Journal of Business and Economics, ISSN 2155-7950, USA
November 2016, Volume 7, No. 11, pp. 1829-1848
DOI: 10.15341/jbe(2155-7950)/11.07.2016/010

http://www.academicstar.us

Dynamics of Innovation Risk Assessment: Using a Generic System Dynamics Model to Assess Innovation Risks in the German Machinery and Plant Engineering Industry

Ralf Dillerup, Daniela Kappler
(Heilbronn University, Germany)

Abstract: Innovation in the German Machinery and Plant Engineering Industry is the source of strategic differentiation or cost leadership. This competitive advantage involves a high number of challenges. Innovation includes a system of items which are complicated, dynamic and multi-dimensional — Innovation is a complex system which is a challenge to manage. Therefore, deviations from companies' innovation objectives, commonly known as innovation risks, are also imminent and increasing. Although most managers are aware of the fact that from a system perspective innovation covers interconnected risks, they are managed isolated and one-dimensional. This separation limits the understanding of interconnections and behavior of risks from a system perspective. The cause of this inadequate management could be ascribed to the weakness of common methods in the risk management process. The limitations can be overcome by using System Dynamics to gain new insights into the interconnection and behavior of risk systems. The research project SYRIMAAN focuses on the development of cause-and-effect relations of main innovation risks in the German Machinery and Plant Engineering Industry and also their dynamics. 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 a systemic and multi-dimensional risk management will be demonstrated.

Key words: innovation risk; holistic risk management; complexity; dynamic; risk systems; risk analysis; risk aggregation; system dynamics

JEL code: M1

1. Innovation Risks in the German Machinery and Plant Engineering Industry

German Machinery and Plant Engineering Industry business models are aligned to the development and production of machinery and plants in the Business-to-Business sector (B2B). Their production is determined by individualized equipment with high investment volumes. The industry is one of the largest industrial employer and also the second biggest industry with more than 6,000 companies. Therefore, the industry is one of the most important industries in Germany. Its special characteristic is determined by Small and Medium Enterprises with

Ralf Dillerup, Dr., Professor, Heilbronn University Graduate School; research areas/interests: business strategy. E-mail: ralf.dillerup@hs-heilbronn.de.
Daniela Kappler, M.A., Heilbronn University Graduate School; research areas/interests: business strategy. E-mail: daniela.kappler@gmx.de.

87% and associated with capital sourcing limitations (Vdma Fui, 2014; Vdma Kzk, 2015). In addition, besides the automotive industry, electrical engineering and the pharmaceutical/chemical industry the German Machinery and Plant Engineering Industry is one of the strongest industry in research. For the industry itself this source is the most important success driver accompanied with special conditions in terms of structure and product portfolio. Therefore, the industry is highly influenced by innovation and their risks. Summarizing up all these special conditions the management is aware of the fact that innovation risk has to be managed sufficient and comprehensive in order to stay in competition.

Innovation is the main driver of success for today's competition (Gassmann, 2006a, 2006b). A lot challenges arise out of this success driver. These challenges are highly interconnected and turns the innovation risk management to a multi-dimensional risk management (see Figure 1) which is complex and dynamic (Gassmann, 2006a; Howell, 2013; Warren, 2008).

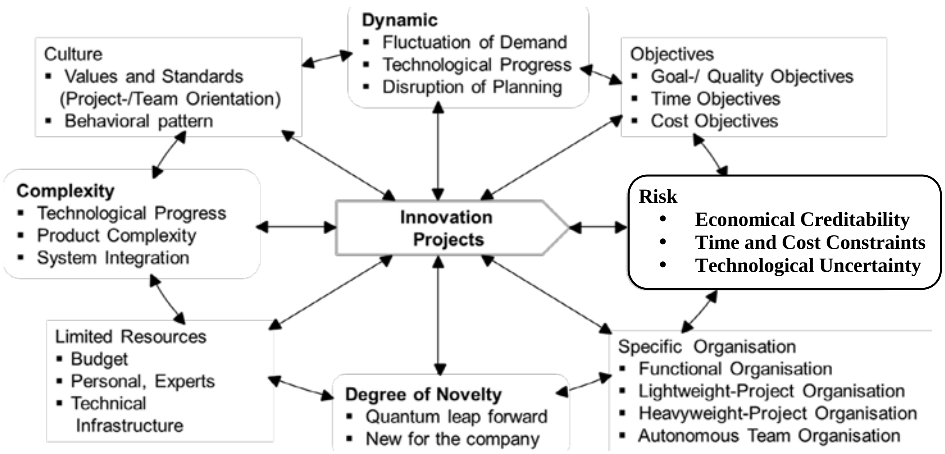

Figure 1 Aspects and Interconnection of Innovation Risks (Gassmann, 2006b, p. S.9)

A lot of research is done about innovation. Common literature about innovation risks discusses several risk categories and aspects. They reflect on a meta perspective the innovation risk which is arising out of the market system (industry) which are determined by the subsystems customers, the own company and competitors (Kotler et al., 2011; Porter, 1980). Especially for the German Machinery and Plant Engineering Industry coopetition or cooperation partners are identified in addition in previous scientific work. In order to get more focused to the industry a scientific literature research was conducted where the main industry innovation risks are identified. Following table represent the main innovation risk aspects and therefore the main risk factors.

Table 1 Innovation Aspects and Risks in the Innovation-Risk-System for the German Machinery and Plant Engineering Industry

Innovation Aspect	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

The cause and effect of this risk could be matched to specific company sections which are

- Human Resource (HR),
- Development and Construction,
- Costs,
- Competences and
- Market.

How these sections are interconnected will be discussed later in the paper. Nevertheless, to understand the difference between the standard risk management perspective and a system perspective on innovation risks, common risk management methods and although their weakness, methods applied in the German Machinery and Plant Engineering Industry and the contribution of a system perspective has to be briefly presented.

Analyzing later on the connections of innovation risks over several sections will offer interesting insights. This finally lead to different assessment results and therefore different priorities in terms of risk management. Due to limitations in terms of time and resource 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 is 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, valuation and aggregation. Starting point is the risk identification. There the risks are identified and priorities are set. The methods applied are quite often risk-checklists. Next step is the risk assessment. Methods applied focus on the evaluation by their probability of occurrence and the extent of loss which determines the decisive parameters of the function. The risk aggregation consolidates the risks. Within the risk aggregation the models and methods of quantification applied base in general on distribution functions and their simulation (Monte Carlo Simulation). Traditional approaches like the arrangement in damage classes, 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 out of these risk management work affects subsequent activities. This is the most difficult and import steps especially in the context of managing risk from a complicacy perspective and their dynamics. Objective of the risk mastery and regulation process is to avoid unbearable risks and to level unavoidable risks on a bearable level. Last but not least the risk control has to be fulfilled. All in all, the risk management process is a continuous one.

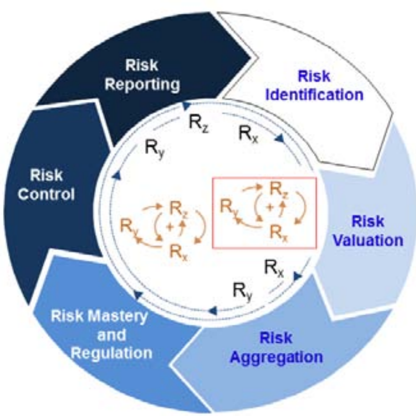

Figure 2 Extended Risk Management Process

Table 2 Weakness in Standard Methods of Risk Analysis

Method	Dynamic	& Complicacy	= Complexity
Ishikawa Diagram	Statically	Broad number of risks	Average
Risk- Check Lists	Statically	Broad number of risks	Average
Scenario Analysis	Limited Dynamic	Limited number of scenarios	Low
Sensitivity Analyses	No cause-effects	Broad number of scenarios	Average
Gaussian bell curve	Gaussian distribution	Broad number of risks	Average
Portfolio Analysis	Limited Dynamic	cause-effect & Feedback	Low
Stochastic	Limited data analysis	Broad number of risks	Average
Monte-Carlo-Simulation	Random walk	Broad number of indicators	Average

By having done an intense 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 by managing cause-effect-relations and the dynamic of risks. Although a wide scope of risk analysis methods and instruments are available, dealing with multi-dimensional risk limits the possible applications. Coming from a system perspective on risk which is determined by the two dimensions' dynamic and complicacy the methods applied where thereupon assessed. In the dimension dynamic the methods were checked for the ability to cover the development over time and time delays. Thereby complicacy gives an idea about the ability to incorporate explicit cause-and-effect-structures and the overall linkages between the risks (Dillerup Kappler, 2015). For summing up previous findings which have been discussed in previous work (Dillerup Kappler, 2015) the lack in the risk assessment refers to the treatment of risk in a one-dimensional, isolated and also not in a system manner. Dynamic aspects were therefore neglected.

2. Process Steps and Risk in Innovation Projects

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 be considered. Therefore, different planning and risk tools are applied in order to cover the specific demands of each phase. Main tools and concepts used in the industry are (Hilpert et al., 2001, p. 44):

- 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 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 admit a proposal will be made (Hilpert et al., 2001, p. 59). Therefore, questions in terms of technical realization, capacity for realization, customer and market strategies, make or buy, joint ventures, etc. and also project risks, when it comes to an agreement, have to be answered. This findings match with the findings on innovation risks in the sample industry excepted 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 (Hilpert et al., 2001, p. 115):

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

The preferred tool in this phase is the concept of the value analysis. This could be applied to assess the attractiveness of the project and is used in the risk identification phase in the common risk management process. An example how the linear risk evaluation works shows Table 3 (Hilpert et al., 2001, p. 66). The assessment of risks takes place by the application of a grading scale. In the example 1 up to 10 is applied.

Table 3 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 isolated from each other (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 talked as independent single risks (Gleißner, 2014, p. 8). Additionally, the application of probabilities is suggested (Hilpert et al., 2001, p. 116). This leads to the classical statically portfolio of the risk evaluation (Figure 3).

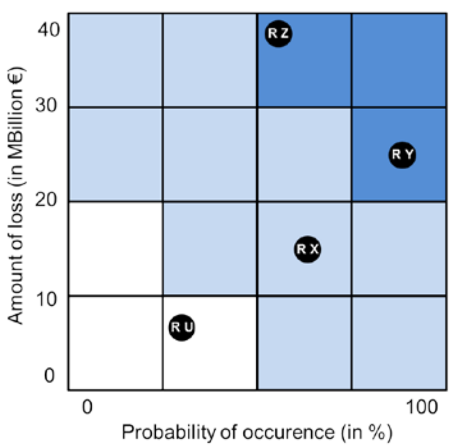

Figure 3 Portfolio of the Risk Evaluation

In terms of the classical risk management approach the cycle is interrupted after the risk aggregation (Figure 4). A project will be seen in this phase more particularized in the several dimensions whereas the risk is only discussed on single risk level (Hilpert et al., 2001, p. 115).

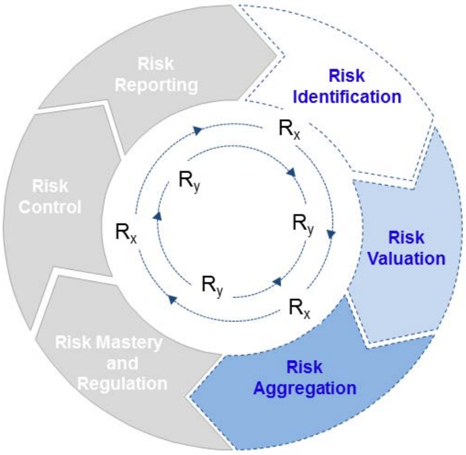

Figure 4 Interrupted Risk Management Process in the Preliminary Clarification Phase

The **proposal phase** is determined as crucial for the overall project or innovation success. The treatment of orders and also the order results will be predefined extensively. Hence, this phase is synonymous of a conception phase. Content subjects from the preliminary clarification phase are refined and again the identified innovation risk is added to these subjects (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 dimension in the project like quality, time, capacity and costs have to be considered during the concept phase, which are highly interconnected. Nevertheless, check lists audit the project on feasibility in an isolated perspective (Hilpert et al., 2001, p. 122).

Simultaneously the risk analysis takes place in this phase. Single project risks are identified by means of risk check lists (Hilpert et al., 2001, pp. 117-119, 169). 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 by the aspect of regulation measurements (Hilpert et al., 2001, p. 115, Figure 5). If the coverage is inapplicable (risk keeping) the prospective damage and probability of occurrence will be defined for each single risk (Hilpert et al., 2001, p. 115).

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 (Hilpert et al., 2001, pp. 80-82). Interdependence between risks or the effect of risk measures on the overall system are not replicated in this project phase (Hilpert et al., 2001, p. 122). Only in the order phase risk management measures (Hilpert et al., 2001, p. 115) and their effect on risks will be tracked (Hilpert et al., 2001, pp. 90-100, 122).

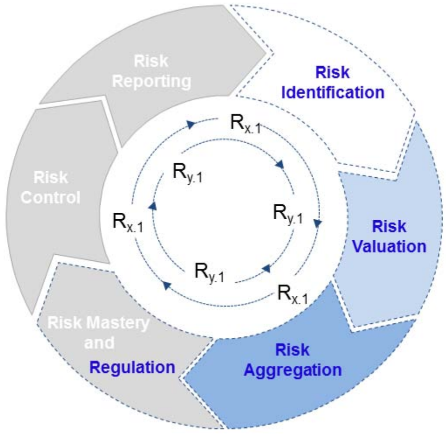

Figure 5 Interrupted Risk Management Process in the Proposal Phase

In the **Transfer Phase** the main focus lies on the specification of responsibility and competence in the project. Beside the coordination of the activities, interfaces, problematic issues and definition of working packages the job of the project team consists in checking the offer details with the necessary data of the order processing up on consistency. Following subjects will be checked content wise (Hilpert et al., 2001, p. 85):

- 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 very detailed in the literature. The perspectives on are not independently of each other and covers all industry-specific risks excepted the risk of "Technology Competence and Knowledge Transfer".

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

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

The change management in the commercial processing check the effects on variety, scope and technical effects by the application of check lists. The dimensions where the effects are reflecting are appointments, guarantees, penalties, costs and capacity (Hilpert et al., 2001, pp. 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 steps and so the circle is completed — the loop of the standard risk management is closed — but not the loops within.

Figure 6 Completed Risk Management Process in the Order Phase

Interrupted risk management process in the proposal phase interrupted risk management process in the proposal phase to cherish the findings so far it has to be pointed out that although the risks (changes in the project) are recognized, judged and are processed in different dimensions, actually feedback effects are neither considered on an atomic nor holist level. This could be ascribed to the high number of used management tools and therefore high numbers of dimensional interfaces. On the one hand, the application of these tools is not developed to consider 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 this different dimensions within the standard usage.

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

3. Risk Assessment Using System Dynamics

To overcome these weaknesses of standard risk management tools and also to close the loops in the risk management process in the German Machinery and Plant Engineering Industry over all stages 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; Raffée, Bodo, 1979). These results are the starting point for simulating complex and dynamic interactions. System Dynamic takes the complexity, feedback loops and the non-linearity of social systems into account (Sterman, 2000). Another point that counts for System Dynamic is to simulate the interaction of quantifiable and related variables on an aggregated overall system level (Dooley, 2002). Also the possibility to keep multidimensional perspectives and connect them with each other without the transmission in a one dimensional perspective militates for a System Dynamics approach.

3.1 Causal Loop Diagram on Innovation Risks

Starting point for the research project was an analysis work based on scientific and specialized literatures and also common views of consultants, auditors, the German Engineering Association and leading companies which finally lead to following research questions:

(a) How are the innovation risks in the machinery and plant engineering defined?

(b) How does the structure of the relevant innovations risks look like?

(c) How do they affect each other?

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

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

As already discussed the innovation aspects in the German Machinery and Plant Engineering Industry have been identified and the appropriate risk factors where matched in previous work. By applying the approach of "Standard Cases: Standard Structures (Standard Models by Kim Warren, 2014 and also other leading System Dynamics Experts, e.g., Brossel, 2004a; Bossel, 2004b; Warren, 2014) a literature research about 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 Table 4.

Table 4 Modelling Standard Risk(s) with Standard Structures

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).

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

Table 5 Innovation Aspects, Risks and Feedback Loops in an Innovation-Risk-System for the Industry

Innovation Aspect	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	R5.1 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

By matching these findings with the findings of the literature of the German Machinery and Plant Engineering Industry an innovation-multi-causal-dynamic-risk-system called SYRIMAAN-Model (Figure 7) was developed. This Causal Loop Diagram has been assessed in several workshops and meetings by System Dynamic experts, consultants of standard risk management methods, auditors, the German Engineering Association and their risk experts and leading companies in the industry.

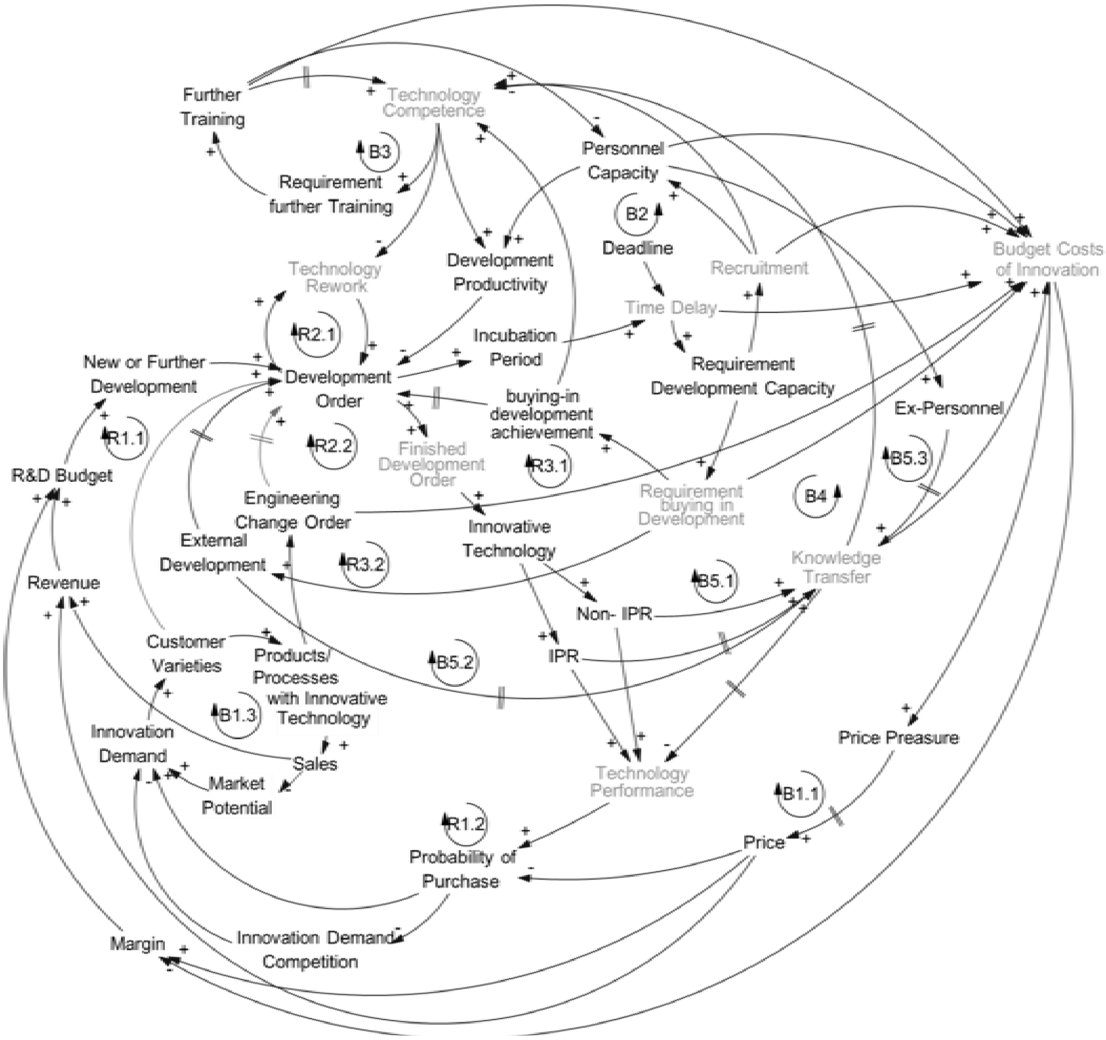

Figure 7 Innovation-Risk-System for the German Machinery and Plant Engineering Industry (Dillerup & Kappler, 2015)

Also in accordance with the approach “Standard Cases: Standard Structures: Standard Models “the System Dynamics model SYRIMAAN 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 SYRIMAAN.

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

(1) Workshops and meetings by System Dynamic Experts and system perspective experts and the German

Engineering Association and their risk experts.

(2) Comparison to reference modes if available and also using similar equations set ups.

During the modeling process the model have passed several times these testing phases. Especially the structure validation test where applied iteratively. The final results of all tests are presented in Figure 8:

	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 8 Applied Validations Test and Final Result after the Testing Phase

Extracts of the modelling process of the causal loop diagram and System Dynamics model SYRIMAAN are presented in previous work (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.

3.2 System Dynamics Simulation Model SYRIMAAN

Starting point for the simulation study is the academic derived SYRIMAAN-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 (Dillerup & Kappler, 2015). In order to differentiate between standard risk behavior and the simulated risk behavior structures in the simulation model were developed in order to show system behavior or being deactivated for the standard approach. The simulation model is able to generate risk behavior based on an isolated and linear understanding and anticipation by the application of classical risk management tools discussed in previous chapters. Due to the fact that the model has more than 110 parameters there have to be a focus on main variables. In order to give a generic and consolidated view on the risk behavior the comparison focus on

- Market launch, which reflects the risk of time delays arising out of the system independently from the sector where it arose.
- Costs and actual margins, which reflects the risk in rising or shrinking innovation budgets. The decision if rising costs will be allocated to the customers could be also defined in the SYRIMAAN model.
- Customers, which reflect the willingness to buy the innovation. This is reflected by the amount of customers

who adopt the innovation. The factors that influence their decision is the market launch, the innovative technology (quality technical), the quality (quality functional) and also the price derived from the costs. This will be compared to the offer of the competitor.

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

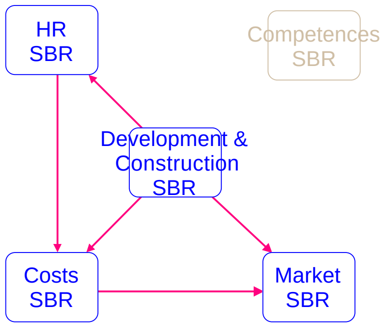

Figure 9 Standard Base Run Configuration

The standard case is derived out the studies mentioned before. The case developed base 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 month (no time delay)
- Fraction of own development: 88.7%
- Fraction that have 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 month
- 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.

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 in the model, the system calculates the way shown in Figure 4. Coming from a “state of the art risk management perspective” there would be following scenario identifiable on the market (Figure 10). First point to be highlighted is, that 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 runs.

Due to the late market entry of the competitor the own company was able to harvest 41 customers out of 100 in period 121 which define round about the tipping point in the innovation-adoption-process in the standard case (Figure 10). Responsible for the unequal development base on the infection theory (Sterman, 2010) modelled in the simulation model. The adoption rate of the company doesn’t adjust on the competitor level due to this phenomenon. For the purpose of comparing the results out of the risk shortage of skilled workers the results shown in Figure 11 is the reference mode which will guide to the comparison.

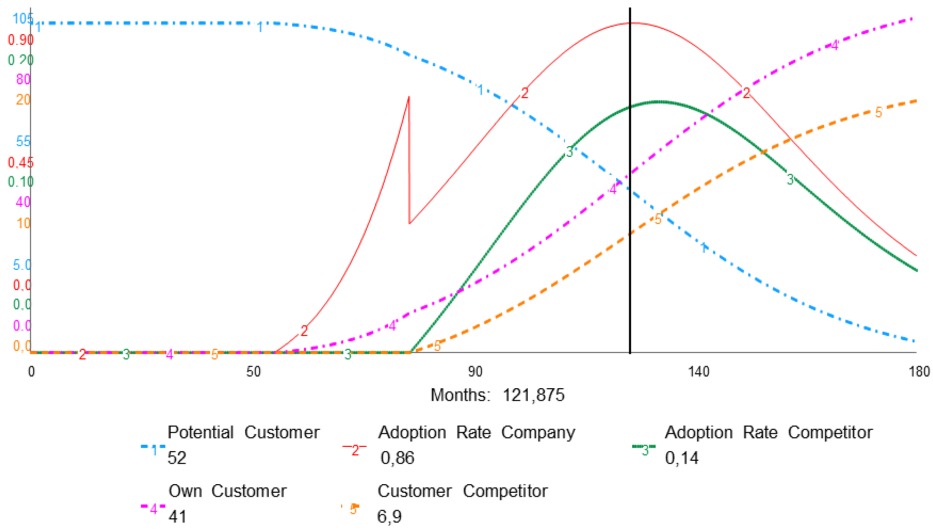

Figure 10 Standard Base Run Market Scenario

Table 6 Standard Base Run Results

Base Run	
Market launch	49.5 Period
Costs	2,413 T€
Actual Margin without penalty!!!	0.6%
Market launch Competitor	77. Period
Market Results after Period 122	
Customers	41%
Customers of the Competitor	6.9%

3.3 Simulation Skills Shortage

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 SYRIMAAN Model, but not in 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)
- …

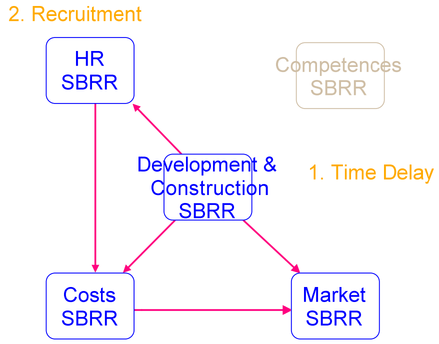

Figure 11 Risk Management in the Simulation Skills Shortage

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 in workers and therefore a recruiting need if the people are not available in the company.

Based on the findings out of the analysis work for the purpose of parametrization the average vacancy time is 1.8 month until the job vacancy is filled.

Figure 12 Standard Base Run Risk-Shortages in Skilled Workers

In the standard perspective there is a linear filling after 1.8 month. This circumstance could be identified in the graph which shows the result in the HR sector (Table 5). There a step of 1 expert is seen in line No. 3 *experts* and also line No. 6 *Final Amount of Employees* after 1.8 month.

The overall effects on the whole system are marginal. Costs decrease by round about 1,000€ due to less employees applied 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 month 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 cost will not be passed to the customers in a short term perspective (the overall assumption have been discussed in the development of the causal loop diagram).

Table 6 Standard Base Run Results 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 couldn’t be discussed further. Nevertheless, it is assumed that the process will be handled linear. Also the human resource capacity is reduced by one person: therefore, also 5 experts are available for development & construction in the beginning. In the systemic simulation the loop B internal capacity extension (Figure 14) is activated.

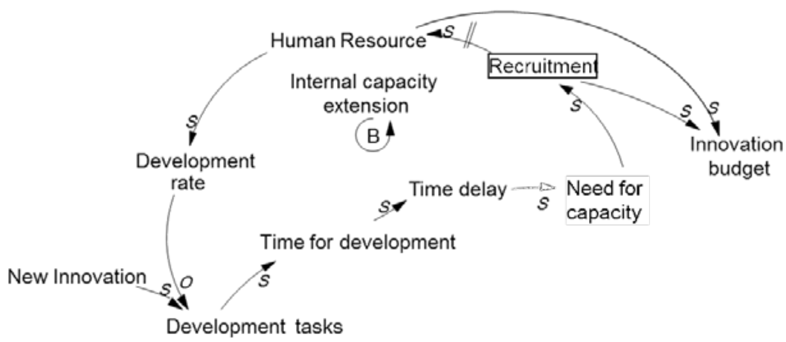

Figure 13 Risk Recruitment Loop B Internal Capacity Extension

Which kind of further systemic circumstance in the HR-Sector have a significant influence on output and performance in the innovation project shows Figure 8. This graph reflects the system behavior evolved over time and should be considered in the risk analysis if the risk of shortage of skilled workers is analyzed. The identified effects base 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 new 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 15):

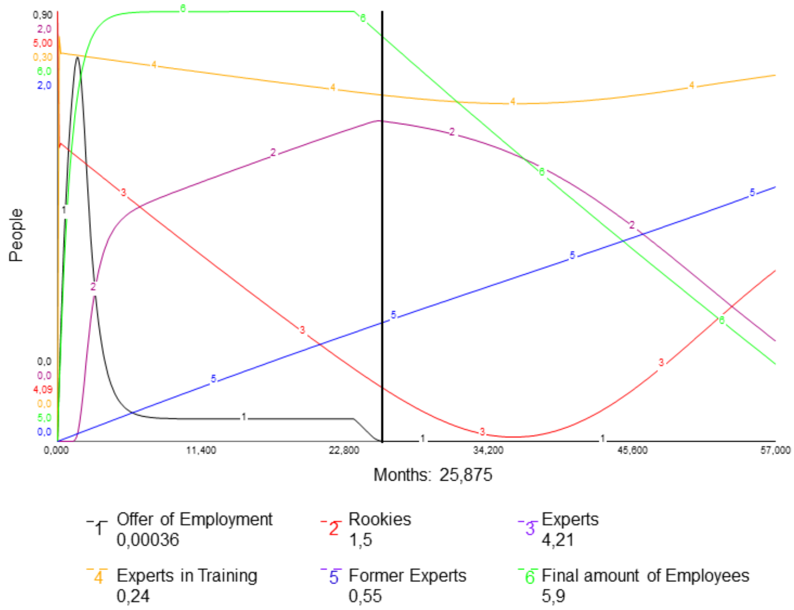

Figure 14 Systemic Base Run Risk - Shortages in Skilled Workers

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 the occupation (see line No.1 *Offer of Employment* and line No. 2 *Rookies*).

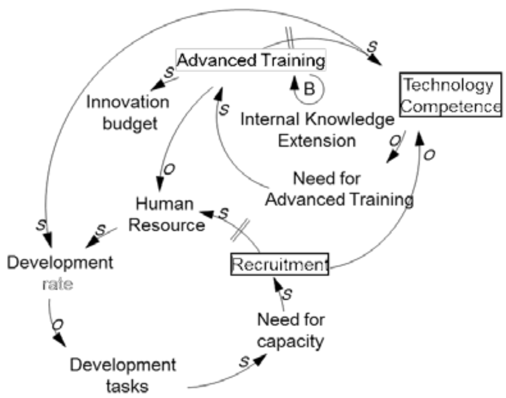

Figure 15 Risk Technology Competence Loop and Internal Capacity Extension

In addition, the model includes a delay until a rooky shift to an expert (see line No. 2 and line No.3 *Experts*). Training on the job affects the available capacity of experts (see line No. 4 *Experts in Training*). These effects are ascribed to the technology competence loop B internal capacity extension (Figure 16). Within the HR-sector there is also the average productivity modeled. Beside the different productivity rates of rookies and expert's further effects affects the productivity. Based on the focus of these papers one will be discussed more detailed. The train the trainers-concept which was already mentioned take effect on the productivity. 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.

Also the risk of fluctuation is processed in the model on a monthly rate based on the current stock of rookies and experts (see blue line No.5 *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 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 in an isolated perspective. The analysis from a systemic view shows 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 16):

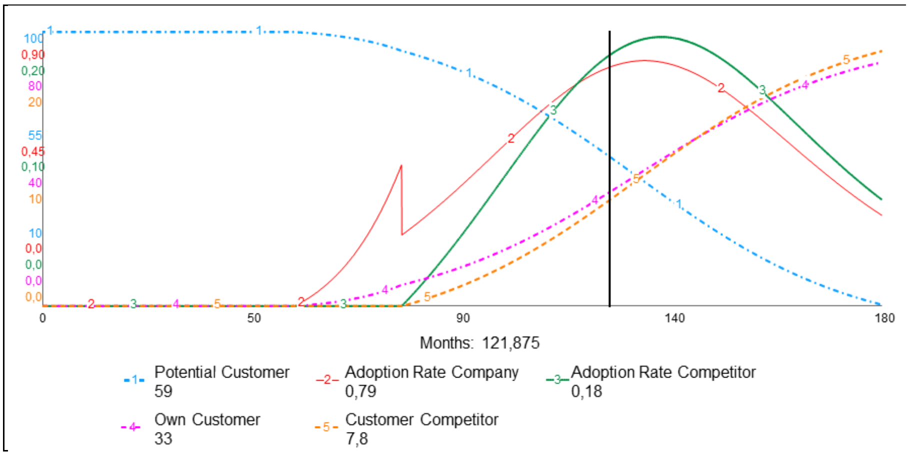

Figure 16 Systemic Base Run Risk Market Scenario

The systemic development within in the HR-sector leads to a time delay of 4.6 months (time delay risk). The penalties (extent of losses) are also not considered in the calculation. Nevertheless, the extend 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 this additional cost reduces the margin by 1.31% to -1.71% (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 the own company. In period 122 the acquisition of customers is decreased by 8% in comparison to the base run risk (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 rises up 4.2 month ascribed to delays and loops considered in the system. Also the budget is affected by an increase of round about 33T€. potential penalties are not considered so far, but should be added. Last but not least there is a loss of 8 customers (%) due to the risk of the time delay (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 arise some further aspects out of the systemic run which have to be considered in a medium and long term perspective. If the single project perspective is left, there will be other risks in addition that arise out of these risks and 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 need in development & construction tie up 5.7 employees for 4.6 month. Therefore, the HR-effect in the origin project has only partly feedback effects in the project but significant effects in all projects that follow up.

On the market side the project risk has also further impacts. In 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.

4. Conclusion

Starting point of the research project *SYRIMAAN* has been an identification of lacks in the risk analysis by treating the risks one-dimensional, isolated and not as a system:

(1) Missing considerations of all plans and the development of each element over time.

(2) The missing causalities between the plans and therefore the causalities of risks.

(3) 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 evaluated 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 and also the simulation model SYRIMAAN was developed which covers all these aspects.

In order to conclude the final findings out of the simulation and the research projected it could be identified that a systemic view on risks leads to other assessments of innovation risks and their behavior over time. It could also have pointed out that the isolated planning, control and risk managing tools in the industry specific project stages could be aggregated by the SYRIMAAN-Model over all stages by keeping the multidimensional perspectives.

By the application of the SYRIMAAN-model, risks could be discussed, assessed and evaluated more detailed in terms of relevance (intensity of risk effects), probability of occurrence (linked to linkages between the risks) and their overall effected by considering the risks in their multi-causal interconnections, multi-dimensional-perspectives and the systemic time delays. Also risk measurements could be tested and evaluated in terms on their risk effectiveness if system behavior is considered.

Although the identified research gap 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 digitalization trend. 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.

References

Authorless 15 (ZEW) (2015). "Branchenreport Innovationen: Ergebnisse der deutschen Innovationserhebung 2014", Maschinenbau. Jahrg. 22. Hg. v. ZEW. ZEW (8), available online at: http://www.zew.de/de/publikationen/branchenreport Innovation.php3?year=2014.

Authorless 25 (Mbau 15) (2015). "Maschinenbau in Zahl und Bild 2015", *Mechanical Engineering — Figures and Charts*, Hg. v. VDMA - Volkswirtschaft und Statistik.

Barlas Yaman (1996). "Formal aspects of model validity and validation in system dynamics", System Dynamics Review, Vol. 12, No. 3, pp. S.183-210.

Bossel H. (2004a). *Systeme Dynamik Simulation–Modellierung, Analyse und Simulation komplexer Systeme*, Books on Demand, Norderstadt.

Bossel H. (2004b). *Systemzoo 3–Writschaft, Gesellschaft und Entwicklung*, Books on Demand, Norderstadt.

Crouhy M. et al. (2006). *The Essentials of Risk Management*, New York.

Davis J. P. et al. (2007). "Developing theory through simulation methods", *Academy of Management Review*, Vol. 32, pp. 480-499.

Denk R. et al. (2008). *Corporate Risk Management - Unternehmensweites Risikomanagement als Führungsaufgabe* (2nd ed.), Wien.

Dillerup R. and Kappler, D. (2015). "Dynamic risk assessment on innovation risks in the German machinery and plant engineering industry", in: *33rd International Conference of the System Dynamics Society*, Cambridge, Massachusetts, USA, July 19-23th, available online at: http://www.systemdynamics.org/web.portal?P1099+0.

Dooley K. (2002). "Simulation research methods", in: J. A. C. Baum (Ed.), *The Blackwell Companion to Organizations*, Oxford, pp. 829-848.

Forrester J. W. (1972). *Industrial Dynamics* (7th ed.), Cambridge, Mass.

Forrester Jay W. and Senge Peter M. (1980). "Tests for building model confidence in system dynamics models", in: George P. Richardson (Hg.), *Modelling for Management: Simulation in Support of Systems Thinking* (2nd ed.), Brookfield: Dartmouth Publishing Company, Ltd., pp. S. 413-432.

Fraser J. and Simkins B. J. (2010). *Enterprise Risk Management: Today's Leading Research and Best Practices for Tomorrow's Executives*, New Jersey.

Gassmann O. and Kobe C. (eds.) (2006a). *Management von Innovation und Risiko: Quantensprünge in der Entwicklung erfolgreich managen* (2. Ed.), Springer: Berlin, New York.

Gassmann O. (2006b). "Innovation und Risiko: zwei Seiten einer Medallie", in: Oliver Gassmann und Carmen Kobe (Eds.), *Management von Innovation und Risiko: Quantensprünge in der Entwicklung erfolgreich managen* (2nd ed.), Springer, Berlin, New York, pp. 3-24.

Gleißner W. (2011). *Grundlagen des Risikomanagements im Unternehmen-Controlling, Unrternehmensstrategie und wertorientiertes Management* (2 ed.), München.

Gleißner W. (2014). "Quantifizierung komplexer Risiken–Fallbeispiel Projektrisiken", *Risiko Manger*, Vol. 22, pp. 1, 7-10.

Hilpert Norbert, Rademacher Günter and Sauter Bernhard (2001). *Projekt-Management und Projekt-Controlling im Anlagen- und Systemgeschäft*, Frankfurt/Main: VDMA-Verl.

Howell W. L. (2013). "Global risks 2013, EDT", *World Economic Forum* (8th ed.), Cologny/Geneva, Switzerland.

Kotler P. and Schellhase R. (2011). *Grundlagen des Marketing* (5 ed.), Pearson Studium, München.

Lott Wolfgang and Lutz Markus (2012). *Produktmanagement im Maschinenbau*, Frankfurt am Main: VDMA.

Morecroft J. (2008). *Strategic Modelling and Business Dynamics — A Feedback Systems Approach*, Chichester, England, Hoboken.

Olson D. L. and Wu D. (2010). *Enterprise Risk Management Models*, Heidelberg.

Porter M. E. (1980). *Competitive Strategy*, Free Press, New York.

Raffée H. and Abel B. (1979). *Wissenschaftstheoretische Grundfragen der Wirtschaftswissenschaften*, Vahlen, München.

Rogers Everett M. (1983). *Diffusion of Innovations* (3rd ed.), New York, London: Free Press; Collier Macmillan.

Romeike F. and Hager P. (2009). *Erfolgsfaktor Risiko-Management 2.0 — Methoden, Beispiele, Checklisten: Praxishandbuch für Industrie und Handel* (2nd ed.), Wiesbaden.

Sterman J. D. (2010). *Business Dynamics — Systems Thinking and Modeling For A Complex World*, Boston.

Stiefl J. (2010). *Risikomanagement und Existenzsicherung - Mit Konzepten und Fallstudien zu KMU*, München.

Tchankova L. (2002). "Risk identification — Basic stage in risk management", in: *Environmental Management and Health*, Vol. 13, No. 3, pp. 290-297.

VDMA FuI (o.V. 18) (2014). "Kennzahlen zu Forschung und Innovation im Maschinenbau", *Hg. v. VDMA Betriebswirtschaft*, available online at: https://www.vdma.org/article/-/articleview/4044482.

VDMA HR (o.V. 34) (2014). "VDMA-Kennzahlen vergleichen, verstehen, verändern", Personalarbeit 2014, *Hg. v. VDMA Betriebswirtschaft*.

VDMA HR (o.V.37) (2015). "VDMA-Kennzahlen vergleichen, verstehen, verändern", Personalstruktur 2015, *Hg. v. VDMA Betriebswirtschaft*.

VDMA KO (o.V. 33) (2014). "VDMA-Kennzahlen vergleichen, verstehen, verändern", Kosten 2014, *Hg. v. VDMA Betriebswirtschaft*.

VDMA KZK (2015). "Kennzahlenkompass: Informationen für Unternehmer und Führungskräfte", Ausgabe 2015-Nur für Mitgliedfirmen des VDMA: VDMA Verlag GmbH.

VDMA PP 2014 (o.V. 17) (2014). "VDMA Studie Produktpiraterie 2014", Produkt- und Know-How Schutz. Unter Mitarbeit von Arbeitsgemeinschaft Produkt- und Know-How Schutz. Hg. v. VDMA, available online at: http://www.vdma.org; http://www.protect-ing.de.

VDMA QM (o.V.32) (2014). "VDMA-Kennzahlen vergleichen, verstehen, verändern", Qualitätsmanagement 2014, *Hg. v. VDMA Betriebswirtschaft*.

VDMA Vertrieb (o.V. 36) (2015). "VDMA-Kennzahlen vergleichen, verstehen, verändern", Vertrieb 2015, *Hg. v. VDMA Betriebswirtschaft*.

VDMA-KZ EuK (o.V. 16) (2012). "VDMA-Kennzahlen Entwicklung und Konstruktion 2012, vergleichen, verstehen, verändern", *Hg. v. VDMA Betriebswirtschaft*.

Warren K. (2014). "Standard cases: Standard structures, standard models", in: *32rd International Conference of the System Dynamics Societ 2014*, available online at: http://www.systemdynamics.org/conferences/2014/proceed/papers/P1302.pdf.

White D. (1995). "Application of systems thinking to risk management: A review of the literature", *Management Decision*, Vol. 3, No. 10, pp. 35-45.