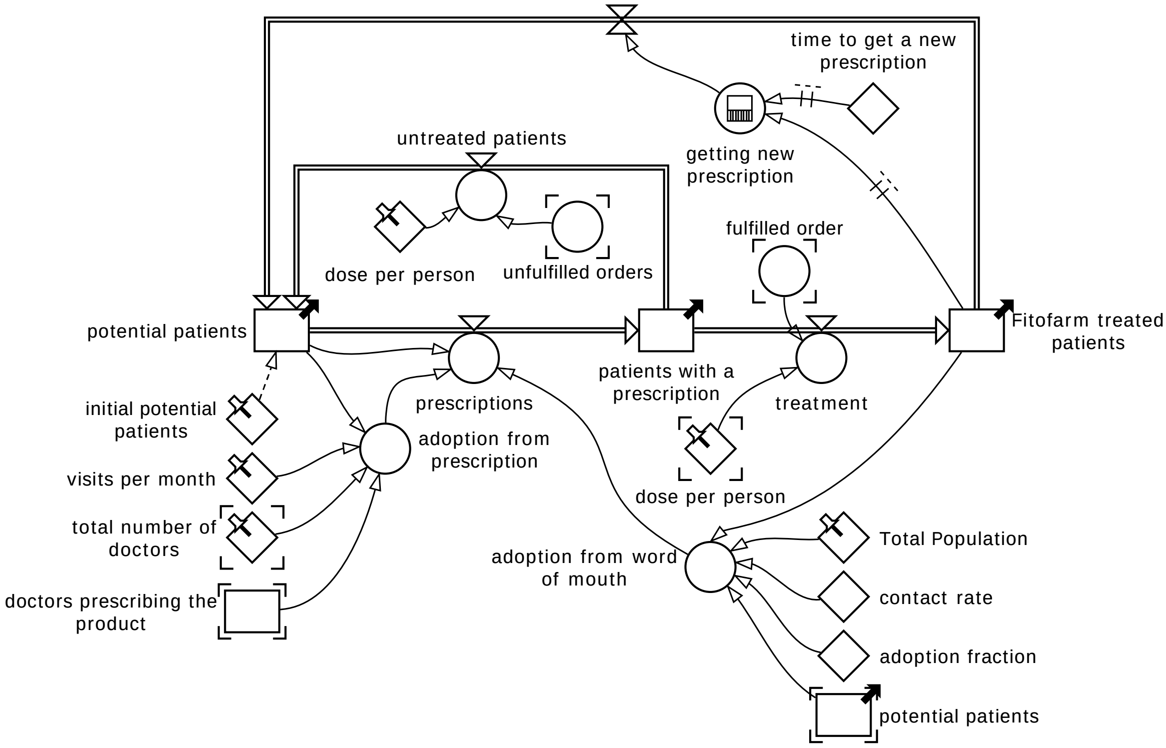


Figure 31: Patients subsystem (SFD)

get a new prescription.

$$rate_{prescriptions} = MIN\left(adoption_{prescription} + adoption_{WoM}, \frac{patients_{potential}}{timestep}\right) \tag{27}$$

After receiving the prescription, the patient has to hand it in at a pharmacy. Basically the product is on stock and he will get it directly. Because of the simplification of the supply chain, every order placed at the pharmacy is abstracted as order to the company. That means, every prescription is treated as incoming order and every fulfilled order is equal to the handing over at the pharmacy. Depending on the *dose per person* ($dose_{per\,person}$) and the amount of *fulfilled orders* ($rate_{order\,fulfilled}$) the weekly number of new *treatments* ($rate_{treatments}$) is calculated.

$$rate_{treatments} = \left(\frac{orders_{fulfilled}}{dose_{per\,person}}\right) \tag{28}$$

If the amount of orders exceeds the actual inventory, a backlog within the production segment will be created (see Chapter 5.3.4). Patients normally do not accept waiting times at the pharmacy and as a consequence they probably take an alternative product. This actuality is mentioned as *unfulfilled orders* ($orders_{unfulfilled}$) and leads to *untreated patients* ($rate_{untreated}$).

$$rate_{untreated} = \left(\frac{orders_{unfulfilled}}{dose_{per\,person}} \right) \tag{29}$$

The actual amount of *patients with a prescription* ($patients_{prescription}$) represents all patients that already received a prescription, but are not treated yet.

$$patients_{prescription} = \int_{t_0}^{t} (rate_{prescriptions} - rate_{treatments} - rate_{untreated}) \; dt \tag{30}$$

After having received the product, the patient will be under treatment for a certain period of time. Assuming, that the patient will not have any problems with the product - intolerance or allergies -, he will not change the treatment until the prescription expires. This period is named *time to get a new prescription* ($t_{prescription}$) and delays the outflow of the actual treated patients - *getting new prescription* ($rate_{new\,prescription}$).

$$rate_{new\,prescription} = DELAYPPL \left(\frac{patients_{treated}}{t_{prescription}}, t_{prescription} \right) \tag{31}$$

$$patients_{treated} = \int_{t_0}^{t} (rate_{treatments} - rate_{new\,prescription}) \; dt \tag{32}$$

$$patients_{potential} = \int_{t_0}^{t} (rate_{new\,prescription} + rate_{untreated} - rate_{prescriptions}) \; dt \tag{33}$$

Across system variables

The actual amount of treated patients was named a key variable. Despite the fact, that they are not creating orders, they are an indicator for the market share. The prescription itself creates the incoming order and therefore the main impact to the production segment. The across system variables of the patient subsystem are mentioned in Table 7.

outbound variable	inbound variable	Section
	doctors prescribing the product	5.3.2
dose per person		5.3.4
	fulfilled orders	5.3.4
prescriptions		5.3.4
	total numbers of doctors	5.3.2
	unfulfilled orders	5.3.4

Table 7: Across systems variables of the patients subsystem

5.3.4 Production

The production layer is adopted from the Inventory and Production Model of Sterman (2000). According to the limitations and the possibility of rejections, the model is modified in some parts. The relationships are shown in Figure 32. The impact on the production segment is the order rate from the patient segment. Assuming there are no incoming orders, the production would not start. Depending on the dose per patient, each order is transformed into an amount of medicine, that basically creates a order backlog and a desired shipment. If the product is on stock, the medicine will be shipped and the backlog is canceled. If the product is not on stock, the order backlog will stay alive and the patient will not get the product immediately. As mentioned in the patient subsystem, the unfulfilled order guides to an untreated patient and decreases the amount of prescriptions.

If there are shipments desired, the company would try to fulfill all requests out of the inventory. That means, every shipped product drains the inventory. The managers of the reference company pointed out, that they are used to keep a certain safety stock. This stock should last at least three weeks and is calculated by the average shipment rate of the last few weeks. If the inventory falls below the desired level, medicine has to be produced. Depending on the gap between desired and current inventory, a certain amount of production starts is calculated. Concerning the manufacturing cycle time and the period of revision in the laboratory, it will take a few days until the batch reaches the inventory.

Figure 33 illustrates the adopted policy structure for a simple manufacturing layer from

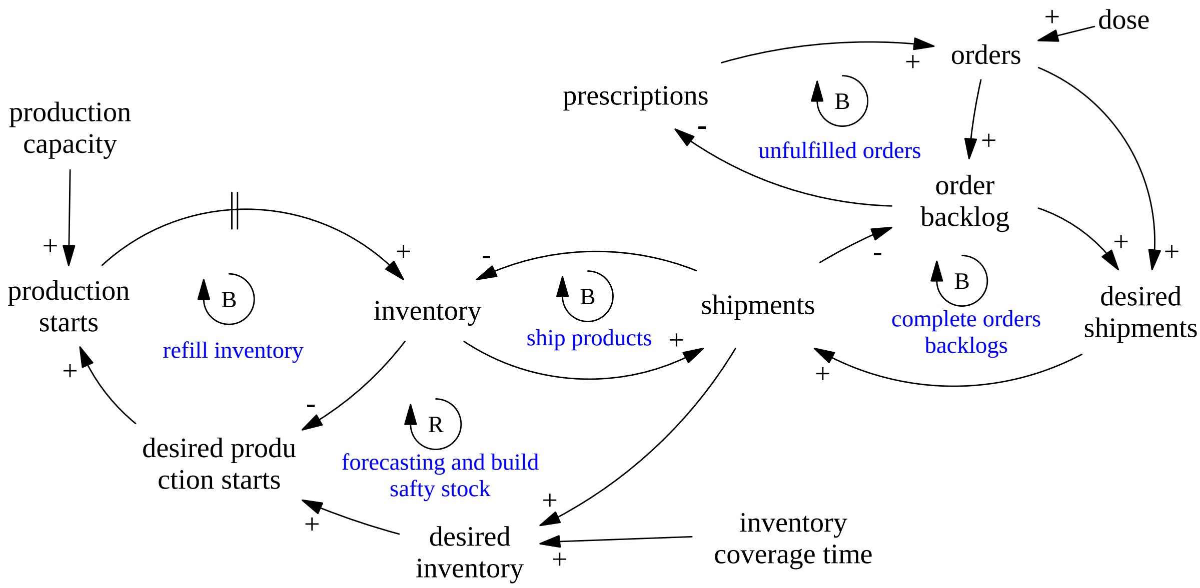


Figure 32: Production subsystem (CLD)

Sterman (2000). The variables below the product flow represent subunits within this model. The manufacturing cycle is divided into three segments. Starting with the production start rate a Work in Process (WiP) inventory is filled and drained by the production rate. This rate mentions the finished products and the storage in the inventory. Already stored products are disposed for shipment. The stockout loop regulates the shipment, based on the inventory level. The WiP control and the inventory control adjust the production starts and moves the current stocks to the desired ones.

Stock and Flow Diagram

The entire Stock and Flow Diagram of the production level, concerning order backlogs and rejections, is demonstrated in Figure 34. Based on the policy structure in Figure 33, all subunits are extended as well. All used variables, abbreviations, values, and units of the production segment are listed in Table 8.

While the patient subsystem uses people as the main unit, the production segment uses drugs. The *order rate* ($orders_{income}$) is given by the amount of new prescriptions multiplied with the dose per person.

$$orders_{income} = dose_{per\,person} * rate_{prescriptions} \tag{34}$$

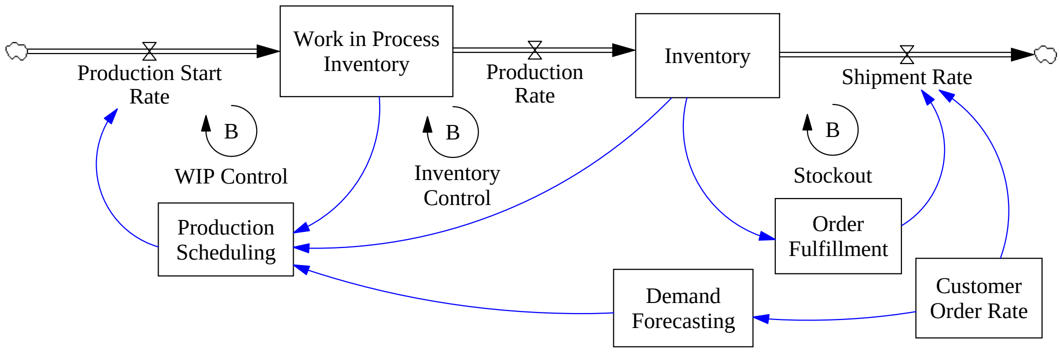


Figure 33: The policy structure of inventory management (Sterman, 2000)

The company tries to fulfill every incoming order as soon as possible, so the order rate is directly connected to the *desired shipment rate* ($rate_{shipment_{desired}}$). If an order *backlog* occurs, they will try to dismount it as soon as possible too. The *target delivery delay* ($t_{delivery_{target}}$) is the time to drain the backlog. Concerning the fact, that patients will take another product, the backlog is also drained by the unfulfilled orders at the same time. So, if the company is not able drain the backlog, the backlog will disappear within a certain time without any production effort. Due to the fact, that the reference company tries to fulfill every order, they are able to fulfill backlog orders within a specific time, that considers an acceptable waiting time of patients.

$$rate_{shipment_{desired}} = orders_{income} + \frac{backlog}{t_{delivery_{target}}} \tag{35}$$

variable name	abbreviation	value	unit
adjustment for inventory	$adj_{inventory}$	-	$\frac{medicine}{week}$
adjustment for WIP	adj_{WIP}	-	$\frac{medicine}{week}$
backlog	$backlog$	-	$medicine$
change in exp orders	$D_{orders_{exp}}$	-	$\frac{medicine}{week^2}$
delivery delay	$t_{delivery}$	-	$week$
desired inventory	$inventory_{desired}$	-	$medicine$
desired inventory coverage	$t_{inventory_{desired}}$	-	day
desired production	$rate_{production_{desired}}$	-	$\frac{medicine}{week}$
desired production start rate	$rate_{starts_{desired}}$	-	$\frac{medicine}{week}$
desired shipment rate	$rate_{shipment_{desired}}$	-	$\frac{medicine}{week}$

Continued on next page

variable name	abbreviation	value	unit
desired WIP	$WIP_{desired}$	-	$medicine$
dose per person	$dose_{per\,person}$	inbound	$\frac{medicine}{month*person}$
expected order rate	$rate_{orders_{exp}}$	-	$\frac{medicine}{week}$
fulfilled orders	$orders_{fulfilled}$	-	$\frac{medicine}{week}$
inventory	$inventory$	-	$medicine$
inventory adjustment time	$t_{adj_{inventory}}$	2	$week$
inventory coverage	$t_{inventory}$	-	$week$
manufacturing and laboratory time	$t_{production}$	initial	day
maximum production start rate	$rate_{starts_{max}}$	initial	$\frac{medicine}{week}$
maximum shipment rate	$rate_{shipment_{max}}$	-	$\frac{medicine}{week}$
maximum waiting time	t_{wait}	1	$week$
minimum order processing time	$t_{order\,processing}$	initial	$week$
order rate	$orders_{income}$	-	$\frac{medicine}{week}$
prescriptions	$rate_{prescriptions}$	inbound	$\frac{people}{week}$
probability to fail test	$prob_{fail}$	initial	%
production rate	$rate_{production}$	-	$\frac{medicine}{week}$
production start rate	$rate_{starts}$	-	$\frac{medicine}{week}$
rejection rate	$rate_{rejections}$	-	$\frac{medicine}{week}$
safety stock coverage	t_{safety}	initial	$week$
shipment rate	$rate_{shipment}$	-	$\frac{medicine}{week}$
target delivery delay	$t_{delivery_{target}}$	1	$week$
time to average order rate	$t_{orders_{avg}}$	3	$week$
unfulfilled orders	$orders_{unfulfilled}$	-	$\frac{medicine}{week}$
WIP adjustment time	$t_{adj_{WIP}}$	1	$week$
WIP inventory	WIP	-	$medicine$

Table 8: Variables used in the production subsystem

If there are enough products on stock, the *shipment rate* ($rate_{shipment}$) is equal to the desired shipment rate. The *minimum order processing time* ($t_{order\,processing}$) is determined by the complexity of the distribution. Due to the fact, that the study area is not that big and the there are many wholesalers in the adjacency, the company can ship

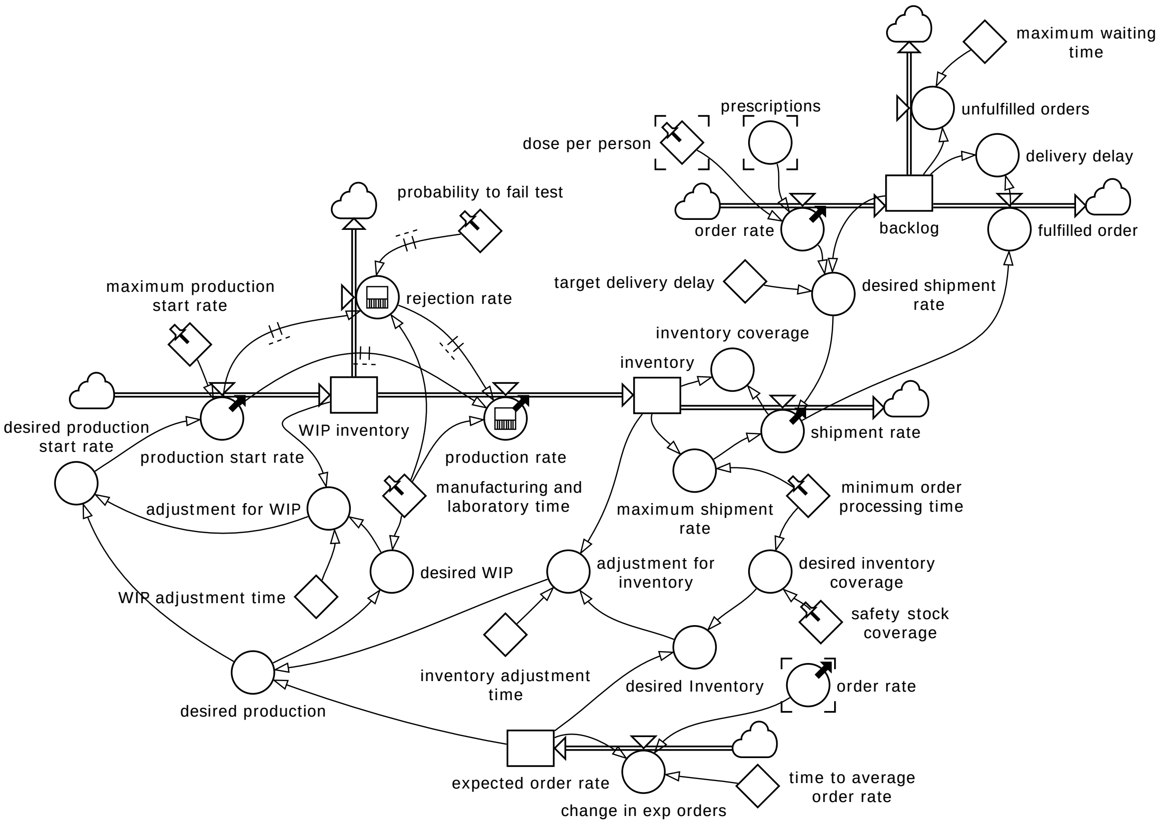


Figure 34: Production subsystem (SFD), modified from Sterman (2000)

a huge amount of medicine within a short period of time. The *maximum shipment rate* ($rate_{shipment_{max}}$) is linked to this *minimum order processing time* and the current *inventory* level.

$$rate_{shipment_{max}} = \left(\frac{inventory}{t_{order\,processing}} \right) \tag{36}$$

There are many different order fulfillment policies dealing with shipment rates at a low inventory level. Companies tend to keep stock for important customers and decrease the order fulfillment rate for normal customers. Depending on the complexity and value of a product, some companies are used to create backlogs, because each unit on stock would trigger high costs and moderate waiting time is accepted by customers. Nevertheless, the reference company tries to ship as much as they can. As mentioned above, a backlog leads to untreated patients (Equation 29), because they will take a substitutable product after a *maximum waiting time* (t_{wait}).

$$orders_{unfulfilled} = \left(\frac{backlog}{t_{wait}}\right) \tag{37}$$

In this case study, every shipment is a fulfilled order as well. The policy of the shipment rate is to ship as much as possible, and if the current inventory is not able to fulfill the demand, than they will ship as much as practicable.

$$rate_{shipment} = MIN(rate_{shipment_{desired}}, rate_{shipment_{max}}) \tag{38}$$

Every incoming order creates a backlog and if the product is available, this backlog will be simultaneously canceled due to the order fulfillment, or else an unfulfilled order will occur.

$$backlog = \int_{t_0}^{t} (orders_{income} - orders_{fulfilled} - orders_{unfulfilled})\, dt \tag{39}$$

The manufacturing process of a product consists of several steps, but to model each step would increase the complexity of the system. System Dynamics is able to model and simulate operational systems, but usually these parts are modeled with a different approach. As already stated in the beginning, the operational management is dealing with other simulation techniques and there are big advantages in combining different applications. Due to the fact, that this case study is focusing on the strategic part, the whole production, packaging and temporary storage is compressed in a single stock, named *Work in Process inventory* (WIP). The *production start rate* ($rate_{starts}$) stands for the amount of medicine that should be produced within a particular period. The whole production process takes a certain time and is considered as a manufacturing cycle time. Also the review of a product sample in the laboratory could last up to one day. Both delays are assumed as a constant, and named *manufacturing and laboratory time* ($t_{production}$). Considering the probability of a rejection - *probability to fail test* ($prob_{fail}$) -, the actual amount of work in process is decreased by two different flows. Basically, production is finished and the product is shipped to the inventory. The rate of finished products per time step is mentioned as *production rate* ($rate_{production}$) and all rejected products as *rejection rate* ($rate_{rejections}$). Both outflows of the WIP are considered as a 3rd-order delay.

$$rate_{rejections} = DELAYINF(rate_{starts} * prob_{fail}, t_{production}, 3) \tag{40}$$

$$rate_{production} = DELAYINF(rate_{starts} - rate_{rejections}, t_{production}, 3) \tag{41}$$

$$WIP = \int_{t_0}^{t} (rate_{starts} - rate_{production} - rate_{rejections})\ dt \tag{42}$$

The inventory is equal to the dispatch warehouse of the company. Each product needs to be stored before shipment.

$$inventory = \int_{t_0}^{t} (rate_{production} - rate_{shipment})\ dt \tag{43}$$

The initial values of WIP and *inventory* are depending on the scenario. In case of a product launch, both stocks are set zero in the beginning.

Assuming a constant shipment rate, an *inventory coverage* ($t_{inventory}$) period is calculated. This number serves as a control value for the inventory management system.

$$t_{inventory} = \frac{inventory}{rate_{shipment}} \tag{44}$$

To calculate the desired production starts each week, the company tend to forecast the expected orders. Fortunately there are no great oscillations, so the *expected order rate* ($rate_{orders_{exp}}$) is calculated as an 1^{st}-order exponential smoothing of the incoming order rate. The *change in exp orders* ($D_{orders_{exp}}$) is averaged, concerning a *time to average order rate* ($t_{orders_{avg}}$).

$$D_{orders_{exp}} = \frac{orders_{income} - rate_{orders_{exp}}}{t_{orders_{avg}}} \tag{45}$$

$$rate_{orders_{exp}} = \int_{t_0}^{t} \left(D_{orders_{exp}}\right)\ dt \tag{46}$$

Machine breakdowns or other unexpected failures should not lead to big problems, because the safety stock should guarantee order fulfillment at any time. Assuming a *safety stock coverage* (t_{safety}) of three weeks and and a *minimum order processing time* of one week, the *desired inventory coverage* ($t_{inventory_{desired}}$) should last at least four weeks. Concerning the *expected order rate* a *desired inventory* ($inventory_{desired}$) is calculated. Although there is limited space available in the dispatch warehouse, the reference product gains as much space as required, thanks to its profitable characteristics.

$$inventory_{desired} = rate_{orders_{exp} * t_{inventory_{desired}}} \tag{47}$$

The discrepancy between the current and desired inventory level needs to be disestablished within a specified period. The *desired production* ($rate_{production_{desired}}$) considers the number of production starts needed to refill the inventory and to fulfill the expected orders. If the inventory level is greater than the desired inventory, the inventory adjustment will become negative. If this value and the expected orders are below zero, the production will stop (see Equation 49).

$$adj_{inventory} = \frac{inventory_{desired} - inventory}{t_{adj_{inventory}}} \tag{48}$$

$$rate_{production_{desired}} = MAX\left(0,\ rate_{orders_{exp}} + adj_{inventory}\right) \tag{49}$$

If the amount of products on stock declines very fast - e.g. caused by a very large order - the inventory adjustment will raise enormously. Even if the order rate gets back to normal, the inventory is not filled yet and the desired production will stay high. A period of many production starts would lead to a high production rate and therefore to a high inventory level. Due to the abundance of medicine on stock, the inventory adjustment would drop below zero and production has to stop until the inventory reaches the desired level. To prevent these high oscillations within the production segment, the WIP inventory has to be considered as well. Moreover, the company tries to balance the production starts to get a good utilization of the manufacturing.

$$WIP_{desired} = rate_{production_{desired}} * t_{production} \tag{50}$$

The *WIP adjustment time* ($t_{adj_{WIP}}$) depends on the production planning and control system of the company. Being aware of the current production rate and the products in temporary storage is one of the major characteristics of good operational management. Basically a period of one week is assumed to adjust the WIP to the desired level. The variable *adjustment for WIP* (adj_{WIP}) discribes the amount of production starts to keep the current WIP at the desired level.

$$adj_{WIP} = \frac{WIP_{desired} - WIP}{t_{adj_{WIP}}} \tag{51}$$

The *desired production start rate* ($rate_{starts_{desired}}$) considers the desired production and the adjustment for the WIP inventory.

$$rate_{starts_{desired}} = adj_{WIP} + rate_{production_{desired}} \tag{52}$$

If the WIP inventory is higher than the desired WIP and the current desired production is zero, the desired production start rate will reach a negative value. Because of these circumstances, the variable *production start rate* ($rate_{starts}$) rate contains a non-negative function (see Equation 53).

$$rate_{starts} = MIN\left(MAX\left(0, rate_{starts_{desired}}\right), rate_{starts_{max}}\right) \qquad (53)$$

Based on the simplification - mentioned in Chapter 5.2.2 (Page 43) -, the production start rate is limited by a *maximum production start rate* ($rate_{starts_{max}}$). This constraint is implemented as a MAX-function in Equation 53 and will set the production start rate to the maximum start rate, if the desired start rate exceeds it.

Response of the production system to a step increase of orders

Dramatic changes in order rates can trigger big problems for the manufacturing. To be aware of highly oscillating production start rates, the WIP inventory needs to be monitored. To illustrate occurring effects, this part should provide a better insight of the production system behavior. A step increase of incoming orders is implemented, to demonstrate the response of this subsystem. The following explanation is not based on the values given by the company. To show the response of the system, the constant values (see Table 9) given by Sterman (2000) are implemented.

variable name	abbreviation	value [$weeks$]
minimum order processing time	$t_{order\,processing}$	2
safety stock coverage	t_{safety}	2
manufacturing and laboratory time	$t_{production}$	8
inventory adjustment time	$t_{adj_{inventory}}$	8
WIP adjustment time	$t_{adj_{WIP}}$	2
time to average order rate	$t_{orders_{avg}}$	8

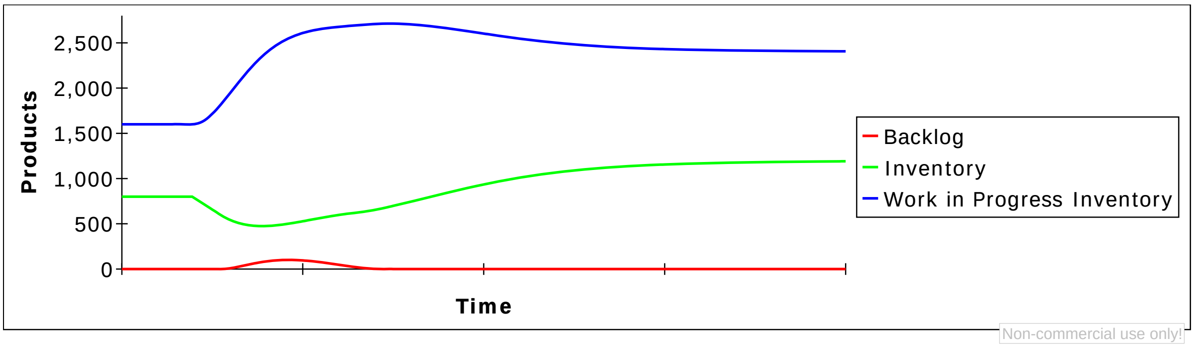
Table 9: Values used for the production system behavior overview

The probability to fail the review is set to zero, therefore no rejections will occur. To start the system in equilibrium, the initial values are set as follow:
$inventory = inventory_{desired}$
$WIP = WIP_{desired}$

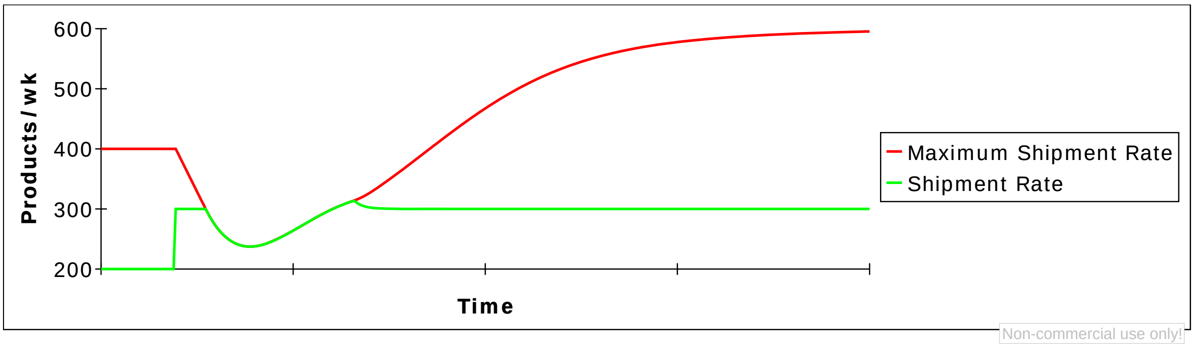
$rate_{orders_{exp}} = orders_{income}$

Based on these assumptions the system behavior is shown in Figure 35. In the beginning the Model is in equilibrium and all orders are fulfilled without creating a backlog. Suddenly the incoming orders increase by 50% from 200 products per week up to 300. The shipment rate steps up to the same amount, trying to fulfill the new order rate. The expected order rate raise and therefore the desired inventory too. Due to the fact, that the production rate is still at 200 products per week, and the shipment is already 300, the inventory is shrinking very fast. The maximum shipment rate is declining as well and reaches the same level as the current shipment rate. At that point, not every order is fulfilled, because the desired shipment rate is not accomplished any more. A backlog will be created and unfulfilled orders occur.

At the same time, the desired production start rate is elevated and the WIP inventory raises. After the manufacturing cycle time, the products reach the inventory and more products are ready to ship. The maximum shipment rate increases, but is still less than the desired shipment rate. The difference between current inventory and desired inventory is shrinking and the desired production start rate is declining, because there is a lot of work in process now. The desired production is still higher as the order rate. The production rate is delayed by the manufacturing time, and exceed the order rate to refill the inventory. After a certain period the maximum shipment rate is greater than the desired shipment rate and all incoming orders will be fulfilled again. The production is still greater as the order rate, due to the fact, that the inventory has to be lifted to a new level, concerning the safety stock coverage. After a certain period, the production system runs in equilibrium again. The production system of the reference company acts similar, but has a different order processing time and especially shorter manufacturing cycles. The response is quicker and assuming a constant order rate with a single step, the system would be stable within a few weeks.



(a)



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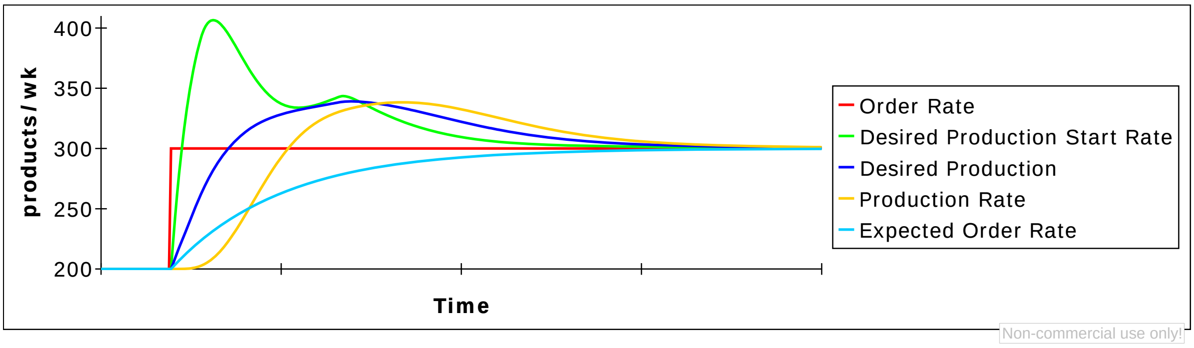


(c)

Figure 35: Response of the production system to a +50% step increase in orders: (a) response of stocks; (b) response of shipments; (c) response of production flows.

Across system variables

outbound variable	inbound variable	Section
fulfilled order		5.3.3 & 5.3.5
unfulfilled order		5.3.3
	prescriptions	5.3.3
	dose per person	5.3.3

Table 10: Across systems variables of the production subsystem

The production part represents the base of the whole model and is mainly focusing on the order fulfillment. Therefore, impacts occur especially in the patient segment. The production start rate defines the costs of manufacture in the financial part. The reference company is aware of the fact, that high inventory levels could trigger costs, but in fact of the desired safety stock coverage this is not an issue. The across system variables of the production subsystem are listed in Table 10

5.3.5 Finances

Success is based on qualitative, such as image and customer relation, and on quantitative issues (Huber, 1985). Quantitative values are easy to comprehend and sometimes easy to calculate. Especially the Return on Investment (ROI) and the Cash-Flow represent numbers of financial success. Huber (1985) mentioned, that particularly the quantitative numbers do not consider long term potentials of success. Many different approaches tend to use more qualitative aspects to calculate comparable numbers. The Shareholder Value approach provides a value of long term success, by considering the return of equity. In addition the Value based Management (VBM) was developed and is mainly used to figure factors of success and to highlight core competences. Kunath (2009) connected strategic factors of success to financial value drivers and mentioned the complexity of their connections. To prevent such high complexity, this case study deals with the Cash-Flow of a single product and does not provide further details of the financial flows beyond. Therefore this financial segment is calculating revenues and costs for the reference product only and each quantity is mentioned as a proportionate value.

Especially the salary of a sales representative. Administrative, packaging, storage, and distribution costs for the reference product, are included in the unit costs. Figure 36 illustrates all impacts on the profit.

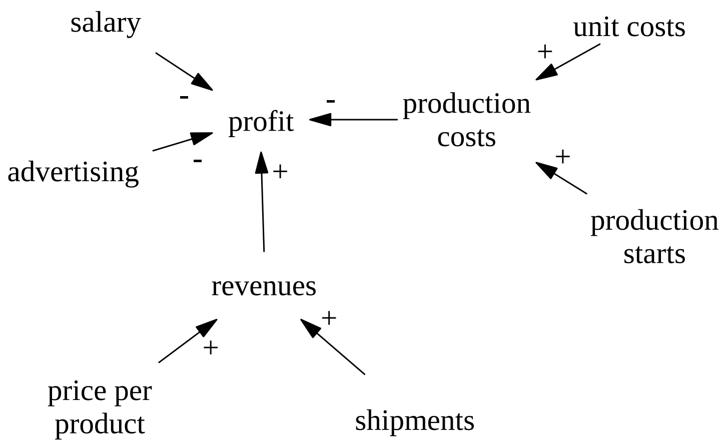


Figure 36: Finances subsystem (CLD)

Stock and Flow Diagram

Figure 37 shows the Stock and Flow Diagram of the financial subsystem. All used variables, abbreviations, values, and units of the financial segment are mentioned in Table 11.

variable name	abbreviation	value	unit
total SR	SR_{total}	inbound	$salesmen$
revenues	$revenues$	-	$\frac{Euro}{month}$
proportionate monthly labor costs	$costs_{labor}$	-	$\frac{Euro}{month}$
proportionate salary	$salary_{proportionate}$	initial	$\frac{Euro}{month}$
profit	$profit$	-	$\frac{Euro}{month}$
production start rate	$rate_{starts}$	inbound	$\frac{medicine}{week}$
price per product	$price_{per\,product}$	initial	$\frac{Euro}{medicine}$
manufacturing costs	$costs_{production}$	-	$\frac{Euro}{month}$
fulfilled orders	$orders_{fulfilled}$	inbound	$\frac{medicine}{week}$

Continued on next page

variable name	abbreviation	value	unit
costs per product	$costs_{per\,product}$	initial	$\frac{Euro}{medicine}$
costs	$costs$	-	$\frac{Euro}{month}$
accumulated profit	$profit_{acc}$	-	$Euro$

Table 11: Variables used in the financial subsystem

Basically the prescription creates an incoming order, and the order fulfillment leads to a treated patient. In this case, every shipment is equal to a fulfilled order. Assuming that there are no delays within the money transfer, every shipment leads to a revenue too.

$$revenues = orders_{fulfilled} * price_{per\,product} \tag{54}$$

The managers of the reference company mentioned, that especially in the field of only available on prescription drugs, price regulations are done by the government. There is a fixed price for each medicine and price fights among competitors are not possible.

Costs arise from two different sources. At first, the *proportionate monthly labor costs* ($costs_{labor}$) depend on the total amount of sale representatives and their *proportionate salary* ($salary_{proportionate}$). Considering, that an experienced sale representative is focusing more on other fields of applications as a rookie, the assumption is made that the proportionate salary should be the same, regardless of their seniority.

$$costs_{labor} = SR_{total} * salary_{proportionate} \tag{55}$$

At second, manufacturing creates costs as well. In coordination with the managers of the reference company, the assumption was made, to skip cost reductions due to mass effects. Apart of the packaging, every production step is automated and the lot sizes are not that big. Due to the high profit margin and the fact, that there is no direct competitor at the market, they are not forced to act like a cost leader and an acceptable production optimization is established.

$$costs_{production} = rate_{starts} * costs_{per\,product} \tag{56}$$

Accumulating Equation 55 and Equation 56 leads to the monthly cost.

$$costs = costs_{labor} + costs_{production} \tag{57}$$

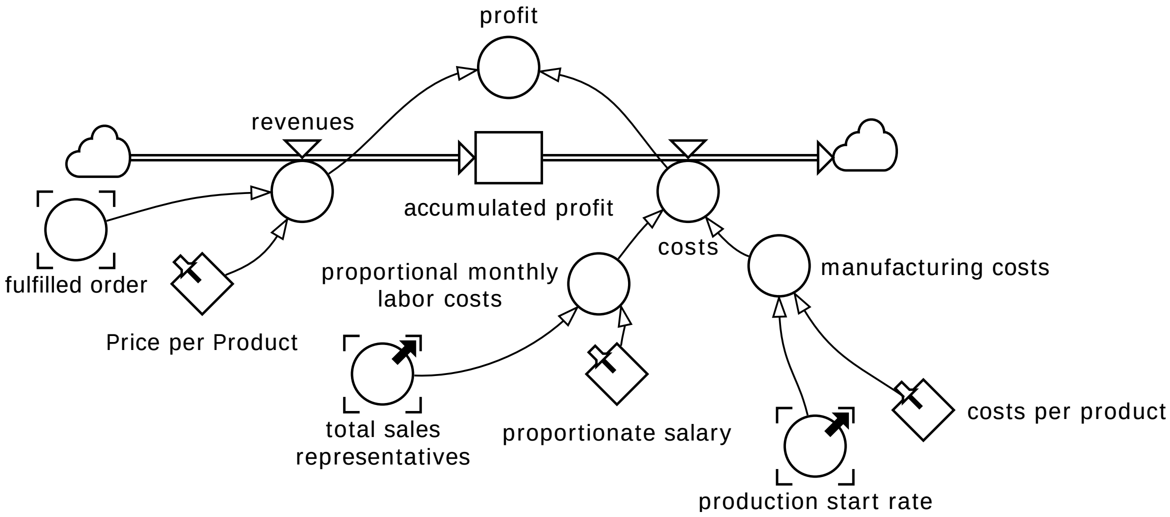


Figure 37: Finances subsystem (SFD)

The profit per time step is easily calculated by subtracting costs from revenues.

$$profit = revenues - costs \tag{58}$$

In addition, the accumulated profit is mentioned as a stock and provides information about the earnings over a the simulation period.

$$profit_{acc} = \int_{t_0}^{t} (revenues - costs)\ dt \tag{59}$$

Across system variables

outbound variable	inbound variable	Section
	fulfilled orders	5.3.4
	production start rate	5.3.4
proportionate salary		5.3.2
	total sale representatives	5.3.1

Table 12: Across systems variables of the finances subsystem

The profit is treated as one of the major key variables for the managers. The short term profit - per month - is strong dependent on the scenario. Especially at a product launch, the profit tend to be negative in the beginning, because the doctors do not prescribe the medicine yet therefore only a few incoming orders occur. In reality the profit would affect the managers decision to hire new sale representatives too. According to the statements before, this behavior could lead to higher personal costs and maybe no significant growth in revenues. To find the optimal amount of sale representatives is one of the major goals of the company. The accumulated profit over the simulation period is the best indicator and reference value within the financial segment. The across system variables of the financial subsystem are mentioned in Table 12

6 Simulation

6.1 Initialization and Settings

The models, explained in the previous chapter, are implemented in the simulation software Powersim® Studio 8. In addition to the initialization of the model, some settings have to be done, to run a simulation. Depending on the application area the adjustments differ. This case study is dealing with a market launch of the reference product. The following chapter contains information about the simulation settings and the initial values for the product launch scenario.

6.1.1 Simulation settings

One of the most important things to do, before starting a simulation, is to define the duration and the time step. PowerSim® Studio 8 also provides multiple integration methods, which are suitable for different approaches. Changing the simulation settings could lead to different solutions and it is very important to be aware of these effects. System Dynamics (SD) deals with nonlinear ordinary differential equations in many cases and they are not solved analytically. Stocks are computed numerically and therefore all calculated numbers are approximated values. By decreasing the simulation step, it is possible to find a better solution.

Duration

Especially in the field of strategic management, the time horizon of simulations is very important. Strategic decisions will not always trigger effects within a very short period of time. Usually the planning horizon is divided into different phases, called short, middle or long term. The literature provides many different scales and it is not well defined where a period ends and another begins. Operational units tend to shorten these time frames, because they are not used to plan lot sizes for more than a few months. At the strategic level, some companies divide the forecasting period in two segments only.

Up to five year time horizon is mentioned as a short term, any further period is considered as long-range planning. Other approaches regard strategic management are dealing with long term objectives, starting at a minimum planning horizon of five years (Lander, 2005). Forrester (1961) mentioned, that the whole realm of long-range planning is a big challenge for management, especially beyond five years. In addition, long-range responses should be viewed with skepticism and short term behavior may set the base of further reactions (Forrester, 2003). Short term models focus on a planning horizon ranging from one month up to five years. Barringer and Bluedorn (1999) stated, that a five years planning horizon - at maximum - may be optimal for entrepreneurial firms because they typically compete in turbulent environments with short product and service life cycles. Market situations will change during a long period and current assumptions are not valid any more. Simulation results after five years would not be plausible any more. As a combination of these different approaches, the duration is set to five years. Considering that constant variables are not changing during the simulation, the behavior is expected to be near equilibrium within this period of time.

Time step

There are three influences, which have to be taken into account, when choosing an acceptable calculation time step. At first the accuracy of the numerical integration, secondly the round-off error and thirdly the consideration of the shortest delay. According to the method of integration, the deviation of the approximated value is strong dependent on this interval. The bigger the time step is chosen, the more inexactly the result becomes. This characteristic requires to minimize the time step as much as possible. Hence, the computing time would increase rapidly. Assuming a one week time step for a simulation period, the system is calculated 260 times. By decreasing the time step to one day, the system needs to be calculated 1820 times. Depending on the scale of the model and the computer, this aggrandizement could cause very long computing time. New computers are very powerful and able to calculate with very small time steps. Therefore, the bottom limit is very low, but reducing the time step would trigger another problem. Each calculated value consists of a small round-off and a truncation error. Sterman (2000) suggested to set the time step between one-fourth and one-tenth of the smallest time constant within the model. Therefore the chosen time step is one day and should provide an acceptable solution with a marginal calculation error.

To show the effects of varying the time step, the model is simulated several times considering different time steps. Figure 38 illustrates the deviation of the accumulated profit over one year, considering different time steps. The series of $dt = 1\ week$ shows a similar behavior, but completely different values over the whole simulation period. This deviation is a consequence of the fact, that such a big time step is even bigger than some delays inside the model. The manufacturing and laboratory cycle time and the minimum order processing time are smaller than the chosen time step and therefore this huge divergence occurs.

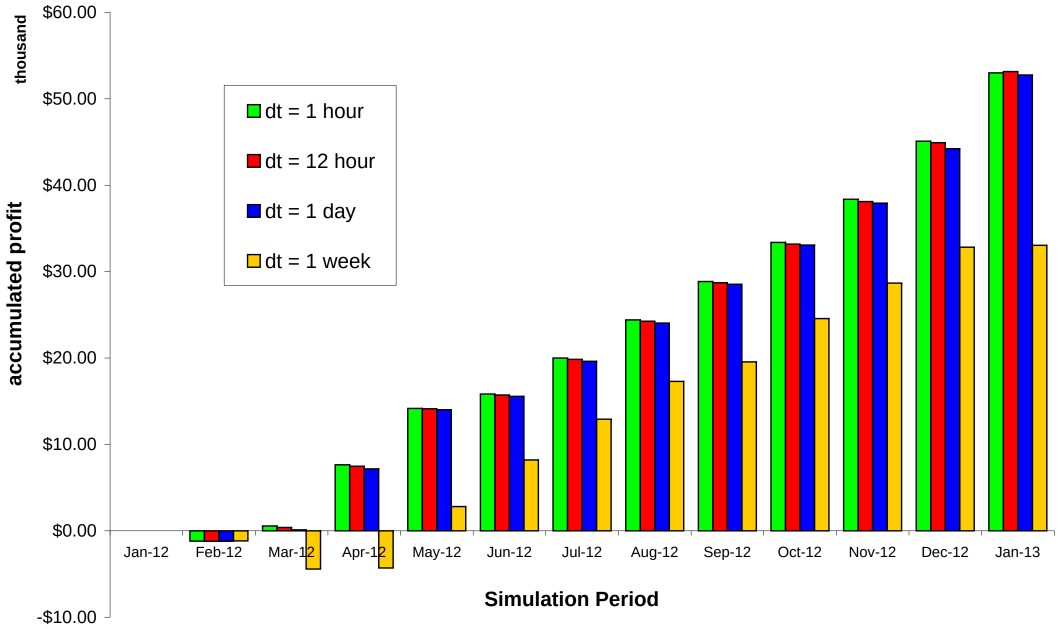


Figure 38: deviation of the accumulated profit over one year, depending on the chosen simulation time step

The environmental subsystems, like doctors and patients, as well as the staff segment contain longer time delays and this effect is not that crucial. The production segment consists of short delays, hence the attitude of this subsystem changes, due to the large calculation interval. High oscillations occur and unnecessarily high production orders are released. Table 13 demonstrates the deviation in percentage of the accumulated profit after one year, compared to the series with a one day time step.

dt = 1 day	dt = 1 hour	dt = 12 hour	dt = 1 week
52757.71 €	+0.46%	+0.76%	-37.36%

Table 13: Percentage deviation of profit, depending on the simulation time step

Smaller time steps lead to a very small deviation (< 1%), compared to the chosen interval, but the computation takes much longer. On a state-of-the-art personal computer this simulation over five years with a time step of one hour takes about two minutes.

Integration method

Powersim® Studio 8 provides different integration methods. First of all the 1st-order Euler Integration, which is adequate for many applications (Sterman, 2000). Usually the impreciseness - within many assumptions - creates a bigger impact as the occurring error due to the integration method. Therefore the 1st-order Euler Integration is adequate for almost every model, that deals with human behavior or social systems.

This error of approximation is not acceptable in some physical or technical models and therefore the Euler Integration is not appropriate. Powersim® Studio 8 provides other integration methods, such as the 2nd, 3rdand 4thorder Runge-Kutta with fixed time steps. Integration errors are smaller, hence this method allows larger time steps, but more computation power per time step is required.

Runge-Kutta integration methods may have problems in calculating discontinuous elements, such as steps or pulses. As a result of the social and human segments, that are included in this model and the discontinuous hire signal, the 1st-order Euler integration method is chosen.

6.1.2 Initialization

As already stated in the previous chapters, the simulation is concerning the market launch of the reference product, consequently all actions start on January 1st, 2012. Two sales representatives - one of them is treated as an experienced - advise potential doctors, which are still unaware of this product. If the company desires to hire new staff, they will not exceed a growth rate of 1 per year. That means, they will double their employees up at maximum. This hire decision is based on the ratio of current and desired consultation frequency. Based on the 1500 potential prescribing doctors in the study area and the number of average consultations per day and sales representative of about 12, the actual frequency is about 0,5 consultations per doctor and month. The major question of the managers was, how sales volume and profit would change, if each doctor is advised once per month, therefore the desired advice frequency is set to one per month.

The advertising effectiveness is not included in this basic scenario and thus set to zero. As shown in Figure 28 each doctor loses satisfaction in prescribing a particular medicine, owing to many different issues. The *time of being a prescriber* ($t_{prescriber}$) is set to 4 weeks. After this period the doctor will be treated as a doctor, that is unaware of the product.

Presuming that every untreated patient is visiting a doctor once a month to get an appropriate treatment is a critical part. The individual behavior of untreated patients and those who have no valid prescription are very different. Untreated patients visit the doctor in a more sporadic, even lower frequency and patients with an expired prescription will renew it within a few days. Therefore this assumption is based on an average behavior of this group. The validity of a prescription lasts three months and in some specific cases even longer, but these exceptions are not integrated, because some patients tend to renew their prescription before it expires. The monthly dose per person is usually one package of medicine. Some treatments need a higher dose, but in coordination with the managers the lion's share is figured with this number. The study area is located in Macedonia and about 2,5% of the two million inhabitants are treated as potential patients for a treatment with the reference product.

The adopted production sub-model is initialized with numbers given by the reference company. The safety stock should last at least three weeks, concerning an expected order rate, which is based on the average of the last three weeks. As a result of the well organized distribution paths, the order processing time is about one week. Within this short period, an already stored product is brought to every pharmacy in the study area. As already stated in the production section, the manufacturing takes about three days, from raw material up to the storage in the dispatch warehouse. As a consequence of the testing in the laboratory, this cycle time is increased by one day. The probability to fail the test or a rejection occurs in the manufacturing process is assumed to be about 2% and is treated as constant over the whole simulation period. To mention the existing bottleneck in the distribution path, the maximum rate of production starts is set to 250 products per week.

At least, the financial data has to be initialized. As already mentioned in Chapter 5.3.5 the reference product captivates by its high profit margin. The price is regulated by the government and set to 14 €. The costs are set to 6 € per product.

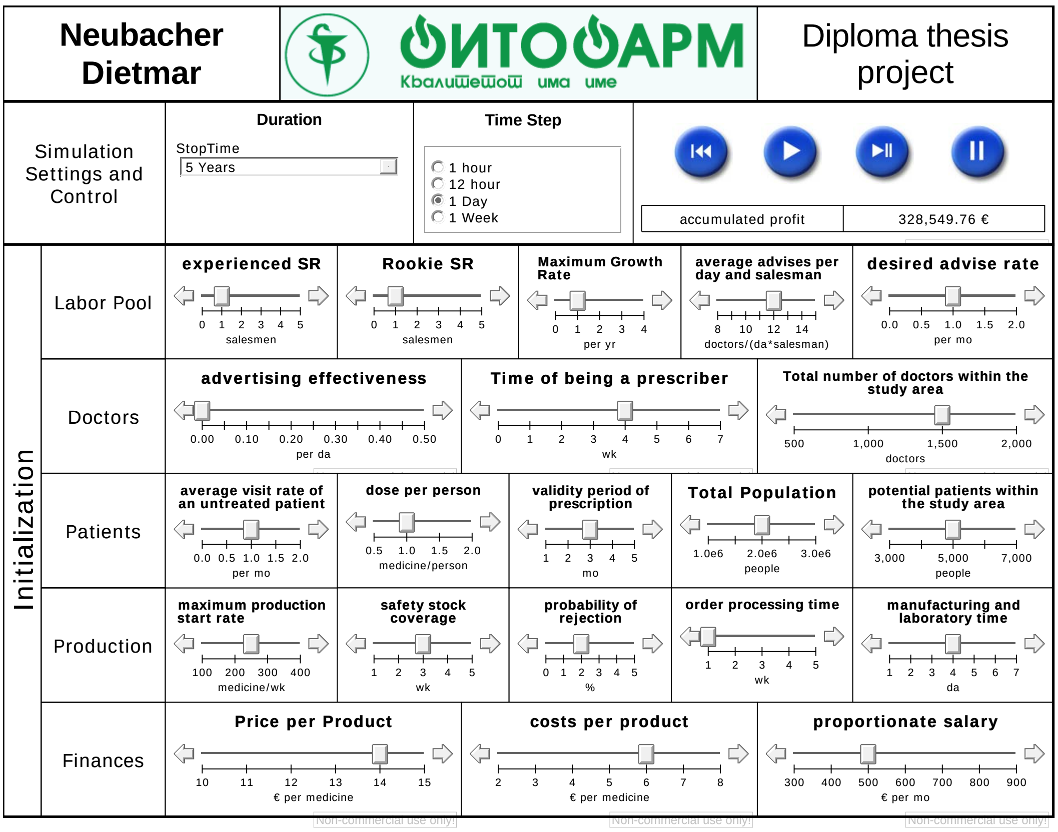


Figure 39: Implemented control panel for simulation settings and initialization of the model

Figure 39 illustrates the implemented control panel. In the upper part, the simulation settings could be adjusted. Buttons make it possible to handle the simulation in the presentation mode. The initialization of the model is located in the lower part and each variable could be modified at the beginning of a simulation. Some variables are able to be adjusted manually during the simulation by a few clicks in the control panel. Another panel provides an overview of all stocks and flows within the system. Figure 40 depicts this panel and the time dependent behavior of the stocks and flows.

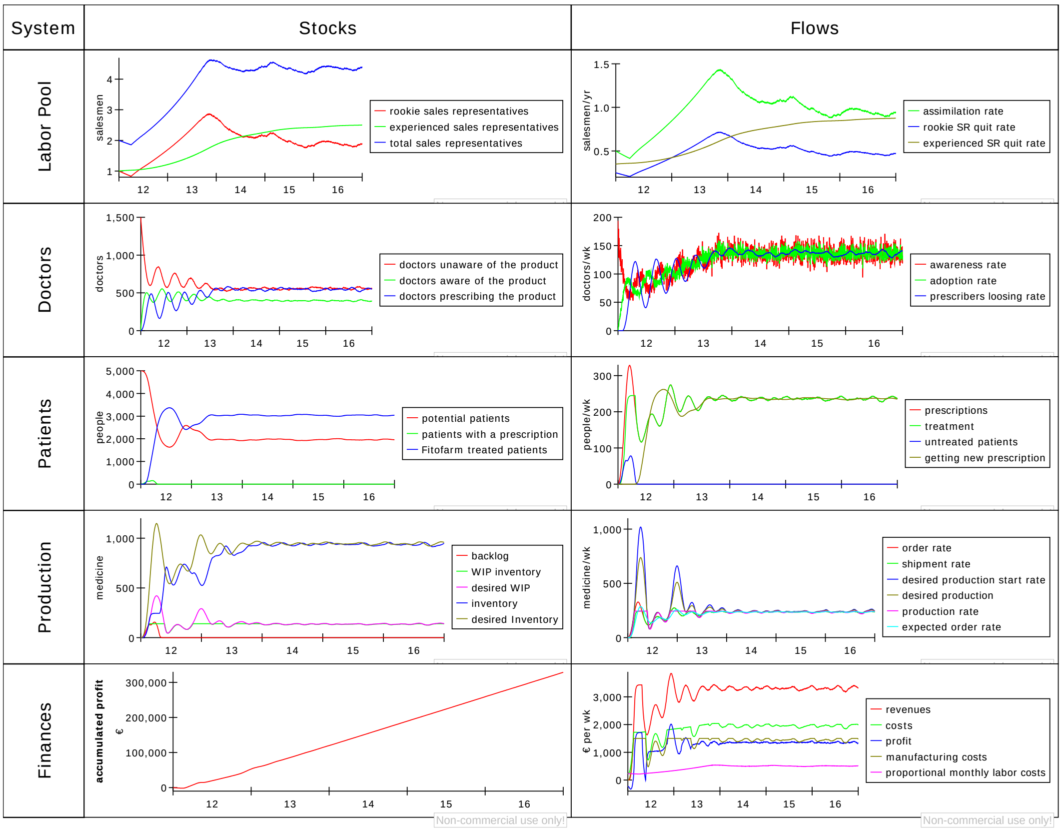


Figure 40: Implemented overview panel shows the main stocks and flows of the subsystems

6.2 Results

The simulation provides useful information for each subsystem. Diagrams illustrate the time dependent behavior of variables, especially the stock and flows. The results of the product launch simulation are explained in this chapter.

6.2.1 Labor pool

Based on the initialization, the current amount of sales representatives (salesmen) does not achieve the desired advice frequency. Therefore the company starts hiring in the beginning. Due to the time delay between hiring and being a rookie of three months, new employees arrive after the first quarter. The assimilation rate is low and as a consequence of the continuous outflow - representing quits - the total amount of sale representatives is shrinking in the beginning.

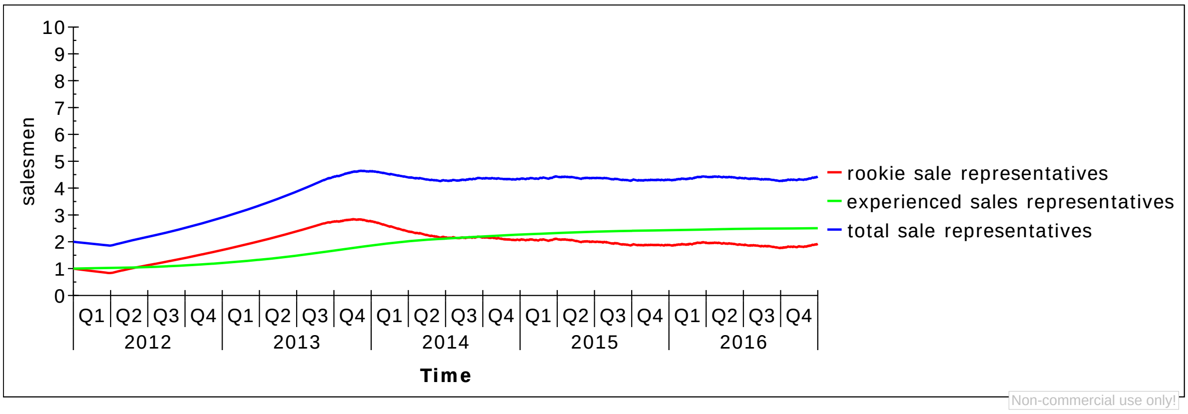


Figure 41: Time dependent behavior of labor pool

Figure 41 shows the characteristics of the labor pool segment. The company hires new staff until the desired advice frequency is exceeded. Due to the time delay, an overshot occurs, hiring stops, and after a certain period of time the system is near equilibrium. After ten quarters (Q2 - 2014), the company needs to replace quitting people only. The amount of rookies continues declining, considering the assimilation time of two years, they will be treated as an experienced sales representative afterward.

6.2.2 Doctors

The doctor segment displays a high oscillation in the beginning, as a result of the included time delays. The initial amount of doctors represents all potential doctors and none of them is still aware of the product. There are two sales representatives yet, which are starting to advise the physicians at a low frequency. Figure 42 illustrates a rapid decline of unaware doctors in the beginning. At first every doctor needs to become aware of the product and therefore no prescribing physicians exist in the early phase.

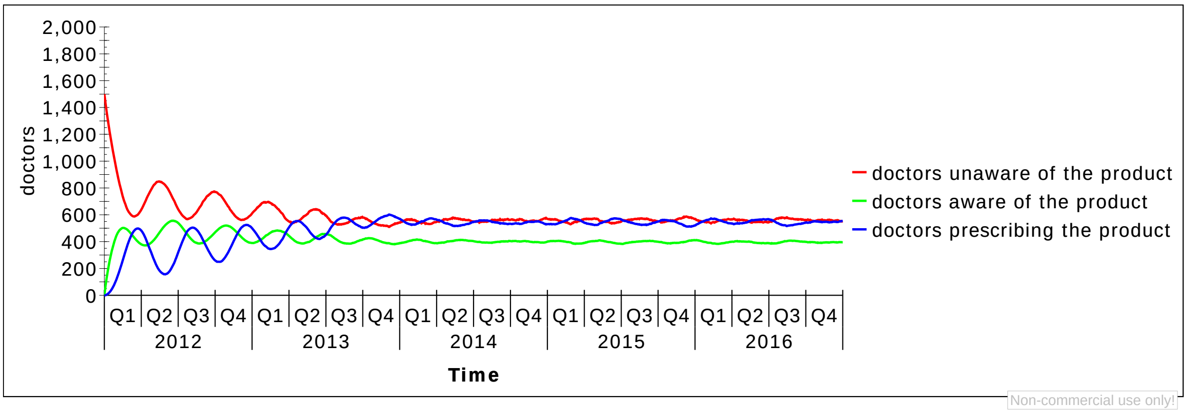


Figure 42: Time dependent behavior of doctors

An aware doctor becomes a prescriber after being consulted, hence the amount of doctors prescribing the product is rising very fast within the first quarter. Every twice-visited doctor is now prescribing the medicine. After a certain period he will lose interest in prescribing the product and therefore a lot of current prescribing physicians disappear and increase the stock of unaware doctors. After a period of about two years the system tends to be near equilibrium. To gain more prescribers the numbers of sales representatives has to be increased.

6.2.3 Patients

In the beginning there are no treatments as well as no prescriptions. As mentioned in the previous chapter, each untreated patient tends to visit the doctor once a month. Considering the previous statement, there are only few doctors that are currently prescribing the medicine and most patients stay untreated in the beginning. After a few months a particular amount of physicians prescribes the medicine to patients and thus the number of patients with prescription rises. The current quantity of already produced medicine is not enough to fulfill all incoming orders, therefore a certain amount of patients will not get the medicine immediately. This small number of untreated patients is represented as a small bulge after the first quarter in Figure 43

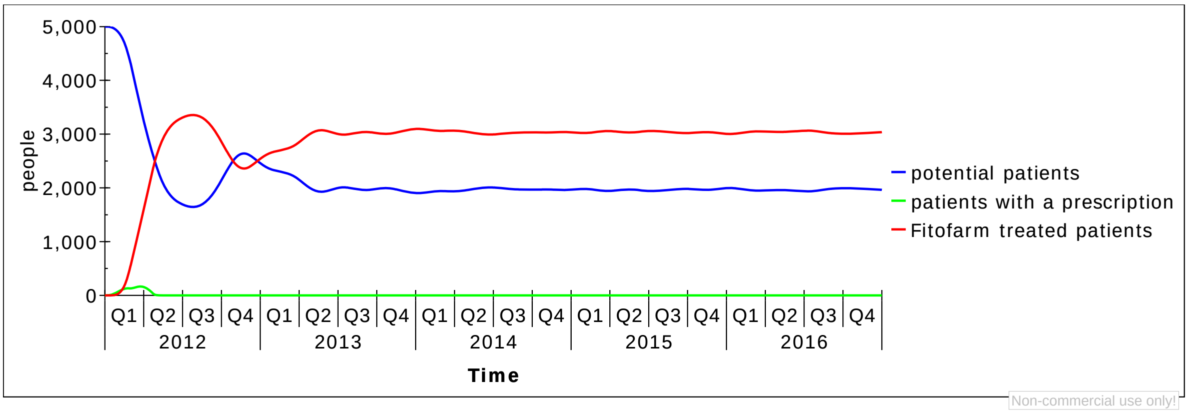


Figure 43: Time dependent behavior of patients

After this short occurrence, the manufacturing is able to fulfill every order in time and all patients with a valid prescription will get the product immediately. As a consequence of the increasing number of prescribing physicians, the amount of treated patient shows an exponential growth. Concerning the validity period of prescriptions, most of them expire after three months. After two quarters a bulk of currently treated patients have to renew their prescription and the exponential growing behavior is retarded. They will be considered as untreated patients again. After about six quarters, the system seems to be in equilibrium, according to the stable numbers of prescribing doctors.

6.2.4 Production

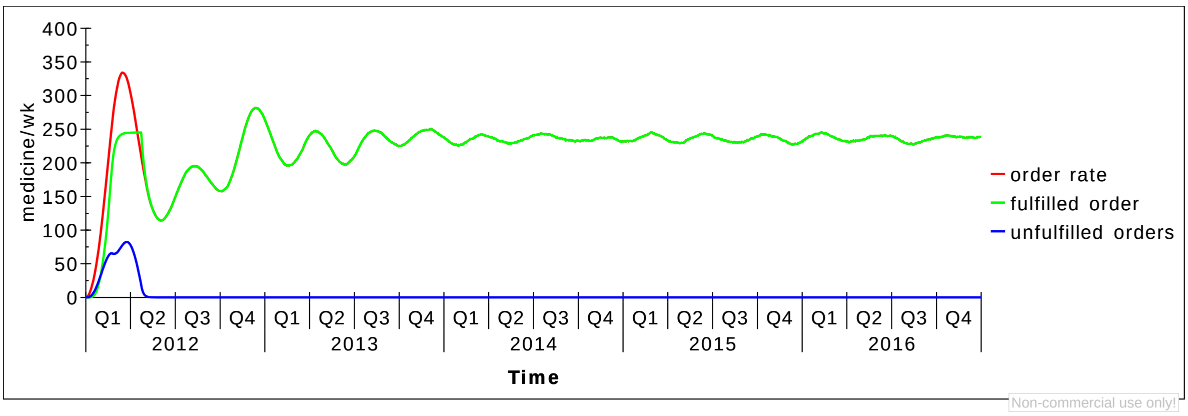


Figure 44: Time dependent behavior of orders

Based on the simplification of the distribution chain, each prescription is equal to an incoming order. The order rate in Figure 44 is not able to be fulfilled in the beginning, because the actual amount of products on stock is not high enough. The order fulfillment ratio is beneath one and therefore unfulfilled orders occur.

Figure 45 illustrates the behavior of the production flows, the current, and the expected order rate. Especially in the beginning a constant growth of the order rate and the fact, that there is no safety stock yet, raises the desired production enormously. The limitation of the manufacturing is caused by limiting the number of production starts to 250 per week and as a consequence the production rate does not exceed this value, even if the desired values would force it.

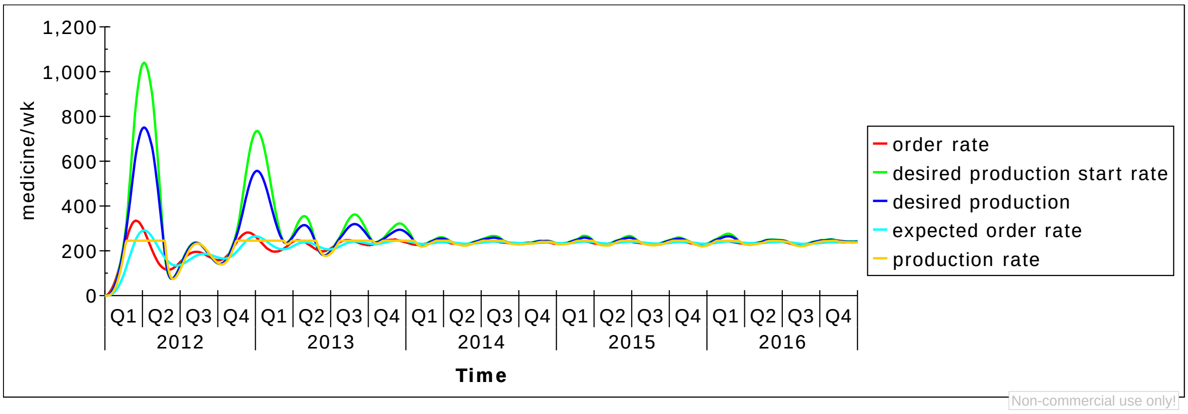


Figure 45: Time dependent behavior of production rates

As a result of the oscillating amount of new prescriptions - equals incoming orders - and the already filled inventory, the desired production falls below the expected order rate after two quarters. In the beginning a lot of untreated patients need to be satisfied and a high production rate is required. After a few months a lot of patients are treated and they do not need more until their prescription expires. After about five months the inventory is able to fulfill all orders and the safety stock is built. To provide a good capacity utilization, the work in process inventory should be as stable as possible. Figure 46 shows the time dependent behavior of all stocks included in the production subsystem.

To figure the time dependent order fulfillment Figure 47 depicts the maximum, desired and current shipment rate. As already explained above, the desired shipment is not

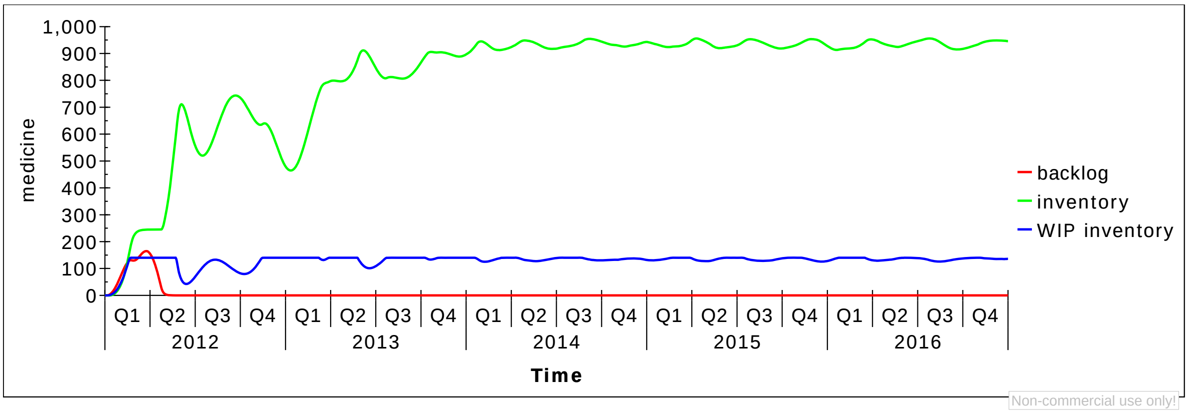


Figure 46: Time dependent behavior of production stocks

fulfilled in the beginning. According to the shipment policy of the reference company, they will ship as much as possible and therefore the current shipment rate equals the maximum. The desired shipment rate drops, as a result of the decline of the order rate (see Figure 44).

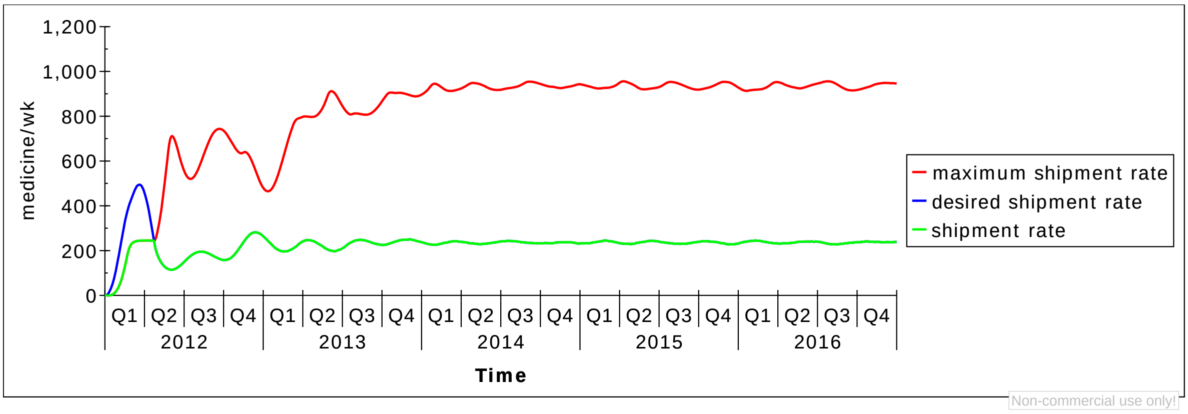


Figure 47: Time dependent behavior of shipments

After a few months, the desired shipment rate is equal to the maximum shipment rate. All orders will be fulfilled at that time and further as well. Until the order fulfillment is reached, a safety stock will be built. Due to the fact, that the desired shipment rate is not exceeding the maximum shipment rate during the rest of the simulation period all orders will be fulfilled and the safety stock should guarantee this situation in case of any unexpected events.

6.2.5 Finances

Figure 48 shows the time dependent behavior of the financial values. The revenues follow a similar characteristic as the incoming orders, apart from the early phase, when not every order can be fulfilled. The costs consist of the labor costs and manufacturing costs. The personal expenditure demonstrate a very stable and easily calculated behavior. After the early oscillations, the manufacturing costs exceed the labor costs quite clearly.

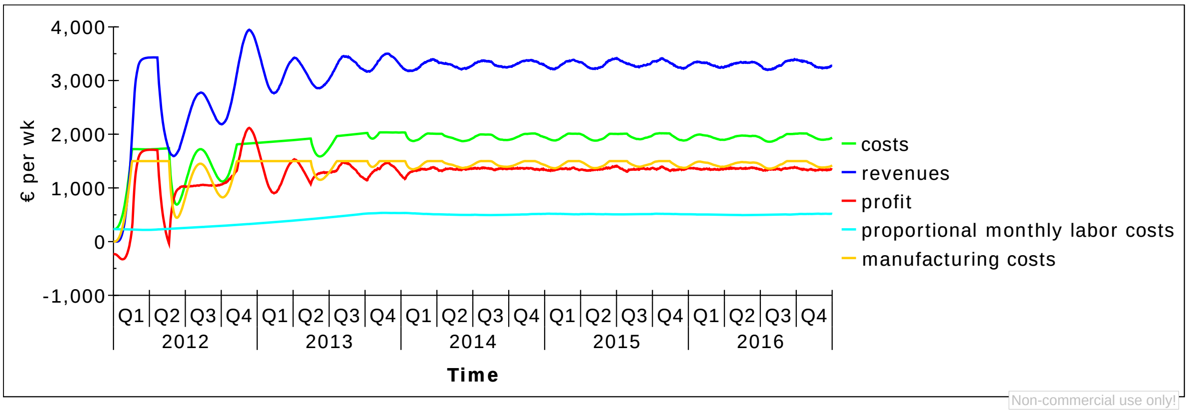


Figure 48: Time dependent behavior of finances

6.3 Basic Adjustments and System Responses

This chapter focuses on the options for managers, because they can affect the systems behavior in many different ways and the simulation enables a variety of adjustments. Not each variable is amenable to be influence by managers, but they can set targets and constrains especially for the sales representatives and the production.

One of the major questions for managers is how to deal with the composition of their sales force. Currently they employ two sales representatives, which leads to an consultation frequency of about 0.5 visits per month and doctor. These employees are not able to visit more physicians, therefore a higher desired advice frequency triggers hiring decisions.

It seems plausible to target a very high consulting rate, to increase the sales volume. In the product launch scenario, the desired advice frequency was set to one consultation

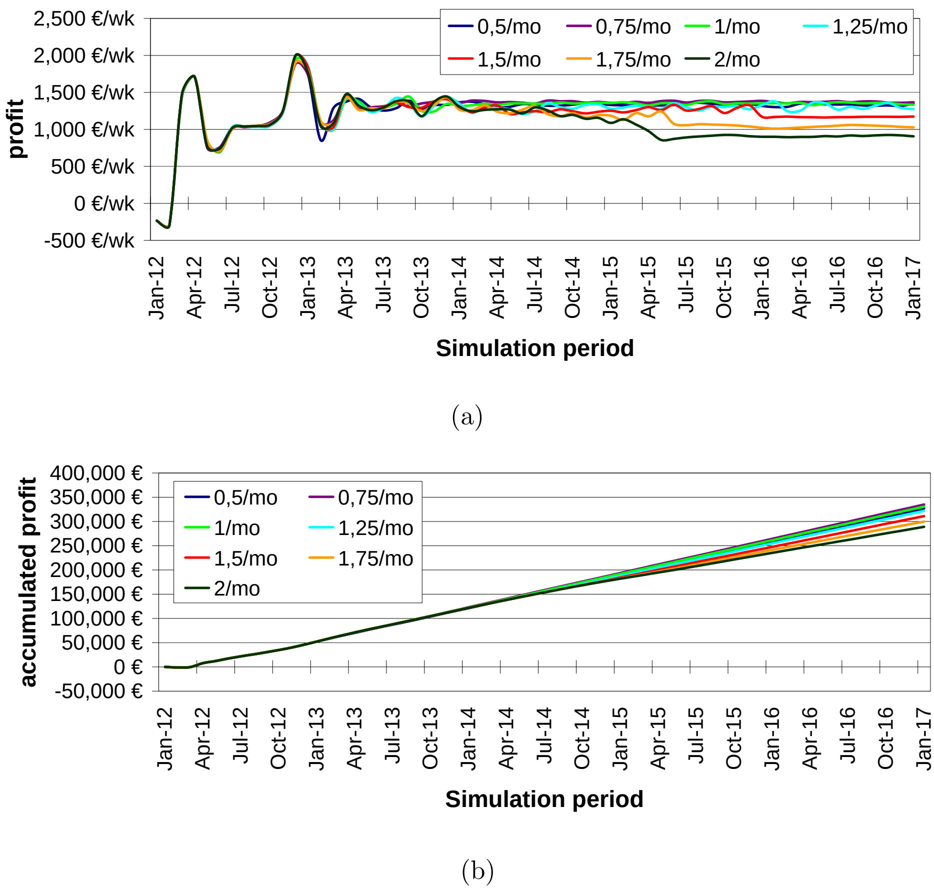


Figure 49: Financial deviation, depending on the desired advice frequency - (a) Variations in the weekly profit; (b) Variations in the accumulated profit

per month and therefore the number of sales representatives need to double at least. But what would happen, if this target is set different? Figure 49(a) shows the behavior of the profit over the simulation period concerning different targets. All other initial and constant values stay unmodified. In the early phase all series act similar, because each is hiring the same quantity of sales representatives. The targeted amount of employees will be reached sooner, if the desired frequency is low. After this point is passed, the profit development differs. Despite the higher sales volume, all series with a desired advice frequency of more than 1,5 visits per month, show a worse behavior. The profit is still positive, but not as high as in the other series. Due to the limitation in potential doctors and patients, the market is almost saturated. A further increase of sales representatives will only trigger a small amount of new orders. The labor costs are linearly growing, hence the profit declines. A drop occurs in the beginning of 2015, because the desired production exceeds the limitation. Orders are unfulfilled and additional investments in advertising and personal costs will not lead to higher revenues.

0,5/mo	0,75/mo	1/mo	1,25/mo	1,5/mo	1,75/mo	2/mo
326,821 €	334,910 €	330,647 €	321,804 €	310,969 €	299,738 €	288,968 €
-1.16%	1.29%	0.00%	-2.67%	-5.95%	-9.35%	-12.61%

Table 14: Accumulated profit over the simulation period, depending on the desired advice frequency

Figure 49(b) shows the deviation of the accumulated profit over the simulation period. As listed in Table 14 the difference of the accumulated profit could last up to more than 12%. In addition, the accumulated profit is higher in the 0.75 series. This actuality leads to the assumption that a lower desired advice frequency would serve a better overall result.

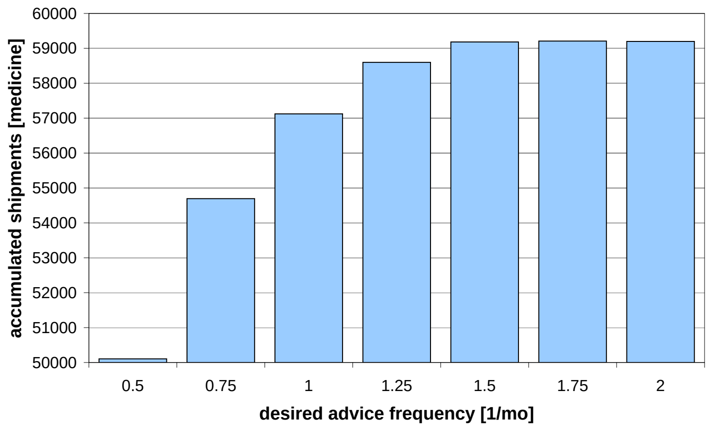
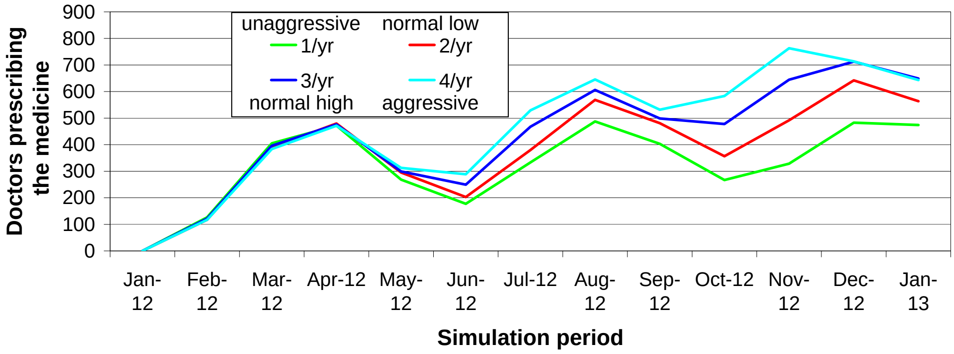


Figure 50: Deviation of accumulated shipments, depending on the desired advice frequency

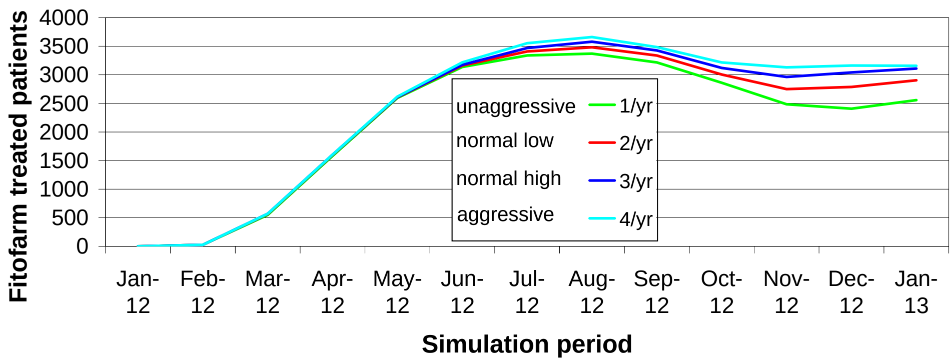
To reach a higher accumulated profit it seems plausible to set the desired advice frequency to 0.75 per month, but more aspects should be taken into account. Figure 50 illustrates the accumulated shipments over the whole simulation period of five years. At a desired advice frequency at about 0.75 per month, 4.25% less shipments are possible.

The current capacity utilization is far away from maximum and therefore it seems plausible to utilize the manufacturing with their premium product as much as possible.

In the following sections some other modifications and their impacts are explained. The simulation period is reduced to one year to show the response of the system in the early phase. At first an aggressive hiring policy should increase the amount of sales representatives very fast and more doctors should be satisfied to prescribe the product. The profit is disregarded in this case, because the production has to fill the inventory, much more production starts are desired and the profit would be negative in the beginning (see Figure 48).



(a)



(b)

Figure 51: Acquirement of (a) doctors; (b) patients - within the first year, depending on the growth rate

Figure 51(b) illustrates the response of the patient treatments, concerning different hiring strategies. Especially in the early phase, some companies try to gain as much influence as possible. This behavior in the early phase can trigger great success in the long-range. The patient and doctor subsystem are based on the Bass Model. Bass (1969) mentioned, that the pressure for the adoption of the product depends on the actual amount of people that already adopted the product. This is also known as the word of mouth effect and describes encounters of people and the possibility that one of them is persuading the other.

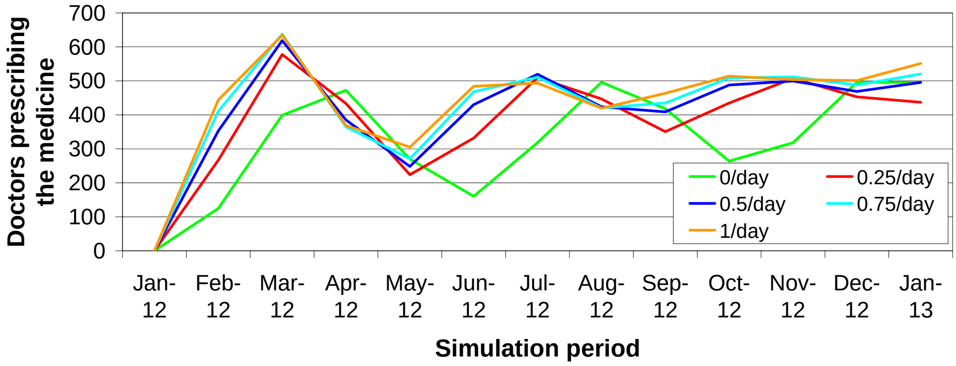
As shown in Figure 51 all series are similar in the first three months, because newly hired personal is not active yet. After this period of vocational adjustment the amount of sales representatives differs. The most aggressive hiring policy achieves the desired advice frequency within three quarters and the normal high series within one year. As a consequence, much more doctors are advised and will prescribe the medicine (see Figure 51(a)). Hence patients will get a prescription for the reference product more likely and the number of treatments raises. In the most aggressive way, about 20% more treated people could be achieved after one year.

Another external impact is the creation of satisfaction due to advertisement. As stated in Chapter 5.1.1 the reference company does not focus on marketing, concerning their current product portfolio, but they are aware of the possibility. Currently they collaborate with a marketing institute for a new product launch and therefore this eventuality is implemented in the model.

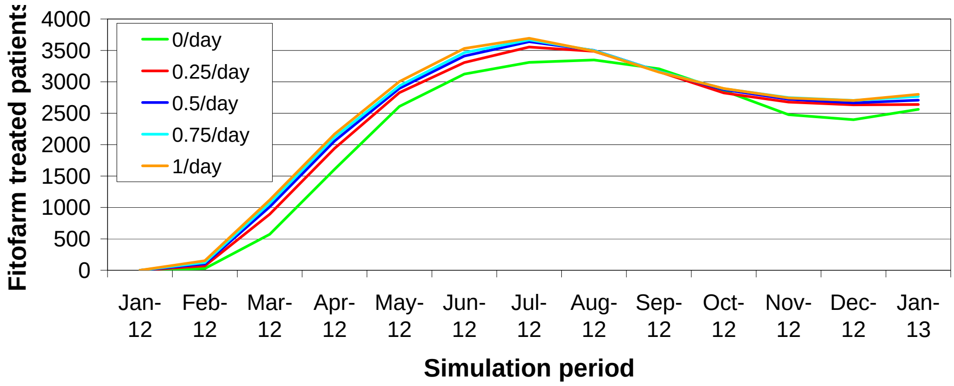
Advertisement is represented as *advertising effectiveness* (eff_{advert}) and figures a rate of daily convinced doctors. It is only treated as an external impact on the adoption process in the doctor subsystem. Certainly, in reality there is correlation to costs as well, but as a result of unavailable data, there is no linkage to the financial segment and the effects are explained in the doctors and patient system only.

Figure 52 illustrates the impacts of advertising in the early phase. Based on the assumption, that this kind of advertising is only effecting physicians, that are already aware of the product, each doctor has to be advised once before the advertising effectiveness creates an impact. The amount of sales representatives is low in the beginning and therefore this effect leads to prescribing doctors very early.

As shown in Figure 52(a), the basic scenario without advertising provides prescribing physicians not until the second visit. Concerning the constant rate of new adoptions, caused by this additional external force, some once visited doctors become a prescriber without any further consulting. As a result, more people will receive a prescription and the amount of treated patients is increasing (see Figure 52(b)).



(a)



(b)

Figure 52: Acquirement of (a) doctors; (b) patients - within the first year, depending on the advertising effectiveness

7 Conclusion

According to the statement of Forrester (1994), that many projects have fallen short of their potential because of failure in understanding and mostly no support for implementation, it seems to be plausible to address these risks to the model as well. The main aspect is, that SD projects should always be evaluated considering their purpose. Especially in the field of strategic management, the scope of systems is endless and therefore each limitation confines the usability of the model. In addition, the lack of information leads to a further shrinking field of application. Hence models will always fit to a specific scenario and will be completely useless for a different one. The reuse of models for as many different scenarios as possible, should be an objective for each modeler.

The qualitative part of System Dynamics (SD) provides a very good method for analyzing the dynamics of the pharmaceutical market. The segmentation allows managers to explore each subsystem solely and to understand the dynamics that arise from the interdependencies of them. As mentioned in the theoretical part, qualitative models explain the feedback processes within the systems and in addition the top-down approach allows a better understanding of the relationships of higher level subsystems. Resulting from this attitude, the Causal Loop Diagrams (CLD) are very powerful in the field of strategic management. Mapping mental models as feedback processes can be done very fast and does not require much time exposure or augment knowledge. There is no regularity for the modeling process and as mentioned before, a lot of models are not necessarily correct, but their purpose - to assist the thinking - is fulfilled.

While the qualitative models provide a basic overview with a comparatively little effort, the formulation and data fitting of quantitative models are very costly. Another big challenge is to find suitable rates for intangible values, especially in the social environment. Considering these aspects, and the fact, that once chosen constant values or relationships can change during the simulation period, the area of quantitative SD applications is tiny. Many researchers are dealing with huge models and many different variables. Coyle (1998) stated, that some researchers boast with the size of their models and compare them by counting the amount of variables. He argued, that the abundant supply of software seduce people to focus on drawing Stock and Flow Diagrams.

The quality of quantitative models strongly depends on the ability of the modeler, basically the mathematical background and the ability to abstract real situation. The high error rate within these models arise from many different issues (Forrester, 2003). Companies are not willing to spend a lot of money for uncertainty and therefore many implementations were not concluded. But the field of SD research is constantly growing and comprises a variety of subject areas, despite these characteristics.

7.1 Validation and Verification

The conducted case study illustrates the possibility to implement a SD approach to the industry. As already stated above, the scope of application is limited to a very specific purpose. Therefore the basic approach was, to focus on a specific product and a very stable market. According to the managers it was one of their major attempt, to understand the complexity of the industry, especially the impact of their consulting strategy. During interviews, the basic feedback processes were mentioned and the first mental models were created. According to these concepts the data collection began and the model was structured in the basic segments. As a result of the complex market structure, already implemented researches were used to describe the human behavior, particularly the adoption of the product by physicians. Based on the project background, the focus was on the environmental part of the industry and as a consequence the production subsystem was adopted from the literature and modified for this particular purpose. These circumstances simplified the verification process substantially, because many parts were already implemented in many other projects and were proven successfully.

In the next phases more detailed qualitative models were developed and the first quantitative model was created. A lot of validation and verification was done during the modeling process and each system behavior was reviewed by the project members and the managers as well. All assumptions within these systems were reviewed with those responsible. Relationships within the systems were discussed and taken into account. In consequence of the abstraction, the importance of all connections was reviewed and negligible links were omitted, to keep the model as simple as possible, without loosing the suitability.

In order to provide a useful tool for the strategic decision making processes, the quantitative model was implemented in the simulation software. All adjustable parameter are modifiable and different scenarios can be simulated within the same model. The product launch scenario, that is explained in detail in the previous chapter, has shown the basic behavior of the system. Further more, the managers agreed that the achieved results seem to be plausible and the behavior is similar to the expected one.

A detailed validation and verification, based on historical data is not done yet, but some tendencies indicate impressive accuracy.

- Expected optimum
  The managers viewed one consultation per month and doctor to be an optimum advice frequency, which is similar to the result of the simulation.

- Current situation
  Currently the company employs two sales representatives and is manufacturing in a single shift. The capacity utilization is distinctly beneath the constraints and this characteristic is also shown by simulating the present situation.

Resulting from these facts, the model seems to be suitable for further usage and should provide a useful tool in the strategic decision making processes.

7.2 Interpretation

The results given by the simulation illustrates some very interesting options for the management. The main purpose of the model is to provide information about market reactions by changing the amount of sales representatives and therefore the frequency of consultations. Currently the company is not subjected to constraints and the reference product generates acceptable profit. An increase in sales force will lead to even better revenues, but the simulation demonstrates, that there is a point where the profit starts shrinking. By doubling their current amount of sales representatives this point will be reached. Further growth still leads to higher sales quantity and of course a good capacity utilization. But as a result of the existing bottleneck, the production will eventually reach its limitation and a negative impact to the market occurs. Each unfulfilled order leads to an untreated patient and therefore to a disappointed customer. It is impossible to spot the real human disappointment and their response, but it seems to be plausible to prevent negative reactions, to secure long term success.

The adoption of the product by physicians is the main factor for success and therefore the possibility to create more satisfaction should be taken into account. Focusing on the number of consultation is only one way to secure the adoption, but basically the main option. Due to the characteristics of the market, there will be no need to focus on different marketing concepts or customer relationship strategies. The reference product does not compete with a similar drug and the price regulation keep the rivalry on a low level.

Very fragile data is used to represent the advice efficiency, because it is based on the subjective viewing of the managers. The reaction of doctors depends on many aspects, which are not possible to model easily with SD. It seems to be dangerous to calculate in average rates and current happenings have shown, that especially the qualification and appearance of a single sales representative is very important. A senior employee can not be replaced by a rookie and suitable replacements are not possible within a short period of time. Unexpected events, like quits of top performers, machine breakdowns or momentous changes in the competition, trigger problems and fast reaction is needed. Although these occurrences are not implemented in the SD simulation, an instant response is possible by simulation runs based on the new initial situation. In addition to the forecasting, optimization and evaluation of different strategies, which are supported by a System Dynamics model, the great advantage is the ability to react deliberate within a short period of time.

7.3 Future Perspective

In the next few months, the SD model will be reviewed by the project members and managers of the reference company. More extensive validation and verification have to be done. This SD model is used as the strategic layer in a hybrid model, hence the operational level is going to be replaced by a Discrete Event Simulation (DES) and appropriate interfaces must be found. Simultaneously to the development of the SD model, a lot of research is done in the field of continuous data exchange between the common software packages for SD and DES.

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