Improving the Management of Innovation Risks

- R&D Risk Assessment for Large Technology Projects

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Abstract

Global network structures of products and services are important value creators for many companies. Complex business models include a variety of relationships and interrelationships within and across different systems particularly in the case of innovation processes. This increases innovation risks. Risk management is becoming more and more important and is crucial for the German Machinery and Plant Engineering Industry (MPEI). Many companies are medium-sized and are using standard static risk management methods. Use of these methods often means that critical situations are detected late, they do not help in the understanding of problem characteristics and their interdependencies and, consequently, lead to erroneous decisions.

Therefore, the modelling of cause-and-effect structures of innovation risks in the German MPEI facilitates the exploration and understanding of the behavioral dynamic of risk clusters. In a comparison of standard risk assessment with the Causal Loop Diagram and the System Dynamics Model of Innovation Risks, the potential of System Dynamics for systemic and multi-dimensional risk management is demonstrated.

In this paper, particular emphasis is given to the risk of shortages of skilled workers from a common and System Dynamics perspective. This is relevant as these shortages are the main risk associated with innovation, impacting on project timings, output and performance amongst others. The research concludes that the development of specific System Dynamic models can help to overcome certain problems and incorporate multi-causal interconnections and multidimensional views on risk.

Keywords: innovation risk, holistic risk management, complexity, dynamic, risk systems, risk analysis, risk aggregation, system dynamics

1. Characteristics of Innovation

German Machinery and Plant Engineering Industry (MPEI) business models are aligned to the development and production of machinery and plants in the Business-to-Business sector (B2B). Their construct is determined by individualized equipment with high investment volumes. The industry is one of the most important in Germany comprising more than 6,000 companies, 87% of which are Small and Medium Enterprises. This is an exceptional characteristic and it follows that it is one of the largest industrial employers. The industry is further characterized by capital sourcing limitations (VDMA FuI, 2014; VDMA KZK, 2015). In addition to the automotive industry, the electrical engineering and the pharmaceutical/chemical industries, the German Machinery and Plant Engineering Industry is one of the strongest industries for research. This is its most important success driver combined with special conditions in terms of structure and product portfolio. The industry is highly influenced by innovation and its associated risks. Given these special conditions, management is aware that innovation risk has to be managed adequately and comprehensively in order to remain competitive.

Innovation is the main driver of success for today’s competition (Gassmann 2006a, 2006b). Many challenges arise from this which are highly interconnected and turn innovation risk management into multi-dimensional risk management (see Figure 1) which is both complex and dynamic (Gassmann 2006a, Howell, 2013, Warren, 2008).

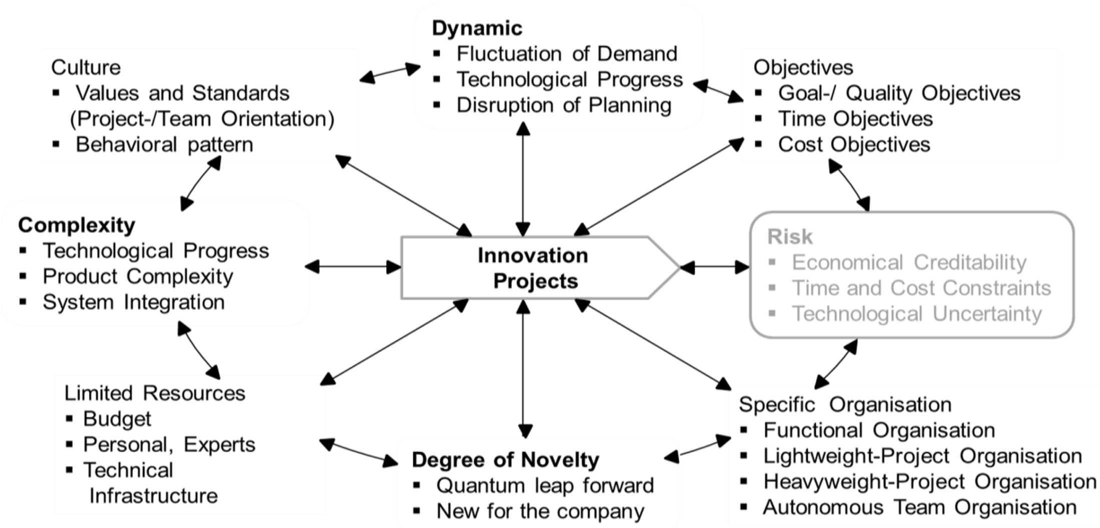


Figure 1. Aspects and Interconnection of innovation risks (Gassmann 2006b S.9)

2. Research Methology

A lot of research has been conducted on innovation. Common themes in innovation literature include multiple risk categories studied from different viewpoints. They reflect on innovation risk arising out of the market system (industry) from a meta perspective which is, in turn, influenced by the subsystems of customers, the company and competitors (Kotler et al., 2011, Porter, 1980). Specifically in relation to the German Machinery and Plant Engineering Industry, coopetition or cooperation partners have been identified in previous scientific work. In order to gain a deeper understanding of the industry, a scientific literature review was conducted and the main industry innovation risks identified. These are represented in the following table:

Table 2. Innovation features and risks in the innovation-risk-system for the German Machinery and Plant Engineering Industry

Innovation Feature	Risk Factors
1. Technology Leadership	Technology Performance
2. Competitive Price	Innovation Budget
3. Quality	Technology Rework
4. Development Time	Time Delay
5.1 Internal Capacity	Recruitment
5.2 External Capacity	Requirement buying in Development
6. Technical Qualification	Technology Competence
7. Knowledge Transfer	Knowledge Transfer

It is envisaged that an analysis of the connectivity between innovation risks will offer interesting insights. An assessment the results is expected to identify different priorities in terms of risk management. Due to the limitations of time and resources, only the risk of shortages in skilled workers will be discussed from a common and System Dynamics perspective in this paper.

To manage risks systematically a standard process was developed which has been recommended by many authors and non-governmental organizations (see Figure 2 based on IDW PS 360; White, 1995; Crouhy et al. 2006; Olson et.

al., 2010; Denk et al. 2008; Romeike/ Hager 2009; Stiefl 2010; Fraser/Simkins 2010; Gleißner 2011). The risk analysis covers the risk identification, evaluation and aggregation. The starting point is risk identification where the risks are identified and priorities are set. The methods applied are quite often risk-checklists. The next step is risk assessment where the methods applied focus on the evaluation of the probability of the occurrence of the identified risks and the extent of potential loss. This then determines the decisive parameters of the function. Risk aggregation consolidates the risks. Within risk aggregation, the models and methods of quantification applied are based, in general, on distribution functions and their simulation (Monte Carlo Simulation). Traditional approaches, like the arrangement within damage classes, the inquiry of maximum loss or values of expectation of loss, are also common practice (Denk et al., 2008; Romeike/Hager, 2009; Gleißner, 2011). The results which emanate from these analyzes affect subsequent activities. These are the most difficult but important steps especially in the context of managing risk from a complicacy and dynamics perspective. The objective of the risk mastery and regulation process is to avoid intolerable risks and to bring unavoidable risks to a tolerable level. Last but not least, the risk control process has to be completed. All in all, the risk management process is a continuous one.

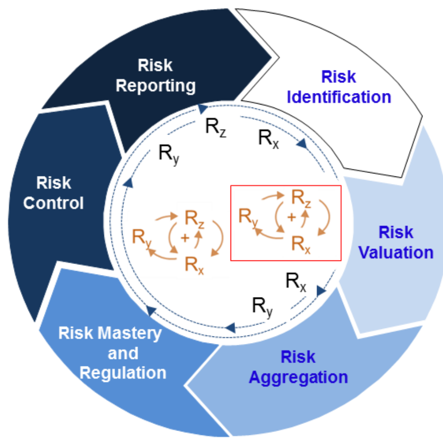


Figure 2. Extended risk management process

By completing an intensive literature review on risk management methods, some methodical weaknesses have to be addressed. These weaknesses refer to the risk analysis in the standard process. Most difficulties arise from the management of cause-effect-relationships and the dynamic of risks. Although wide reaching risk analysis methods and instruments are available, dealing with multi-dimensional risk limits possible applications. Stemming from a system perspective on risk which is determined by two dimensions' complicacy (System Theory) and dynamic (Cybernetic) (see Figure 3), the methods applied were duly assessed. In the dynamic dimension, the methods were checked for their ability to cover development over time and time delays. Thereby complicacy gives an idea of the ability to incorporate explicit cause-and-effect-structures and the overall linkages between the risks (Dillerup/Kappler 2015).

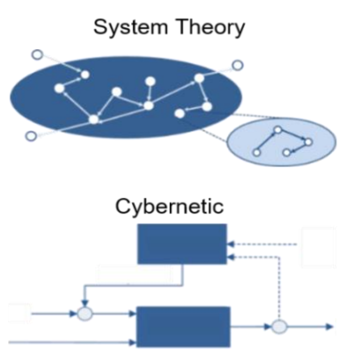


Figure 3. Systems Complicacy und Systems Dynami

To sum up previous findings, which have been discussed in previous work (Dillerup/Kappler, 2015) in both theory and practice, the research gap identified is based on the need to have a generic, dynamic cause-and-effect-structure for innovation risks in order to understand their interdependencies and behavior over time.

3. Planning, Control and Risk Managing Tools in the MPEI Project Stages

Coming from a common perspective on risk management, now the application of methods and tools for the German Machinery and Plant Engineering Industry is discussed. The industry is mainly influenced by projects which are commonly determined by five phases. Each phase has different aspects and dimensions to consider. Therefore, different planning and risk tools are applied in order to cover the specific demands of each phase. The main tools and concepts used in the industry are (see Hilpert et. al. 2001, p. 44ff.):

- Enquiry Process Certificate
- Project Analysis
- Functional Specification Document
- Work Breakdown Structure
- Technical Data Sheets
- Installation Checklist
- Capacity Planning (rough)
- Contract Checklist
- Costing
- Schedule
- Engineering Change Application
- Concurrent Calculation
- Risk Checklists
- Risk Analysis

The examples show the complexity of the dimensions to be managed in innovation projects. In the **Preliminary Clarification Phase,** a rough project assessment will be conducted. Depending on the results of this phase the decision to submit a proposal will be made (see Hilpert et. al. 2001, p. 59f). Therefore, questions in terms of technical realization, capacity for realization, customer and market strategies, make or buy, joint ventures, etc. as well as project risks and the timing of agreements have to be answered. These findings correlate with the findings on innovation risks in the sample industry with the exception of the risk of "Technology Competence and Knowledge Transfer". The risk analysis work covers following risk types which lead to an overview of the total risk of the project (see Hilpert et. al. 2001, p. 115):

- Economical → Innovation Budget
- Timing → Time Delay, Recruitment, Requirement to buy in Development
- Technological → Technology Performance, Technology Rework, Technology Competence
- Other risks → Knowledge Transfer
- Guarantee.

The preferred tool in this phase was the concept of the value analysis. This could be applied to assess the attractiveness of the project and used in the risk identification phase in the common risk management process. An example of how the linear risk evaluation works in shown in Table 2 (See Hilpert et. al. 2001, p.66). The assessment of risks takes place through the application of a grading scale. In the example, 1 up to 10 is applied.

Table 2. Value analysis in innovation projects of the industry

	Weight	10	… 5 …	1	Deal breaker
Economical		Risk far below Average		Risk far above average	
Timing		No risk		Risk far above average	
Technological		Completely Controlled		Risk far above average	
Other risks		No risk realized		A lot of risk	
Guarantee		Minor		Considerable	

The weighted results will be added in isolation from each other (see Hilpert et. al. 2001, p. 67). In the context of risk management, this means that the risk has the same cause but there are no interdependences between the risks and, risks are discussed as independent single risks (see Gleißner 2014, p. 8). Additionally, the application of probabilities is proposed (see Hilpert et. al. 2001, p. 116). This leads to the classical static portfolio of the risk evaluation (see Figure 4).

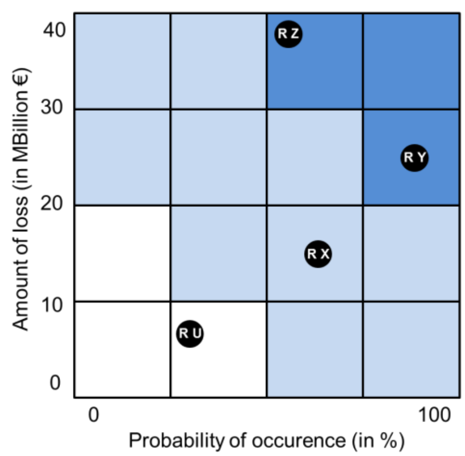


Figure 4. Portfolio of the risk evaluation

In terms of the classical risk management approach the cycle is interrupted after risk aggregation (see Figure 5). A project will be viewed in this phase more particularly on multiple dimensions whereas the risk is only discussed on single risk level (see Hilpert et. al. 2001, p. 115).

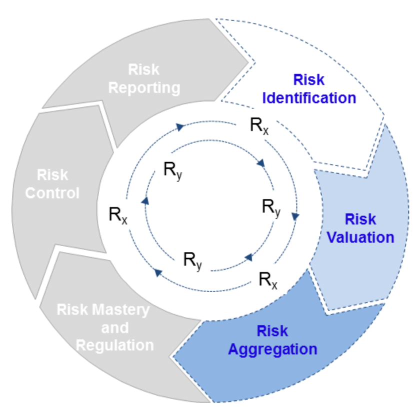


Figure 5. Interrupted risk management process in the preliminary clarification phase

The **proposal phase** is determined to be crucial for the success of the overall project or innovation. The treatment of orders and also the results of orders are extensively pre-defined. Hence, this phase is synonymous with a conception phase. Content subjects from the preliminary clarification phase are refined and, again, the identified innovation risks are added to these subjects (see Hilpert et. al. 2001, p. 61):

- Technical high-class level / specifications,
  → Technology Performance
- Type and structure of the project risks,
  → Technology Rework
- Milestones starting after order placement,
  → Time Delay
- Capacity needs and capacity utilization,
  → Recruitment, Requirement buying in Development
- Make-or-Buy aspects,
  → Technology Competence
- Perhaps cooperation's with other enterprises
  → Knowledge Transfer
- Cost volume (pre-calculations) and timeframe of occurrence → Innovation Budget

It becomes clear that different dimensions in the project like quality, time, capacity and costs have to be considered during the concept phase, and these are highly interconnected. Nevertheless, checklists audit the project feasibility from an isolated perspective (see Hilpert et. al. 2001, p. 122).

Simultaneously, risk analysis takes place in this phase. Single project risks are identified by means of risk checklists (see Hilpert et. al. 2001, p. 117-119 or p. 169f). Strongly linked is the analysis of risks in terms of potential coverage and protections (risk control measures) and also the costs arising from these measures, e.g. insurance premiums, fees etc. This extends the risk management process from the perspective of regulation measurements (see Hilpert et. al. 2001, p.115, Figure 6). If the coverage is inapplicable (risk keeping) the prospective damage and probability of occurrence will be defined for each single risk (see Hilpert et. al. 2001, p. 115).

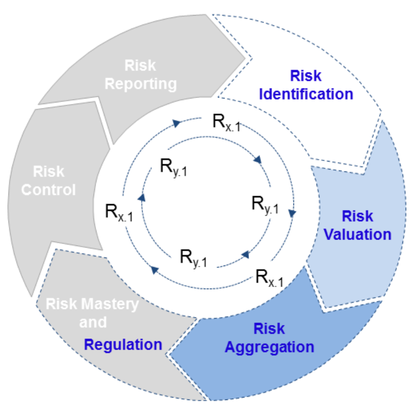


Figure 6. Interrupted risk management process in the proposal phase

These quantitative aspects of the risk analysis will be adopted in the project calculation, so that the risk itself is only reflected in purely monetary dimensions (see Hilpert et. al. 2001, p. 80-82). Interdependence between risks or the effect of risk measures on the overall system are not replicated in this project phase (see Hilpert et. al. 2001, p. 122). Only in the order phase, risk management measures (see Hilpert et. al. 2001, p. 115) and their effect on risks will be tracked (see Hilpert et. al. 2001, p. 90-100 & 122.)

In the **Transfer Phase** the main focus lies on the specification of responsibility and competence in the project.

Besides the coordination of the activities, interfaces, problematic issues and the definition of working packages, the job of the project team consists of checking the offer details with the necessary data for the order processing consistency. The following subjects are checked content wise (see Hilpert et. al. 2001, p. 85ff.):

- Comparison of order and offer
- Specification and actualization of targets of the project
- Planning of the implementation process and reservations

After the **placement of the order** the project turns in to the processing. In terms of project and risk controlling, this phase is discussed in considerable detail in the literature. The perspectives are on

- Technology → Technology Performance,
- Cost → Innovation Budget
- Milestones/ Capacity and Development → Technology Rework, Time Delay, Recruitment, Requirement buying in
- Commercial processing → Technology Performance.

They are not independent of each other and cover all industry-specific risks with the exception of the risk of "Technology Competence and Knowledge Transfer".

Being aware of existing interdependence between each other, changes (divergences = risk) in single perspectives are brought into the respective areas. Within the scope of the technology target-performance, comparisons should be brought in in terms of costs and milestones. In the project, calculations are updated. Network plans and Gantt charts as well as appointment lists and capacity overviews form a fundamental basis to check the effectiveness of measures in order to keep to the milestones (see Hilpert et. al. 2001, p. 88ff.).

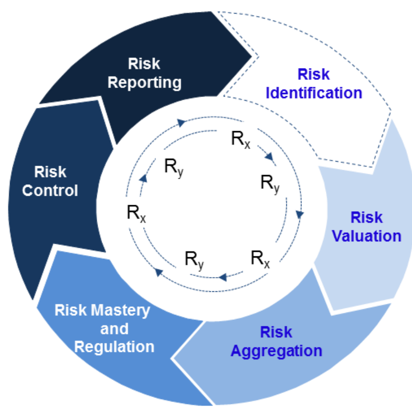


Figure 7. Completed risk management process in the order phase

Change management in commercial processing monitors the effects on variety, scope and technical effects through the application of checklists. The dimensions where the effects are reflected include appointments, guarantees, penalties, costs and capacity. (see Hilpert et. al. 2001, p. 98-101). The project reporting and project documentation close the classical PDCA (Plan-Do-Check-Act) cycle. In this phase, the classical risk management process fulfils all the necessary steps and so the circle is completed – the loop of the standard risk management is closed – but not the loops within.

In terms of the interrupted risk management process in the proposal phase, it has to be pointed out that, although the risks (changes to the project) are recognized, judged and processed from different dimensions, the actual feedback effects are neither considered from a minute nor a holistic level. This could be ascribed to the high number of management tools used and therefore high numbers of dimensional interfaces. These tools were not in fact developed for application in the context of feedback loops and time delays. On the other hand, a systemic view on the total risk assessment is prevented by the application of these management tools with all these different dimensions within the standard usage.

Within the last project phase the **evaluation of the projec**t occurs. In addition to the retrospective calculation of the economic result, the benefit of know-how is evaluated. In any case, the know-how transfer in the context of the technical result is judged in order to ensure continuous improvement (see Hilpert et. al. 2001, p.108-113). The need for action and incorporation of the know-how development and the effects in previous phases is, from a system perspective, identified.

4. Innovation Aspects and Risks in the Innovation-Risk-System

To overcome these weaknesses of the standard risk management tools and to close the loops through all the stages in the risk management process in the MPEI, the System Dynamics approach is identified as an appropriate simulation approach for the overall risk management cycle as well as for the risk analysis, which is the initial step in the risk management process. Within this process, System Dynamics is able to illustrate the system linkages and time delays in the system behavior (Davis et al., 2007; Forrester, 1972; Sterman, 2000; Morecroft, 2008; Rafféе/Bodo, 1979). These results are the starting point for simulating complex and dynamic interactions. System Dynamics takes the complexity, feedback loops and the non-linearity of social systems into account (Sterman, 2000). Another point that supports the use of System Dynamics is the facility to simulate the interaction of quantifiable and related variables on an aggregated overall system level (Dooley, 2002). Furthermore, the possibility to keep multidimensional perspectives and connect them with each other without the transmission into a one dimensional perspective militates for a System Dynamics approach.

4.1 Causal Loop Diagram on Innovation Risks

The starting point for the research project was an analysis of scientific and specialized literature, the general views of consultants, auditors, as well as representatives of the German Engineering Association and leading companies, all of whom informed the following research questions:

a) How can the innovation risks in the machinery and plant engineering be defined?

b) What does the structure of the relevant innovation risks look like?

c) How do they affect each other?

d) Is there a need for adjusting single risks depending on the results of the simulation?

For questions a) to c) a Causal Loop Diagram was developed which was the starting point for the development of the System Dynamics Model and which was used to answer question d).

As previously mentioned, the innovation aspects in the German Machinery and Plant Engineering Industry have been identified and the appropriate risk factors where matched to previous work. By applying the approach of "Standard Cases: Standard Structures (see Standard Models by Kim Warren, 2014 and also other leading System Dynamics Experts e.g. Brossel, 2004a; Bossel, 2004b; Warren, 2014) a literature review of generic business architectures on innovation models, market models, knowledge management and project management in the System Dynamics literature was conducted. By matching them to the findings of the industry research on risks, the list was consolidated to the industry specific approaches which are highlighted in bold in Figure 8.

Potential Standard Structures & Selected Structures (bold)

1. Technology Leadership: ***Maier (1998);*** Milling (1996) auf Basis von Bass (1969); Dillerup (1999); Milling (2002); Morecroft (2008); Warren (2008).

2. Price Competitiveness: ***Maier (1998); Bossel (2004);*** Milling (2002).

3. Quality: ***Lyneis & Ford (2007); Rahmandada & Weiss (2009); Rahmandad & Hu (2010)****;* Ford & Sterman (1998); Lyneis et al. (2001); Love et al. (2002).

4. Time for Development: ***Rodrigues & Williams (1998)****;* Lyneis et al. (2001); Love et al. (2002); Lyneis & Ford (2007); Richardson (2014).

5.1 Internal Capacity Expansion: ***Lyneis & Ford (2007);*** Rodrigues & Bowers (1996); **Ford & Sterman (1998)**; Rodrigues & Williams (1998); McGray & Clark (1999); Lyneis et al. (2001); Morecroft (2008).

5.2 External Capacity Expansion: ***Ford & Sterman (1998)***

6. Technical Qualification: ***McGray & Clark (1999); Lyneis & Ford (2007); Warren (2008*****);** Lyneis et al. (2001); Rodrigues & Williams (1998).

7. Knowledge Transfer: ***Georgantzas & Katsamakas (2008); Warren (2008)****;* McGray & Clark (1999); Luna-Reyes et al. (2008); Rahmandada & Weiss (2009).

Figure 8. Modelling standard risk(s) with standard structures

These results extended the initial Figure 1 from the perspective of the identified feedback loops which shows the system approach and therefore the system behavior of innovation risks.

Innovation Feature	Feedback loops	Risk Factors
1. Technology Leadership	R1.1 R&D Policies R1.2 Competition B1.3 Market	Technology Performance
2. Competitive Price	B2 Pricing	Innovation Budget
3. Quality	R3.1/2 Internal/External Rework Cycle	Technology Rework
4. Development Time		Time Delay
5.1 Internal Capacity	B5.1 Internal Capacity Expansion	Recruitment
5.2 External Capacity	R5.2 External Acquisition R5.3 External R&D Placing	Requirement buying in Development
6. Technical Qualification	B6.1 Internal Acquisition of Knowledge B6.2 External Acquisition of Knowledge	Technology Competence
7. Knowledge Transfer	B7.1 Knowledge Drain Reverse Engineering B7.2/3 Knowledge Drain External/ Internal	Knowledge Transfer

Figure 9. Innovation features, risks and feedback loops in an innovation-risk-system for the industry

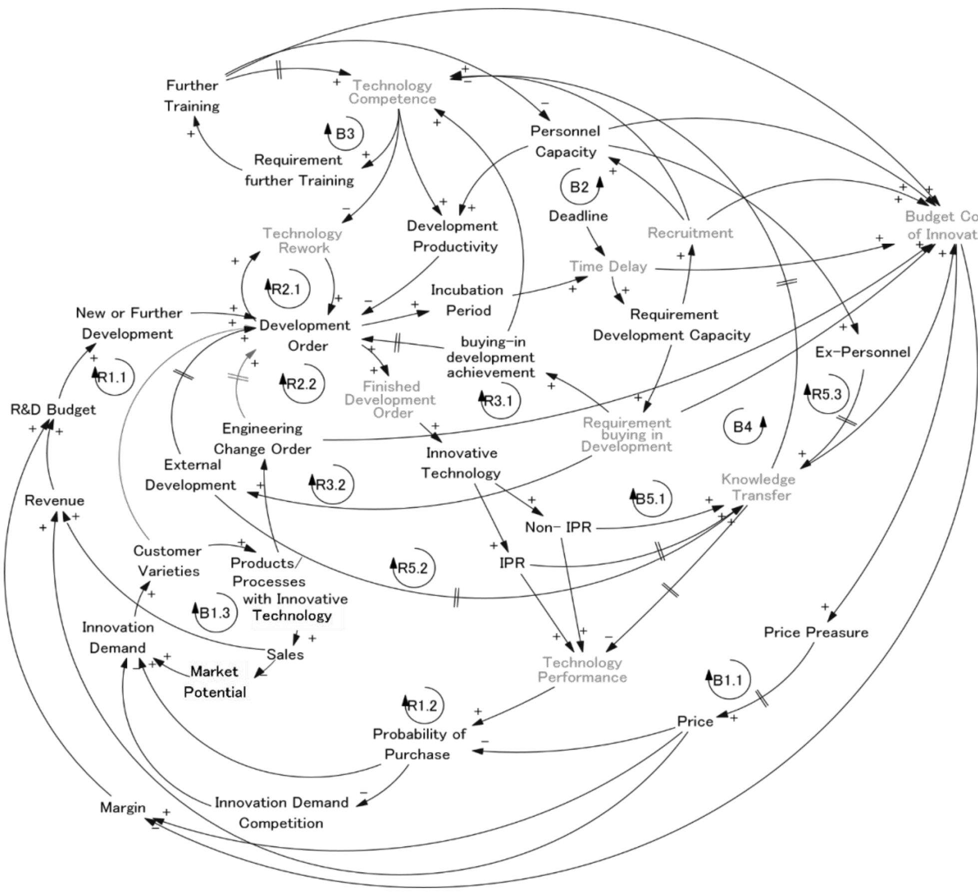


Figure 10. Holistic Innovation-Risk-Net for the Machinery and Plant Engineering

(see Dillerup/Kappler, 2015)

By matching these findings with the findings of the literature on the German Machinery and Plant Engineering Industry an innovation-multi-causal-dynamic-risk-system called INNO_CLD-Model (see Figure 10) *was* developed. This Causal Loop Diagram has been assessed in several workshops and meetings by System Dynamic experts, consultants for standard risk management methods, auditors, the German Engineering Association and their risk experts as well as leading companies in the industry.

Also in accordance with the approach "Standard Cases: Standard Structures: Standard Models "the System Dynamics model *INNO_SIM* was created. With the support of several System Dynamics experts the generic structures and models were adjusted, extended and aggregated to the System Dynamics Model *INNO_SIM*.

4.2 Validation Milestones

For validation purposes the common accepted validation processes in the System Dynamics literature were applied (see Barlas 1996; Forrester/Senge 1980; Sterman 2010). Due to the requirements of the research proposal the *INNO_SIM-Model* has to be a generic simulation model of innovation risks for the industry. Not all validation tests could be applied within this theory-driven simulation model and a focus was set on the validation tests of the model structure. The validation process incorporated several methods:

1. Workshops and meetings by System Dynamic experts and system perspective experts, the German Engineering Association and their risk experts.
2. Comparison to reference modes where available and also the use of similar equations set ups.

During the modeling process the model passed these testing phases several times. The structure validation test in particular was applied iteratively. The final results of all tests are presented in Figure 11:

	Testing \ Sector	HR	Competences	Development & Construction	Market	Costs
model structure	Boundary Adequacy (Structure) Test	Aggregation level appropriate	Aggregation level appropriate	Aggregation level appropriate	Aggregation level appropriate	Aggregation level appropriate
	Structure Verification Test	Model structure reality compliant	Model structure reality compliant	Model structure reality compliant	Model structure reality compliant	Model structure reality compliant
	Parameter Verification Test	Parameter reality compliant	Parameter reality compliant	Parameter reality compliant	Parameter reality compliant	Parameter reality compliant
	Dimensional Consistency Test	Dimensions consistent	Dimensions consistent	Dimensions consistent	Dimensions consistent	Dimensions consistent
	Extreme Conditions Test	Behaviour reality compliant	Behaviour reality compliant	Behaviour reality compliant	Behaviour reality compliant	Behaviour reality compliant
model behaviour	Behaviour Prediction Test	Behaviour valid	Behaviour valid	Behaviour valid/ reproduced	Behaviour valid/ reproduced	Behaviour valid
	Behaviour Anomaly Test		Model structure valid			
	Boundary Adequacy (Behaviour) Test	Structure appropriate	Structure appropriate	Structure appropriate	Structure appropriate	Structure appropriate

Figure 11. Applied validations test and final result after the testing phase

Extracts of the modelling process of the Causal Loop Diagram *INNO_CLD* and System Dynamics model *INNO_SIM* are presented in previous work (see Dillerup/Kappler 2015). The current paper catches up at this point by presenting the risk "shortage of skilled workers" from an isolated and system perspective.

5. Simulation Case and Transfer Results

5.1 Parametrization Proposal

The starting point for the simulation study is the academically derived *INNO_SIM*-Model of innovation risks in the German Machinery and Plant Engineering Industry which was partly presented in the previous chapter and also partly discussed in a previous paper (see Dillerup/Kappler 2015). In order to differentiate between standard risk behavior and simulated risk behavior, the simulation structures were developed in order to show system behavior which was deactivated for the standard approach. Therefore, the simulation model is able to generate risk behavior based on an isolated and linear understanding and anticipation through the application of classical risk management tools discussed in previous chapters. Due to the fact that the model has more than 110 parameters there has to be a focus on the main variables. In order to give a generic and consolidated view on the risk behavior, the comparison focuses on:

- Market launch, which reflects the risk of time delays arising out of the system independently of the sector where it originated
- Costs and actual margins, which reflect the risk in increasing or shrinking innovation budgets. The decision to allocate increasing costs to customers can be also defined in the *INNO_SIM* model.
- Customers, who indicate a willingness to buy the innovation. This is reflected in the number of customers who adopt the innovation. The factors that influence their decision are the market launch, the innovative technology (quality technical), the quality (quality functional) and also the price derived from the costs. These will be compared to the offerings of the competitor.

The parametrization proposal is based on an intense data analysis of several statistical studies. These studies are conducted regularly by the German Engineering Association and are exclusively available for association members. The studies cover different sectors of a company in the industry (see Authorless 15 ZEW 2015, Authorless 25 Mbau 2015; Hilpert et al. 2001; Lott/Lutz 2012; VDMA FuI 2014; VDMA HR 2014; VDMA HR 2015; VDMA KO 2014; VDMA PP 2014; VDMA QM 2014, VDMA Vertrieb 2015; VDMA KZ EuK 2012):

- VDMA KPIs - Comparison, Understanding and Changing:
  - Development and Construction, 2012
  - Cost Management, 2014
  - Human Resource Management, 2014
  - Human Resource Structure, 2015
  - Quality Management, 2014
  - Sales, 2015
- Research and Innovation, 2014
- Product Piracy, 2014
- MPI in Figures and Graphs (2015)
- Industry Report of innovation – Machinery Engineering Industry (2014, 2015)
- Product Management in the Machinery Engineering Industry (2012)

5.2 Initial Settings and Standard Base Run (SBR)

The standard case was derived from the studies mentioned before. The case developed is based on a company size of less than 250 employees and a new product development project. For the base run of the simulation model, which is the reference mode to evaluate the risk behavior, is defined as followed:

- Number of experts in the human resource sector (HR-sector): 6 employees (no recruitment risk, no risk regarding requirement buying in development)
- Time needed for a new product development (plan): 23.5 months (no time delay)
- Proportion of own development: 88.7%
- Proportion that has to be changed (rework buffer): 6% (risk of technology rework is considered)
- Quality (functional = performance): plan 100%
- Quality (technical = output): plan 100 tasks (relatively 100%)
- Margin: 0.6% (No risk of innovation budget)
- Total innovation cycle (milestone market introduction): after 49.5 months
- Market introduction competitor: after 77 months (match with the duration of a further development which is round about 27 months after period 49.5 which was the market launch of the company)

- The competitor offers the same product regarding quality, price and output.

To show the extent to which the results are different from those of the *INNO_SIM* model by the application of classical risk analysis methods as described in chapter 3 and which further findings can be derived from the *INNO_SIM* model, a comparison of the results of both methods is presented. Two simulation scenarios were defined:

The first simulation corresponds to an isolated "linear cause-and-effect relationship" with no feedback and time-delay effects. This scenario is referred to as the "SBR Plan". This scenario is compared with the "SBR System". The same simulation model is used to determine the results for the plan and system scenario. In the plan perspective, the simulation is adjusted to a non-feedback perspective which shows the isolated and linear way of the standard risk perspective. If the parameters of the standard base run are entered into the model, the system calculates the manner shown in Figure 12. This perspective is isolated and static and the effects are treated as linear and refers to the Risk Matrix were risks are presented by the volume of loss and probability of occurrence (see Figure 13).

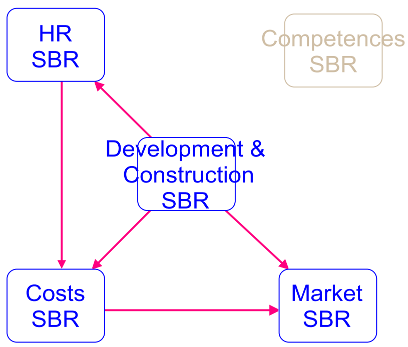


Figure 12. Standard base run configuration

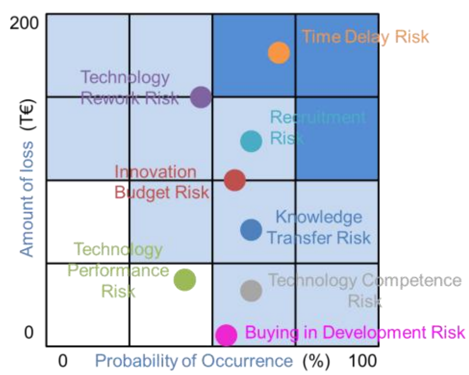


Figure 13. SBR Plan Perspective

Starting from the identified innovation risk systems, the risks and results are formed in the dynamic risk analysis in a multidimensional manner (see Table 3). These effects are then activated for the SBR System and reflect the non-linear and interconnected perspective (see Figure 14).

Table 3. SBR Plan Perspective

Perspective	Result	Unit
Company	Market Launch	Month
	Quality	%
	Technology Performance	Performance
	Costs	€
	Actual Margin **without penalty**	%
Competitor	Market Launch	Month
	Quality	+/- %
	Technology Performance	+/- %
	Price	+/- %
Market	Customer	Amount Customer
	Competitor-Customer	Amount Customer

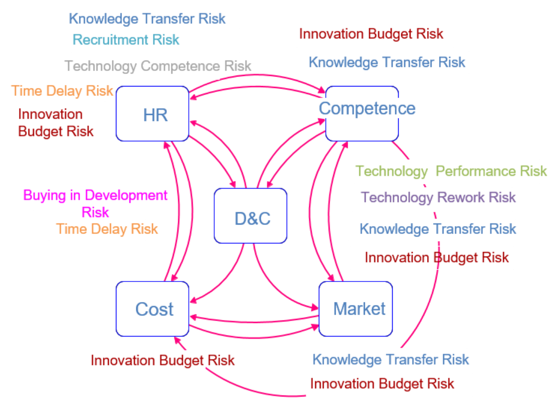


Figure 14. SBR Plan Perspective

5.3 Simulation Results – Standard Base Run (SBR) Plan and System

In the Standard Base Run System, a comparison of both perspectives with the same parameterization initially demonstrated a coherence in quality and technology (see Figure 15). Following a second review, a risk in the development time was discovered. This was due to developments in the HR sector.

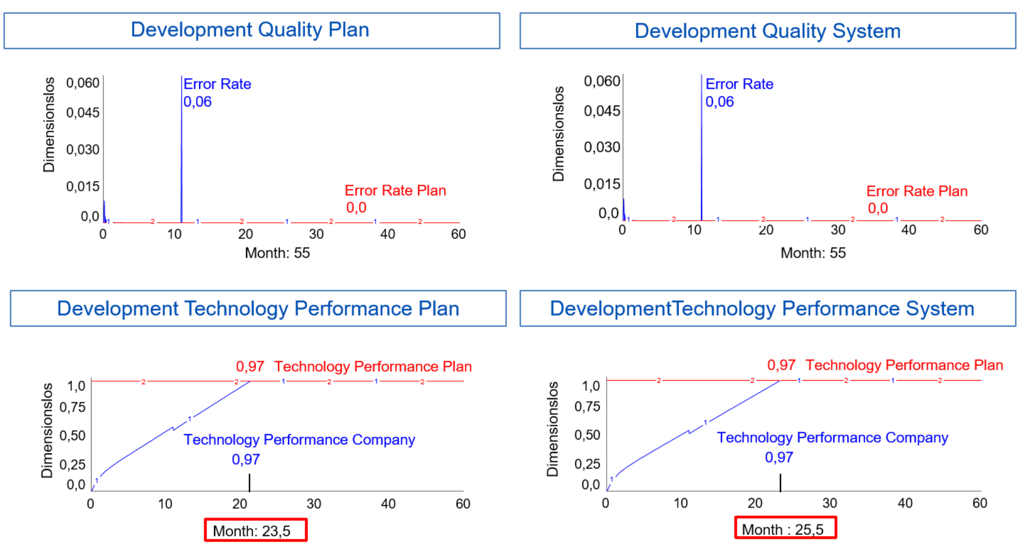


Figure 15. Standard Base Run (SBR) Plan and System

In the scenario plan, no systemic effects or other substantive differentiations were included in the analysis. In the scenario system, however, these effects are taken into account. This is the reason for the various developments in the personnel sector.

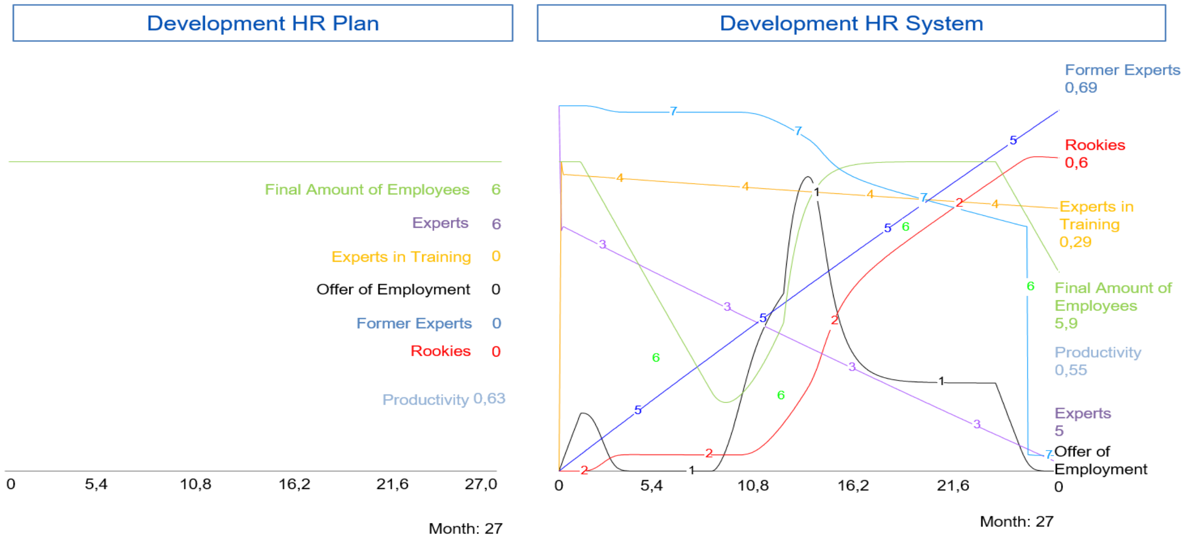


Figure 16. Development in the HR-Sector

The declining stock of experts is due to experts-in-training and fluctuating numbers of experts. With a time delay, jobs are advertised and inexperienced employees are hired. The number of employees is dynamic. The different competencies lead to different productivities.

Coming from a "state of the art risk management perspective" only the following scenario would be identifiable in the market (see Table 5 left column "Plan"). Due to the late market entry of the competitor, our 'own' company was able to harvest 41 customers out of 100 in period 121 which defined the approximate tipping point in the innovation-adoption-process in the SBR Plan. Sterman's (2010) infection theory was applied to show the reactions of customers in terms of their choice after the launch of the innovation. The adoption rate of the company doesn't adjust to the competitor level due to this phenomenon.

Table 5. SBR results

Market Development System

	Result	Standard Base Run		
		Plan	System	Risk (Deviation in %)
Company situation	Market launch	49,5	51,5	+ 4,0
	Quality (Funktional) in %	100	100	0
	Technology Performance	97	97	0
	Costs in T€	2.413	2.412	- 0,05 + Time Delay Risk
	Actual Margin **without penalty in %**	0,6	0,7	+ 16,6
Market Situation 121,5 Month	Customer Amount	41	38	- 7,3
	Competitor Customer	6,9	7,3	+ 5,8

However, as can also be seen in the table, the risk development is different from a systemic perspective. The market launch date has shifted by 4% in the personal sector alone.The system inherent risks and the associated effects on the overall result are already apparent in the basic scenario. In the system scenario, internal capacity risks lead to risks of timing and costs as well as long-term lack of customer potential (competition risks) presented in the following figure.

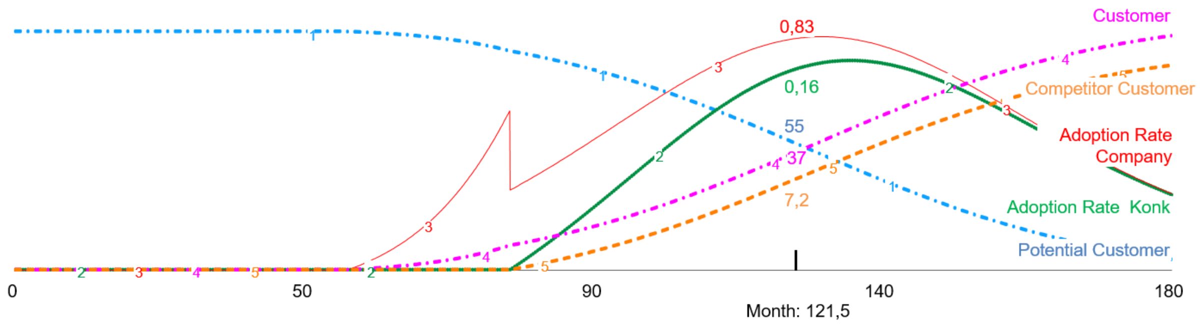


Figure 17. Market Development in the system perspective

The graph shows the commonly known innovation-phase-shape *(*Rogers 1983). For the purpose of comparison, the result or the market graph will be offered also in further iterations. For the purpose of comparing the results of the risk shortage of skilled workers the results shown in Figure 17 is the reference mode which will guide the comparison.

5.4 Standard Base Run Risk (SBRR) - Shortages in Skilled Workers

The scenarios that present best the differences between the standard view on risk management and the systemic view are defined as "base run risk" -scenarios. For the purpose of this paper the human resource risk "shortage of skilled workers" was chosen to show the main risk of innovation. This risk affects, in reality, all five sectors in the *INNO_SIM* Model, but not the common risk management thinking in the German Machinery and Plant Engineering Industry.

The cause of shortages in skilled workers has several aspects in the Base Run risk:

- More tasks in research and development as expected (higher technology performance = output)
- Fluctuation (capacity)
- Missing knowledge (productivity, ability of specification)
- …

In the simulation model the human resource capacity is reduced by one person: therefore 5 experts are available for development & construction. The circumstance of missing workers leads to an anticipated time delay which initializes a demand for workers and therefore a recruiting need if the people are not available in the company.

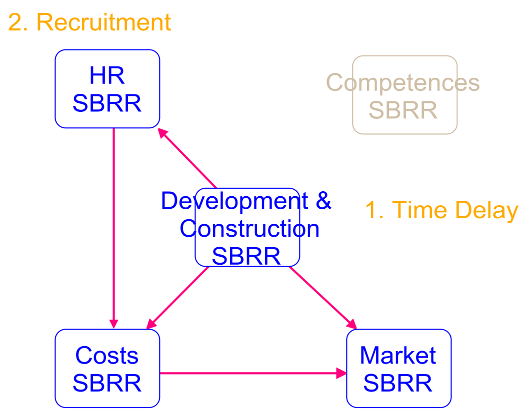


Figure 18. Risk management in the simulation skills shortage

Based on the findings of the analysis for the purpose of parametrization, the average vacancy time is 1.8 months until the job vacancy is filled.

In the standard perspective, there is a linear filling after 1.8 months. This circumstance could be identified in the graph which shows the result in the HR sector (see Figure 19). There, a step of 1 expert is seen in after 1.8 months.

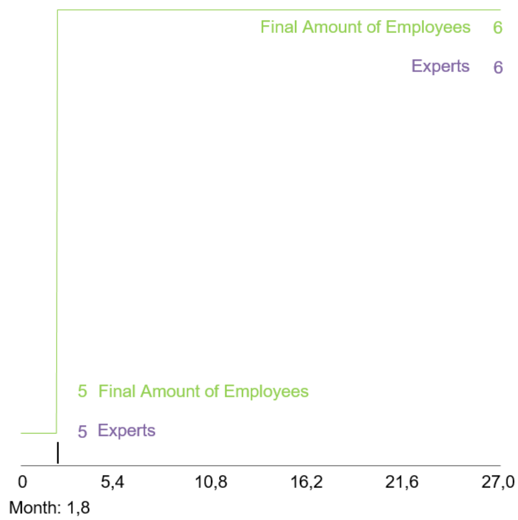


Figure 19. SBRR – Plan Shortages in skilled works

The overall effects on the whole system are marginal. Costs decrease by round about €1,000 due to fewer employees applying for development & construction in order to reach the same output level and same performance level. Nevertheless, out of the recruitment risk another time delay risk evolved. There is a delay of 0.4 months in terms of the market launch. Potential penalties (extent of losses) are not considered in the calculation due to missing numerical information. This penalty has to be included in the risk calculation in real life projects! The assumption in the simulation model is, that higher costs will not be passed to the customers in the short term (the overall assumptions have been discussed in the development of the causal loop diagram).

The question if this "longer" cause and effects chain is tracked in the standard view can't be discussed further. Nevertheless, it is assumed that the process will be handled in a linear manner. Also the human resource capacity is reduced by one person: therefore, 5 experts are available for development & construction in the beginning. In the systemic simulation the loop B internal capacity extension *(*see Figure 20) is activated.

Table 6. SBRR- Plan in the scenario shortages in skilled workers

Risk Situation 5 Employees – Base Run Risk	
Market launch	49.9 Period
Costs	2,412 T€
Actual Margin **without penalty**	0.66% + penalty for Time Delay
Market launch Competitor	77. Period
Market Results after Period 122	
Customers	41%
Customers of the Competitor	6.9%

The question if this "longer" cause and effects chain is tracked in the standard view can't be discussed further. Nevertheless, it is assumed that the process will be handled in a linear manner. Also the human resource capacity is reduced by one person: therefore, 5 experts are available for development & construction in the beginning. In the systemic simulation the loop B internal capacity extension (see Figure 20) is activated.

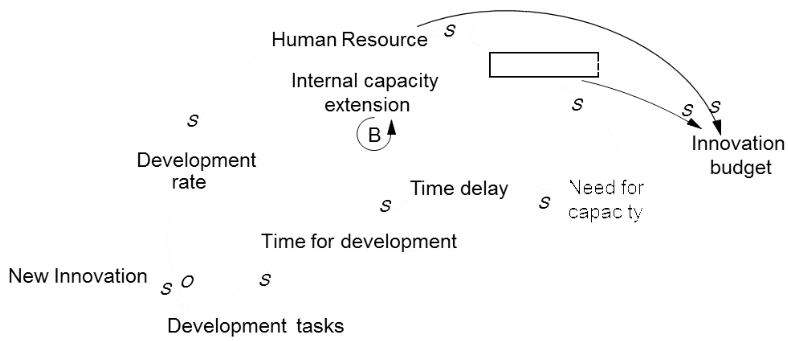


Figure 20. Risk Recruitment Loop *B* Internal capacity extension

The kind of further systemic circumstance in the HR-Sector has a significant influence on output and performance in the innovation project shown in Figure 11. This graph reflects the system behavior which has evolved over time and which should be considered in the risk analysis if the risk of shortage of skilled workers is analyzed. The identified effects feature also on the analysis work of the studies:

- Several main focuses: development and construction, other activities (among other things e.g. train the trainers
- Different classifications of the human resource
- Fluctuation rate of newly occupied and continuance employee's vacancy
- Vacancy times and non-occupation
- Advancement of human resources

If only these circumstances are included in the HR-sector the following development arises in the simulation model (Figure 21):

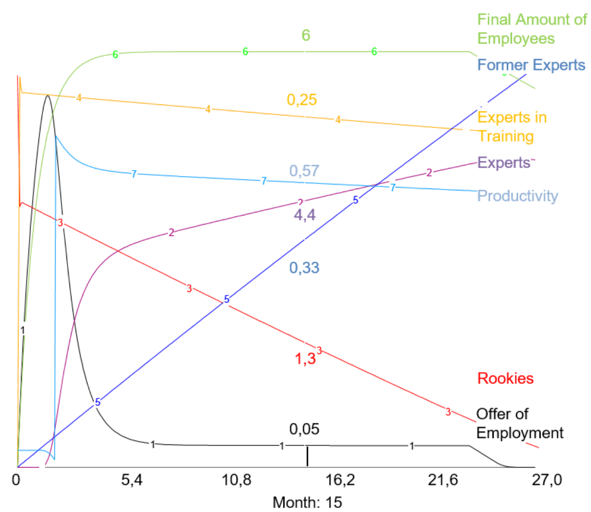


Figure 21. Systemic base run risk - Shortages in skilled workers

All these non-linear behaviors are ascribed to time delays and feedback loops. The model considers a time delay between advertisement of the vacancy and its subsequent occupation (see line *Offer of Employment* and line *Rookies*).

In addition, the model includes a delay until a rooky becomes an expert. Training on the job affects the available capacity of experts (see line 4 *Experts in Training*). These effects are ascribed to the technology competence loop B internal capacity extension (see Figure 22). Within the HR-sector the average productivity is modeled. The different productivity rates of rookies and experts further affects productivity. Based on the focus of this paper one will be discussed in more detail. The train the trainers concept, which was already mentioned, effects productivity. The starting point is the assumption that the advancement of the rookies happens in the project phase (training on the job). Therefore, the human resource capacity in terms of the *Final amount of Employees* is not affected. Nevertheless, it is considered that training measurements of the experts limits their productivity and therefore the development rate.

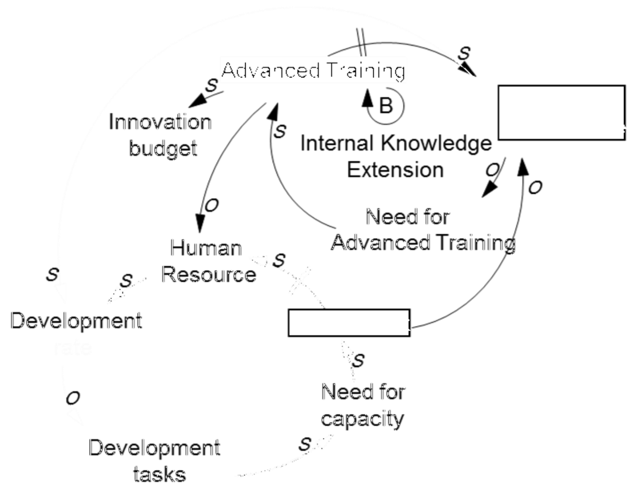


Figure 22. Risk technology competence loop and internal capacity extension

Also, the risk of fluctuation is processed in the model at a monthly rate based on the current stock of rookies and experts (see line *Former Experts.* The effect on the rookies is not present in order to keep an appropriated overview).

To sum up all the findings, it has to be pointed out that it is not only the shortage of skilled workers has to be considered when the available capacity is analyzed. Also, time delays and other effects affect the capacity although it did not seem to be considerable from an isolated perspective. The analysis forms a systemic view showing the significance of all these effects. If only the effects in the HR-sector are considered another reaction could be identified in the market (Figure 23):

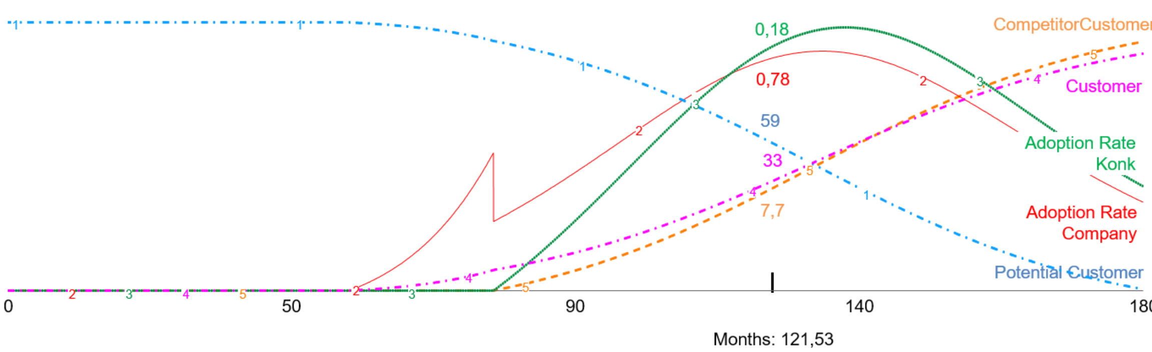


Figure 23. Systemic base run risk market scenario

The systemic development within in the HR-sector leads to a time delay of 4.2 months (time delay risk). The penalties (extent of losses) are also not considered in the calculation. Nevertheless, the extent of losses was significant, increasing due to longer processing times which are ascribed to the limited resource. Up to €33,000 have been spent in addition for the HR-capacity applied for the project. These additional investments are ascribed to the systemic perspective in the HR-sector. Only these additional costs reduce the margin by 1.31% to -0.71% (risk innovation budget).

The effects on the market arise out of the market entry delay. The assumptions in terms of quality, technology and pricing in comparison to the competitor are not adjusted and therefore equal to our 'own' company. In period 122, the acquisition of customers decreased by 8% in comparison to the base run risk (see Table 7).

Table 7. Systemic run results in the scenario shortages in skilled workers

Risk Situation 5 Employees – Systemic Run	
Market launch	54.1 Period
Costs	2,445 T€
Actual Margin **without penalty!!!**	-0.71%
Market launch Competitor	77. Period
Market Results after Period 122	
Customers	33%
Customers of the Competitor	7.8%

To conclude, there is a need to differentiate between standard risk behavior and the System Dynamics risk behavior. The risk of time delays increases and can be ascribed to delays and loops considered in the system. Also, the budget is affected by an increase of approximately €33K. Potential penalties have not yet been considered, but should be added. There is a loss of 8 customers (%) due to the risk of the time delay (see Table 8).

Table 8. Results comparing standard and systemic risk behavior

	Base Run	**Risk Situation 5 Employees – Base Run**	**Risk Situation 5 Employees – Systemic Run**
Market launch	49.5 Period	49.9 Period	54.1 Period
Costs	2,413 T€	„2,412 T€“	2,445 T€
Actual Margin without penalty!!!	0.6%	„0.66%“	-0.71%
Market launch Competitor	77. Period	77. Period	77. Period
Market Results after Period 122			
Customers	41%	41%	33%
Customers of the Competitor	6.9%	6.9%	7.8%

Last but not least, there are some further aspects emerging from the systemic run which have to be considered form a medium and long term perspective. If the single project perspective is left, there will be other additional risks which would affect the total risk position of the company.

Coming from an internal perspective the delay of the project would influence the available HR-capacity in other projects. The time needed in development & construction ties up 5.7 employees for 4.6 months. Therefore, the HR-effect is only partial in the original project but has significant effects in subsequent projects.

On the market side the project risk has also further impacts. From a medium term perspective, a reduced customer base could influence the potential customer base if further developments of the innovative product are considered. This would activate the loop *Competition* and close the loop of the overall innovation risk system.

6. Conclusion

The starting point of the research project *INNOMOD* was the identification of a gap in the considerations of all plans and the development of each element over time, for example:

1. The missing causalities between the plans and therefore the causalities of risks;
2. The multidimensional perspective on performance and therefore the missing multidimensional perspective on risks (Dillerup/Kappler 2015, p.8).

To close the research gap it was determined that the development of a specific System Dynamic model could overcome this problem and also incorporate multi-causal interconnections and multidimensional views on risk (Dillerup/Kappler 2015, p.9). Based on the adapted approach of “Standard Cases: Standard Structures: Standard Models “by Kim Warren, 2014, the Causal Loop Diagram *INNO_CLD* and also the simulation model *INNO_SIM*, was developed and which now covers all of these aspects.

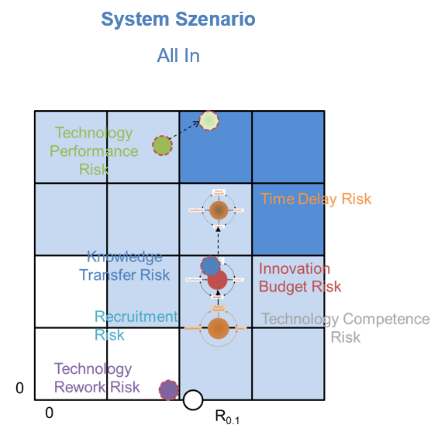
It can be concluded from the closing findings of the simulation and the research conducted that a systemic view on risks leads to other assessments of innovation risks and their behavior over time. It can also be pointed out that the isolated planning, control and risk managing tools in the industry specific project stages can be aggregated by the *INNO_SIM*-Model throughout all stages by keeping the multidimensional perspectives.

Through the application of the *INNO_CLD* and the *INNO_SIM*-Model, risks can be discussed, assessed and evaluated in more detail in terms of relevance (intensity of risk effects), probability of occurrence (linked to linkages between the risks) and their overall effectiveness by considering the risks in their multi-causal interconnections, multi-dimensional-perspectives and the systemic time delays.

Both INNO-Models provide project-specific and realistic risk management tools that meet the requirements of holistic perspectives, complexity assessment and decision support, and can improve the quality of the risk assessment.

Market Development

	Result	Systemszenarien Basis	Risk	Risk All in	Total Deviation in %
Company situation	Market Launch	51,5	54,1	54,1	+ 5,3
	Quality	100	100	99,63	- 0,37
	Technology Performance	97	97	80,6	- 16,9
	Costs	2.412	2.445	2.636	+ 9,3
	Actual Margin **without penalty**	0,7	-0,7	- 8,6	- 1.328
Market Situation 121 Month	Customer Amount	38	33	21	- 44,7
	Competitor Customer	7,3	7,8	12	+ 64,4



Furthermore, risk measurements can be tested and evaluated in terms on their risk effectiveness if system behavior is considered.

Although the research gap identified seems to be closed, some limitations have to be considered and should be tracked in further research work. Only effects which have been explored in System Dynamics literature as well the studies of the German Machinery and Plant Engineering Industry where considered. Further research could continue at this stage by applying field search in order to assess these remaining effects. There is also a lot of movement in the industry due to the trend of digitalization. Industry 4.0 is discussed intensely and could influence the HR-sector by having a more detailed view on the classification of the employees. Also, the development & construction and competence-sector will be probably influenced. Therefore, the further development of this issue has to be tracked and processed.

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