Knowledge in Risk Assessment and Management

Edited by

Terje Aven and Enrico Zio
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List of Contributors

Eirik Bjorheim Abrahamsen
University of Stavanger, Norway

Terje Aven
University of Stavanger, Norway

Christine L. Berner
DNV GL, Norway

Torbjørn Bjerga
University of Stavanger, Norway

Kevin Coyne
Office of Nuclear Regulatory Research, US Nuclear Regulatory Commission, Washington, DC

Ivan Damnjanovic
Texas A&M University

Roger Flage
University of Stavanger, Norway

Sven Ove Hansson
KTH, Sweden

Bjørnar Heide
Petroleum Safety Authority Norway, Norway

Nicola Pedroni
Laboratoire Genie Industriel CentraleSupélec Université Paris-Saclay, France

Jon Tømmerås Selvik
University of Stavanger, Norway

Nathan Siu
Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC

Shital Thekdi
University of Richmond, USA

Vegard L. Tuft
Safetec Nordic AS, Trondheim, Norway

Pietro Turati
Laboratoire Genie Industriel CentraleSupélec Université Paris-Saclay, France

Jan Erik Vinnem
Norwegian University of Science and Technology, Norway
List of Contributors

Beate R. Wagnild
Safetec Nordic AS, Trondheim
Norway

Olga M. Slyngstad
Safetec Nordic AS, Trondheim
Norway

Marja Ylönen
VTT Technical Research Centre of Finland

Enrico Zio
Systems Science and the Energetic Challenge Chair
Foundation Electricité’ de France
Laboratoire de Genie Industriel (LGI)
CentraleSupélec
Université’ Paris-Saclay
France
and
Department of Energy
Politecnico di Milano, Italy
This book is about knowledge in risk assessment and management. Why a book on this subject? It is because the assessment and management of risk is fundamentally based on the knowledge and information available. Paradoxically, recognizing this simple fact is an important step forward. Indeed, recently the need has arisen of explicitly specifying the concept that risk is conditioned on knowledge (K). Then, the methodologies and approaches for risk assessment and management are to be seen as the supports for incorporating knowledge into a systematic, rigorous and transparent framework. In other words, risk assessment and management is a way of producing, representing and presenting knowledge about phenomena and the future, and then informing decision makers. This is achieved by developing models, representing and expressing uncertainties, propagating the uncertainties and using probabilities or other measures to describe risk. The description of risk is conditional on the knowledge K, as for example a probability is a judgement of uncertainty given some knowledge of the uncertain process or event. Knowledge is typically based on data and information, and takes the form of justified beliefs – often stated as assumptions in the risk model and characterization.

The value of the risk assessment and management, then, stands on the quality of the methodologies and approaches adopted, and on the strength of the knowledge K on which these are built. Whereas procedures of quality assurance have been developed for the former, how to deal with the latter – knowledge K – is still an open issue and a research challenge in risk assessment and management. How should it be described and evaluated in the risk assessment? How should it be reflected and taken into account in the decision-making process of risk management? This book aims to make some contributions to clarifying the problem, answering some of the questions and meeting the related practical challenges.

The book comprises 12 chapters on the fundamental concepts, ideas, principles and approaches involved (Part I), risk assessment and decision-making methods and issues (Part II) and applications (Part III).
Part I

Chapter 1 sets the stage by looking into the fundamental issues and principles related to knowledge characterization in risk assessment and management. An example is used to drive the illustration. The example is simple but sufficiently complete to allow clear discussions of critical aspects of the process, including risk conceptualization and measurements, treatment of uncertainties, characterization of the knowledge available, accounting for potential surprises, consideration of vulnerability, and robustness and resilience.

Chapter 2 follows up by providing a deep look into the concept of knowledge. The chapter reflects on how the knowledge concept used in risk assessment matches the wealth of studies on knowledge that we find in philosophy and sociology. It is questioned how the risk field can learn from these studies, for further developing the knowledge dimension of risk assessment and management.

Chapter 3 discusses the treatment and communication of uncertain assumptions in relation to risk assessments. The chapter describes a formal setup that connects the risk concept, the risk description, risk indices, and the knowledge dimension, including the assumptions in particular. Then, it presents a scheme for systematizing uncertain assumptions, and it is shown how it can be used to provide recommendations on strategies for the treatment of such assumptions from both a risk analyst’s and risk manager’s perspectives. The setup and scheme build on recent advances in uncertainty-based risk conceptualizations, including, in particular, the concept of assumption deviation risk: the so-called NUSAP notational scheme for uncertainty and quality in science for policy, and the assumption-based planning framework.

Chapter 4 presents a general framework that can provide information about the validity of the assumptions made in a risk model about a system’s future behavior, in order to provide early warnings. This is highly relevant for risk assessment and management, as any model-based risk description is strongly dependent on the underlying modeling assumptions and the validity of these assumptions is difficult to express. This question needs to be addressed to adequately understand, assess and manage risk, in particular the risk related to potential surprises and unforeseen events. The framework described in the chapter is based on a signal-processing approach that monitors for signals associated with a trend change in the system’s behavior.

Chapter 5 provides an in-depth analysis of uncertainty analysis in a risk assessment and management context. Given the relevance of uncertainty in risk assessment and management – and indeed the importance of what is not known just as much as what is, the chapter presents a general framework for uncertainty analysis, building on what we are uncertain about, who is uncertain and how we should represent or express the uncertainties. The framework has two distinct features:
● a clear distinction between uncertainty as a concept and the way uncertainty is measured or described
● a distinction between the uncertainty of the analysts and that of the decision makers.

Chapter 6 addresses the concept of completeness uncertainty. The interpretations found in the literature of this term are ambiguous, and its treatment appears difficult. The chapter aims at clarifying what the concept is about and it shows that in essence it can be treated as model uncertainty.

Chapter 7 reflects on issues related to the quality of a risk assessment, addressing both “scientific criteria” and “being useful” in a decision-making context. New insights are gained by considering two novel aspects:

● the perspective of risk assessment, which shifts the focus from the accurate risk estimation to the characterization of knowledge and lack of knowledge
● the recognition that decision makers need to go beyond the conditional risk as described and assessed by the risk analysts and experts, to consider unconditional risk.

The quality of risk assessment is then discussed in this context, highlighting the questions of what it depends on, how it can be ensured and checked.

Chapter 8 puts forward modeling and simulation as ways to explore and understand system behavior, for identifying critical scenarios and avoiding surprises. Recognizing that for complex systems, the simulation models can be:

● high-dimensional
● black-boxes
● dynamic
● computationally expensive

the chapter presents adaptive strategies for guiding the simulations so as to increase knowledge of the critical system behavior in a reasonable computational time. Two simulation frameworks for hazard identification are proposed: one focusing on the search for extreme unknown consequences associated with a given set of scenarios and the other focusing on the exploration of those scenarios, potentially leading the system to critical consequences and the retrieval of the corresponding root causes.

Part II

Chapter 9 presents a decision-support prioritization method that incorporates uncertainty through strength-of-knowledge (SoK) and target-sensitivity assessments. Current thinking for assessing these uncertainties and their importance in the decision-making process is based on a probabilistic
perspective and decision analysis. The chapter presents a new method for prioritizing investments with consideration of the most influential uncertainties from the decision-making point of view, thereby allowing for systematic SoK considerations. The method is demonstrated on an emergency management system that is vulnerable to future economic, environmental, and political factors.

Chapter 10 addresses the issue of structuring decisions in the process of risk management. When the decision procedure starts, it is often unsettled or unknown exactly:

- what issues are going to be decided upon
- whether a single decision is going to be made about all of them or the decision will be subdivided and in that case how
- when the decision(s) should be made
- what options are open to the decision-maker(s)
- the criteria for a successful decision.

In the chapter, the structuring of decisions is systematized by dividing it into ten major components. Conceptual tools are introduced that can be used for the analysis and management of each of these components. Careful investigation of the consequences of different ways of structuring decisions can provide decision makers with the knowledge needed to ensure the efficiency and transparency of the risk management decision process.

Part III

Chapter 11 presents a practical approach to risk assessment – quantitative risk analysis (QRA) – of offshore oil and gas installations from design to operation, highlighting the importance of knowledge and related assumptions. A QRA is a powerful decision-support tool, used in many industries exposed to major accident risk. QRAs are often large and comprehensive, and are sometimes criticized for providing results too late, being too costly and not adequately addressing uncertainty and possible deviations in input parameters.

Chapter 12 outlines another way to show how knowledge can be incorporated in risk assessment and management practice. An extension of the method currently used by the Norwegian Petroleum Safety Authority to express the level of risk and to detect trends in risks in the Norwegian petroleum industry is suggested. This extension incorporates specific robustness and knowledge assessments.

Chapter 13 illustrates the risk-related knowledge management challenges faced by a safety authority (specifically, the United States Nuclear Regulatory Commission), but also by the risk assessment and management community as
a whole. It explains the use of risk information and knowledge in the practice of regulatory decision-making, highlighting its multi-faceted character, which leads to challenges for knowledge engineering and the development of information systems supporting knowledge management. Approaches to improving the management of risk information for increased knowledge are also described.
Acknowledgements

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Part I

Fundamental Ideas, Principles and Approaches
1

Risk Assessment with Broad Uncertainty and Knowledge Characterisation: An Illustrating Case Study

Terje Aven and Roger Flage

University of Stavanger, Norway

This chapter presents a risk assessment of a master’s degree programme in risk management. The assessment is to support decision-making on how to best develop the programme in the coming years. The aim of the chapter is to perform this case study to show how a risk assessment can be conducted and used when risk perspectives are adopted that highlight knowledge and uncertainty characterisations that go beyond the standard approach based on consequence and probability estimation. Such perspectives have been given considerable attention recently, and real-life examples have been sought, showing the practical implications of these perspectives. The example is simple and allows for clarifying discussions of critical aspects of the analysis process, including risk conceptualisation and measurement, treatment of uncertainties, characterisation of the knowledge available, accounting for potential surprises, as well as vulnerability, robustness and resilience considerations. It is concluded that with integration of the new ideas from the early planning stages, the risk assessment is not more difficult to run than with the traditional approach; the decision process is, however, in our view substantially improved because the decision makers are better informed on many of the aspects important for the decisions to be made.

1.1 Introduction

The Petroleum Safety Authority Norway (PSA-N), which is an independent government regulator with responsibility for safety, emergency preparedness and the working environment in the Norwegian petroleum industry, has recently introduced a new definition of risk, which states that risk represents the consequences of an activity along with the associated uncertainty (PSA-N 2015). The previous
definition was based on a traditional consequence and probability perspective in line with the triplet of Kaplan and Garrick (1981), covering scenarios, consequences and probabilities. Work has been initiated in the industry to understand the practical meaning and implications of this new definition from PSA-N.

The Society for Risk Analysis (SRA) has just issued a new glossary on key risk concepts (SRA 2015), which allows for several definitions of risk. However, in all the definitions referred to, events/consequences and uncertainty are key components, and the issues about practical meaning and implications are also relevant. As a third example, we would like to mention the ISO 31000 standard on risk management (ISO 2009), which has also built the definition of risk on uncertainty and not probability. In the standard, risk is defined as the effect of uncertainty on objectives.

When it comes to the risk description in a risk assessment, it is necessary to use a measure of the uncertainties, and the question is then what the alternatives are and what measure should be used. Uncertainties are related to knowledge and, hence, describing uncertainties is about describing not only the knowledge itself but also the quality of this knowledge.

Considerable theoretical work has been conducted on this topic, aimed at clarifying the understanding of the key concepts and providing recommendations on how to best describe risk; see for example Aven (2012) and Flage et al. (2014).

Experience from practical risk assessment work has shown that many people struggle to see the difference between the old consequence–probability-based risk perspective and the new ideas; for example, what is the difference between uncertainty and probability? Also, there is a concern that the new way of thinking will lead to more complicated assessments, emphasising uncertainties too much, with the result that communication between analysts and decision makers will be made unnecessarily difficult.

To meet these challenges, there is a need for work that can contribute to clarifying the difference between the traditional perspectives and the new ones, pointing to the differences and demonstrating what these new ideas add to current practice.

In our view, the best way of doing so is to present and discuss simple, easily understandable examples (case studies), which make it possible to highlight the ideas without being disturbed by a lot of technical details. The present chapter aims to do precisely this. We present parts of a risk assessment, including the planning and use stages, of a master’s degree programme in risk management, in which the assessment is based on the new ideas about risk. The assessment is to be used to support decision-making at the university, and in this chapter we discuss the main process stages and findings, highlighting issues linked to differences in risk perspectives and what the new way of thinking adds to current practice. In an appendix, we present an overview of the key features of the new perspectives that were required to adapt the existing theoretical work to a more practical context. The case study considered has a qualitative analysis focus.
The remainder of the chapter is organised as follows. Firstly, in Section 1.2, we present the case study in more detail. Then, in Sections 1.3 and 1.4, we look into the planning of the risk assessment and the execution of the assessment, respectively. Section 1.5 covers the use of the assessment, having a focus on risk management and related decision-making. Section 1.6 discusses the analysis process and findings, and, finally, Section 1.7 provides some conclusions.

1.2 The Case Study

The University of Stavanger officially became a university in 2005, after a review process showing that certain quality requirements were met. However, it has offered risk and safety-related programmes at master’s level (two-year programmes, building on a bachelor’s degree of three years duration) for about 30 years. During the first 10 years, these programmes were based on petroleum and offshore engineering study programmes; later, they were also oriented towards societal safety. Gradually, the offshore and petroleum-based programmes have been made more general, and now the master’s programmes offered are run with a wider risk management and societal safety focus. Still, the applications are to a large extent related to oil and gas, and one of the specialisations of the risk management programme is in offshore safety.

The trend in recent years has been towards an increase in international students and a corresponding reduction in Norwegian students. Student recruitment has always been an issue, as the competition related to getting the best students from the bachelor’s engineering programmes is tough. The oil and gas industry has attracted many talented students, but the industry’s need for candidates varies greatly, along with the oil price. Environmental concerns are also factors in this respect, when looking into the future of the programme.

To support decision-making on how to best develop the master’s programme in risk management in the coming years, the risk assessment presented in this chapter was been carried out. As explained in Section 1.1, we have sought to do this in the most “current way”; that is, in line with the new perspectives on risk.

1.3 Planning of the Risk Assessment

The main activities of the planning stage of the risk assessment are:

- clarification and specification of the decisions to be supported by the risk assessment
- the development of the objectives of the assessment
- establishing the scope of the assessment – clarifying what aspects and features to include and not include in the work.
Other activities, such as organisation of the work, will not be further discussed here.

As mentioned in Section 1.1, the overall main objective of the risk assessment is to support the decision-making process on how to best develop the master’s programme in risk management in the coming years. As a first step, the main stakeholders involved are identified: students, academic staff (professors), administration, potential employers (industry, public sector…) and society as a whole. For each of these stakeholders, we identify a set of ideal goals/criteria; see Table 1.1.

From this, the following aims of the risk assessment are formulated:

a) Identify gaps between these goals/criteria and the current status.
b) Identify events and factors that could have strong effects on the achievement of the above goals/criteria, or other issues of importance for the development of the programme in coming years.
c) Suggest a set of measures that is considered necessary to bridge the gap and meet these goals/criteria and avoid potential negative consequences and surprises.
d) Assess the risk associated with implementing or not implementing these measures, as well as costs and benefits in a wider sense, highlighting all relevant pros and cons.
e) For the risk judgements, follow the approach presented in the appendix, which in brief means that the following tasks should be carried out in this case:
   - Identify events that could result in goals/criteria being/not being met.
   - Identify underlying events/factors/sources/threats that could be of importance in this regard.
   - Assess the probabilities of these events using a suitable interval probability scale.
   - Assess the strength of knowledge supporting these judgements. Identify assumptions on which these probability judgements are based. Assess possible deviations from these assumptions. Consider ways of improving relevant knowledge.
   - Scrutinise the assessments by letting others in the organisation check the assessments, in particular for knowledge gaps and signals and warnings.
   - Assess the robustness and resilience if something unlikely/surprising should occur.
   - Consider measures to improve the robustness and resilience.
   - Carry out an ALARP (As Low As Reasonably Practicable) process to further reduce risk.
f) Derive a priority list of the measures for implementation, based on different potential policies.
<table>
<thead>
<tr>
<th>Stakeholders</th>
<th>Ideal goals/criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students</td>
<td>An education that provides good opportunities for relevant jobs</td>
</tr>
<tr>
<td></td>
<td>Highly qualified staff (professors and administration)</td>
</tr>
<tr>
<td></td>
<td>Exciting and stimulating scientific environment</td>
</tr>
<tr>
<td></td>
<td>A good social environment</td>
</tr>
<tr>
<td>Academic staff (professors)</td>
<td>Recruiting good students</td>
</tr>
<tr>
<td></td>
<td>High international research and development level supporting the programme</td>
</tr>
<tr>
<td></td>
<td>Use of modern teaching and communication means</td>
</tr>
<tr>
<td></td>
<td>Highly motivated as lecturers and supervisors</td>
</tr>
<tr>
<td></td>
<td>Driving force for further developments</td>
</tr>
<tr>
<td>Administration</td>
<td>Professional service for the students</td>
</tr>
<tr>
<td></td>
<td>Professional service for the academic staff</td>
</tr>
<tr>
<td></td>
<td>Driving force for further developments</td>
</tr>
<tr>
<td>Potential employers</td>
<td>Perceive and find candidates from the programme highly competent and motivated</td>
</tr>
<tr>
<td></td>
<td>Good contact with academic staff</td>
</tr>
<tr>
<td></td>
<td>A significant need for candidates from the programme</td>
</tr>
<tr>
<td>Society</td>
<td>Candidates add value to the society with their competence and skills</td>
</tr>
<tr>
<td></td>
<td>Scientific staff add value to society</td>
</tr>
</tbody>
</table>
The assessment was carried out by core academic staff in the Risk Management group at the Department of Industrial Economics, Risk Management and Planning at the University of Stavanger. The implementation of the suggested measures will depend on decision processes at the department and school levels, managed by the head of department and the Dean, respectively.

1.4 Execution of the Risk Assessment

Brainstorming sessions were conducted to carry out the activities associated with aims (a)–(c): identify gaps, events and factors, and measures to bridge the gaps.

A list of gaps was identified and divided into two categories: those judged as the most important, and others. Table 1.2 summarises the results for two such gaps, where the first gap is considered the most critical one. We focus our discussion on this gap. It states that to meet the goals formulated in Table 1.1, a main challenge is recruitment of good students. The current requirement to enter the Risk Management programme is an average grade of C or better from an engineering (or similar) bachelor’s programme, and the number of applications has been fairly stable in recent years: slightly above the minimum level to fill the study programmes with qualified students. At the same time, we see that the master’s programme in industrial economics has a large number of applications, which results in higher bachelor’s grade point averages requirements. Two obvious explanations for this are that economics and business are well known to students at high school level and the master’s programme in industrial economics is well known in Norway and internationally: it is a prestigious programme and the salary and career prospects are very good. Risk management, on the other hand, is a new field and not so well known to many students.

To recruit better students to the risk management area, it is suggested that a specialisation in risk management be established under the industrial economics master’s programme. The programme already offers courses in risk management, and the suggestion could be seen as a further development of an already established link between these two areas. Another measure being considered is to apply to become a “centre of excellence”, a prestigious research centre, supported by the Research Council of Norway. The idea would be that such a centre would make the risk management programme better known, both nationally and internationally, attracting more students. As a third measure, initiatives are considered for making risk management a subject at high school level. Realising this aim would, however, be a long process, but it could strongly influence recruitment success.

The next task is to conduct a risk assessment of these measures. We restrict attention to the measure M1, and the base case, i.e. doing nothing and
Table 1.2 Examples of identified gaps, important events and factors, and measures to bridge the gaps.

<table>
<thead>
<tr>
<th>Identified gaps</th>
<th>Events and factors (risk sources, threats)</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recruitment of more good students</td>
<td>Labour market, Oil-price volatility, Programme judged as attractive for future careers, Highly recognised programme</td>
<td>Risk and safety group obtains Centre of Excellence status, Risk management not a subject in schools, nor in the bachelor's programmes at the university, Develop a specialisation in risk management as part of master’s programme in industrial economics (M1)</td>
</tr>
<tr>
<td>Limited use of modern teaching and communication means</td>
<td>Professors up to date on these means and motivated, Quality of tools is good, Sufficient resources made available</td>
<td>Recording of lectures, Use of short videos highlighting key topics in each course</td>
</tr>
</tbody>
</table>
Knowledge in Risk Assessment and Management

We proceed as today. We then go systematically through the issues listed in the guideline presented in the previous section and in the appendix. Tables 1.3 and 1.4 summarise some key points in these assessments for the base case and M1, respectively.

We see from Table 1.3 that the analysis group judges that, proceeding as today, it is quite likely that we will see a reduction in the recruitment of good students. This judgement is based on several assumptions, including that the master’s programme is perceived among students as being strongly oriented towards petroleum applications. Although the programme has a generic risk assessment and management focus, it has a history linked to oil and gas, it offers a specialisation in offshore safety and the scientific staff work closely with the petroleum industry. The petroleum industry is currently under pressure: it is subject to intervention by governments, driven by climate change policies, and this may strongly affect young people in their choice of education. Fewer students will look for petroleum-oriented programmes. This may also affect student applications to the risk management programme. If the oil price remains low, the recruitment to petroleum-related programmes is likely to be further weakened. The analysis group has based its probability judgements on a fluctuating oil price, bringing a better incentive to invest in the industry, and more optimism. However, they judge it unlikely that a high oil price will lead to much higher interest in the study programme, given the current “green societal change”. If the oil price increases, we may see improvements in recruitment, but we have previous experience that a very high oil price causes many candidates to end their studies after finishing their bachelor’s degree, since in those circumstances the industry’s demand for new employees is so high that they can easily get a job without a master’s degree.

The assumption that competition to get the best students is increasing is prompted by the fact that universities and colleges offer an increasing number of master’s programmes, and the marketing for these is more and more intense. The value of good students is very high in a university system, as these students represent a key recruitment base for PhD programmes.

The competition assumption is given a low assumption deviation risk score, because the analysis group considers it very likely that this assumption will hold. The two other assumption risks in Table 1.3 are judged as medium assumption deviation risk. This is based on an overall evaluation of the probability of deviations from the assumptions, the implications from these deviations, and the strength of knowledge supporting these judgements.

To assess the strength of knowledge supporting the probability assignments, the assumptions’ deviation risks are taken into account, as are the availability and amount of data/information, different views among experts, and judgements of the basic understanding of the phenomena and processes being studied, in line with the approach outlined in the appendix. The events considered are unique future events, and the data and information available are more or
Table 1.3  Summary of risk judgements* for the base case: no specific measures implemented.

<table>
<thead>
<tr>
<th>Events that could result in goals/criteria not being met</th>
<th>Events that could be of importance in this regard</th>
<th>Assessed probabilities for these events</th>
<th>Key assumptions made</th>
<th>Assessment of deviation risk</th>
<th>Assessment of the strength of knowledge supporting the probabilities assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>A reduction is seen in the recruitment of good students ($A_{a_1}$)</td>
<td>Low/high oil price The risk and safety group at the university obtains centre of excellence status</td>
<td>$0.25 \leq P(A_{a_1}) \leq 0.50$</td>
<td>The competition to get the best students is increasing The masters programme in risk is perceived as strongly oriented towards petroleum applications The oil price continues to fluctuate</td>
<td>Low</td>
<td>Medium</td>
</tr>
</tbody>
</table>

*As defined in the list at the end of Section 1.4.
Table 1.4 Summary of risk judgements* for the measure M1.

<table>
<thead>
<tr>
<th>Events that could result in goals/criteria not being met</th>
<th>Events that could be of importance in this regard</th>
<th>Assessed probabilities for these events</th>
<th>Key assumptions made</th>
<th>Assessment of deviation risk</th>
<th>Assessment of the strength of knowledge supporting the probabilities assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>The specialisation is not approved ($A_1$)</td>
<td>New head of department</td>
<td>$P(A_1) \leq 0.10$</td>
<td>No change in head of department</td>
<td>Low</td>
<td>Strong</td>
</tr>
<tr>
<td>A very low number of students in industrial economics choose the specialisation in risk management ($A_2$)</td>
<td>The students find the specialisation unattractive (e.g. because of too much safety focus)</td>
<td>$0.25 \leq P(A_2) \leq 0.50$</td>
<td>People in the industrial economics group accept the risk management specialisation</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>The specialisation continues to have a risk focus more than a safety focus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The students in industrial economics following the risk management specialisation are weak ($A_3$)</td>
<td>The weak students choose the risk management specialisation</td>
<td>$P(A_3) \leq 0.10$</td>
<td>The recruitment to the industrial economics programme continues to be strong</td>
<td>Low</td>
<td>Strong</td>
</tr>
<tr>
<td></td>
<td>Recruitment to the industrial economics programme is significantly weakened</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*As defined in the list at the end of Section 1.3.