Safety rule modifications in the Norwegian railway system

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Abstract.

There is much invested in safety rule development, implementation and control of compliance, but the scientific knowledge about how to modify them is limited. This paper presents results from a case study of four safety rule modification processes in the Norwegian railway system. The cases modified rules for traffic operation and infrastructure maintenance.

The study reveals that the cases applied a strategy given the name "reverse invention". This strategy diverged from the intention of the cases to apply so called hierarchical and risk based approaches, and took more advantage of existing railway knowledge than these. The cases demonstrated four different ways of using risk analyses in the modification work. Also, they provided arguments for and against different rule principles in different contexts. The processes contributed to a revival of railway knowledge. However, as only written elements are systematically stored in organizational memory this knowledge might be in danger.

1. Introduction

It is surprising that even though much is invested in safety rule development, implementation and control of compliance, there is limited scientific knowledge about performing safety rule modifications (Hale & al., 2003). Therefore, this paper presents an overview of the main results from a PhD work where four safety rule modification processes in the Norwegian railway system were studied[1]. Special attention is given to the intentions of the cases to develop hierarchical rule systems and to base the rule development on risk analyses, i.e. hierarchical and risk based approaches.

1.1 The trend towards hierarchical and risk based approaches

In many older systems, it has been common to have safety-rules providing detailed prescriptions to the operative staff of what to do in response to predicted situations or requirements to the states of the system (Hale, 1990). The knowledge base for the development of such prescriptive rules were usually extensive knowledge of the systems' functioning combined with knowledge derived from practical experiences with accidents and dangerous events (Rasmussen, 1997).

There is now a trend towards "hierarchical" and "risk based" approaches to safety-rule development (See for instance Hale & al, 1997; Hovden, 1998; Maidment, 2002; Reason, 1997) This trend refers both to the system of the rules themselves and how they are developed.

Regarding the rule system, different types of rules can be related to each other in a hierarchy:

[1] The thesis can be found at http://www.sintef.no/content/page1____3094.aspx

- At the highest level there are rules directed at safety management and outcomes.
- At the lowest level there are rules providing more or less detailed prescriptions about what to do or the state of technical equipment.
- In the middle there might be two types of rules. One type describes how to make decisions about what prescriptive rules are needed to fulfill the goal oriented rules (Hale, 1990; Hale & Swuste, 1998) The other represent a mixture of prescriptive and outcome oriented rules (Reason, 1997).

Often the hierarchical approach is associated with organizational hierarchies, but not necessarily (Hovden, 1998). The approach can also be associated with different levels of a safety management system (Hale, 1990; Hale & Swuste, 1998).This implies that higher order rules should be set at the central higher levels of the hierarchies. When found necessary the lower levels of these hierarchies translate these rules into lower level rules. This represents a deductive "top down" approach to the rule development (Hovden, 1998). This also implies that some kind of risk assessment is required to decide upon the necessity of rules.

However, different rule principles seem to be more or less compatible with different contexts. First, different types of rules correspond to different control principles (Rasmussen, 1997; Rasmussen & Svedung, 2000; Reason, 1997). Outcome oriented rules are compatible with feedback control and require opportunities for feedback. Prescriptive rules are compatible with feed forward control and require opportunities for preplanning of activities.

Second, different types of rules require different time to think (Hale & Swuste, 1998; Rasmussen & Svedung, 2000). Outcome oriented rules require time to figure out the appropriate action for the intended outcomes. In prescriptive rules the task to translate intended outcomes into actions is already done.

Third, a system's characteristics with respect to interactive complexity and tightness might influence how centralized the system's coordination should be. When the system is characterized by high interactive complexity and loose coupling Perrow (1999) argues for decentralized coordination. When the system is linear and tight coupled he argues for and centralized coordination. In a complex and tight coupled system there is a dilemma between centralized and decentralized coordination. In dynamic and unpredictable systems it is generally difficult to preplan activities.

Fourth, different types of rules put different requirements upon rule-imposers' and rule-followers' competency (Hale & Swuste, 1998; Kirwan & al., 2002; Rasmussen & Svedung, 2000; Reason, 1997). Outcome oriented rules require that rule developers are able to define the necessary outcomes for safe performance and that rule-followers are able to translate the outcomes into actions or states. Prescriptive rules require that rule developers are able to define safe actions or states and that rule-followers have the skills to perform the required actions.

Regarding the "top down" approach there might be requirements of democratic elements, such as seen in the Norwegian Working Environment Act. This implies that there might be elements of an inductive "bottom up" approach (Hovden, 1998). Furthermore, the risk assessments can be used more or less in combination with insights derived from other sources of knowledge (see for instance Chapman & Dimitrijevic, 1999).

Table 1 below summarizes the approaches, normative implications and associated problems.

Table 1 Summary of hierarchical and risk based approaches

Hierachies	Type of hierarchy	Normative implications	Associated problems
Rule solution	Type of rule solution: o High level management- and goal-oriented rules o Mid range mixed solutions or decision rules o Low level prescriptive rules	Different rule solutions require different competency both from rule-imposer and rule-follower. Rule solutions differ in suitability to different contexts Rule solutions differ in vulnerability to contextual changes	What if the suggested rule solutions do not fit the actual situation with respect to o Rule context o Competency of rule-imposer o Competency of rule-follower
Position of rule-imposer	Level of authority of the rule-imposer: o High level international and governmental level o Mid range company and management level o Low level operative management level	High level centrally positioned rule-imposers impose high level rules Mid range rule-imposers impose mid range rules Low level rule-imposers impose low level rules	
Direction of rule development	Type of rule solution to use as starting point for the rule development	Start with higher order rules and deduce lower level rules from these. Base the rules on risk assessments	What work strategy to choose if low level rules already exist? How to combine risk analyses with rule development in an evolutionary practice oriented tradition?

1.2 The safety-rule tradition of the Norwegian railway system and modification projects

The Norwegian railway system has had a rule tradition with prescriptive rules directed at the operative staff at the lower levels of organizational hierarchies. The rules have been developed with growing knowledge of the system's technology, activities and interactions and with experiences of unwanted events or accidents. Much of the knowledge has been derived from practice and consisted of more or less collective tacit and explicit knowledge. This railway knowledge was shared through an internal educational system, practice oriented trainee programs and socialization. (Gulowsen & Ryggvik, 2004)

In the Norwegian railway system, and in particular in the Norwegian Railway Inspectorate, there have been initiatives to make increased use of outcome oriented rules[2]. Furthermore, the Norwegian railway system is required to base the safety work upon some kind of risk assessment (Samferdsels-departementet, 2001). This requirement is also understood as referring to safety-rule development.

The development towards hierarchical and risk based approaches was evident in two different projects of the Norwegian railway system. One project was established for modification of the "traffic safety rules". In general, these rules were detailed prescriptive action rules that coordinated the activities of the staff involved in traffic operations. The management of this project encouraged the rule developers to "think new", develop outcome-oriented rules formulated as goals and to base these upon risk analyses. From

[2] Information from Director Johnsen of the Norwegian Railway Inspectorate, 3/5/2003.

the beginning, the rule-imposers were the Norwegian Railway Administration. Later this responsibility was transferred to the Norwegian Railway Inspectorate.

The other project had as purpose to improve the management of infrastructure maintenance. One element in this project was to modify the “maintenance rules”. These rules were organized in different sets for each subsystem of the infrastructure. They were mainly detailed prescriptive action or state rules directed at the operative staff that served both safety and other purposes. The different subsystems had varying characteristics regarding time sequencing of activities, communication and coordination. Also, in this project the management encouraged the rule developers to “think new”. This meant to increase the use of triggering requirements and to base the rules on risk analyses. The triggering requirements should define conditions in the infrastructures that should trigger off maintenance activities, i.e. define outcomes for maintenance activities. The rule-imposers were the Norwegian Railway Administration.

2. Research question, research method and generalizability of results

The two presented projects represented an opportunity to study real life safety rule modifications. The responsible and involved actors of the two projects were positive to make the projects subject for research. On this background, the following research question was raised: *“How did the Norwegian railway system respond to new requirements for safety rule modifications?”*

This question is a “how” question. However, the study also had as ambition to give attention to possible explanations for revealed phenomena. Therefore, to answer the research question an explorative and qualitative approach and a case study design were chosen (Miles & Huberman, 1994; Yin, 1994).

The project modifying the traffic safety rules was chosen to represent one case. This case was followed until the work was transferred to the Norwegian Railway Inspectorate. Among the subprojects of the Maintenance project, the projects modifying rules for the signal-, power supply- and superstructure-infrastructure were chosen as cases. These cases were followed until the rules were approved.

The information for the study was gathered by interviews of 41 people that had been involved in the modification processes, studies of selected project documents and participation in 4 different meetings. The analyses were performed as an iterative process inspired by Grounded theory (Strauss & Corbin, 1998). The analytic tools and results influenced further data collection and further data-collection developed the analytic tools.

The results and conclusions of the study are based on a few cases in one particular railway context. Accordingly, conclusions should be critically judged before applied to other contexts. To extend the generalizability of the conclusions studies of modification processes in other contexts are required.

3. Results and discussion; the strategy of Reverse invention

In this chapter the main results of the study are thematically presented and followed up with discussions. Then the underlying pattern of Reverse invention and the impact of the processes upon railway knowledge is presented and discussed. Finally, practical implications are summarized.

3.1 A hierarchical approach?

All cases tried to "think new" and to use the intended "top down" approach to rule development, i.e. to start with the development of higher order outcome oriented rules. This work was based on the railway knowledge of the rule developers. When available, risk analytic results were used as supplement.

The cases soon abandoned this strategy. The main reasons were that existing lower order rules and associated knowledge was highly trusted and that it was experienced as a waste to start from scratch without taking advantage of knowledge associated with these rules. Instead, all cases used a "bottom up" approach where existing low level prescriptive rules and associated knowledge were used as outset for the developmental work. In this way knowledge associated with pre-existing rules was brought forth.

Also, existing prescriptive rules appeared remarkably persistent. Out of concerns for safety the cases critically judged the outcome oriented rule solutions with railway knowledge as reference. All cases found outcome oriented formulations to be useful, especially for educational and motivational purposes. However, they did not trust that they sufficiently controlled known risks. The Traffic rule case abandoned outcome oriented rules and decided to stay with the prescriptive rule solution. For educational purposes it intended to supplement the prescriptive rules with goal oriented formulations. Due to limited resources, this plan was cancelled. The Maintenance rule cases developed triggering requirements followed by explanatory texts. These were supplemented with prescriptive rules to a greater extent than expected. The prescriptive rules were placed as appendixes in the rule sets.

The most important factors that influenced the choice of rule principle were:

- Severity of potential accidents
- Experienced need to follow distinct procedures to achieve safe performance
- Needs for coordination and fast decisions combined with limited opportunities for communication and feedback to involved actors during the course of actions
- Rule-followers' wishes for clear instructions based on worries for making mistakes and for sanctions
- Concerns that new rule principles required a new type of competency from the rule-followers combined with limited possibilities for extensive introduction courses. This was particularly evident in the Traffic rule case.

The characteristics of the rule-imposers were not an important concern for the choice of the rule solutions. However, interviewees and particularly those representing the rule-imposers were concerned that the extensive use of prescriptive rules implied requirements to rule-imposer's competency.

The chosen rule solutions also imply that the hierarchy of rule solutions was not linked with positions of rule-imposers in the organizational hierarchies. This was particularly evident in the Traffic rule case. However, the solutions paralleled the positions of the rule-followers.

The decisions of the cases are supported by theory:

- The concerns for the limited possibility to take advantage of existing knowledge when applying a deductive strategy are supported by Lindblom (Lindblom, 1959).
- A comparison of theory about control principles and systems' characteristics with the contexts of the rule sets gives support to the choice of rule principles (Rasmussen, 1997; Rasmussen & Svedung, 2000; Reason, 1997; Perrow, 1999). This theory also implies that a development towards more diversity and less predictability will increase the need to focus upon feedback control principles.

Accordingly, such a development will cause problems for the prescriptive rule tradition and call for increased use of outcome oriented rules that require better conditions for feedback, communication and time to think.

- Theory combining control principles with requirements to rule-followers' knowledge, give support to the concerns about rule-followers' competency (Hale & Swuste, 1998; Rasmussen & Svedung, 2000; Reason, 1997). This implies that a move towards outcome-oriented rules needs to be followed by a plan for preparing the rule-followers for this change.
- The rule-followers wishes for clear information about what to do are supported by theory of the sanctioning function of rules (Hale & Swuste; 1998). Accordingly, a plan for preparation of rule followers must take this function into consideration.
- The concerns for requirements to rule-imposers' competency associated with the prescriptive rule solution are also supported (Hale, 1990; Rasmussen, 1997; Reason & al. 1998).

3.2 A risk based approach?

When it comes to the use of risk analyses in the modification processes, the four cases demonstrated four different solutions that gave the risk analyses different functions:

- The Traffic rule case developed their prescriptive rules with existing rules as an outset and in an iterative process with the evolving risk analyses. The activities raised questions to each other. Accordingly, the risk analyses contributed as decision support and were used to ensure quality and validate existing or new rules. The case developed and described their risk analytic method and method for interaction between rule development and risk analyses.
- The Signal case started with risk analyses and finished them before the rule writing. The two tasks were performed by different persons. Therefore the risk analyses could have served as the main fundament for the rule development. The rule developer tried this approach. However, he did not want to throw away all the knowledge and work invested in the existing prescriptive rules. Instead, he went on to develop the triggering requirements based on these rules and with risk analytic results as supplement. Hence, the main function of the risk analyses was to contribute as decision support, ensure quality and validate existing or new rules.
- The Power-supply started to develop rules on the basis of existing rules and railway knowledge before it was settled that the case should apply risk analyses. When it was settled to use risk analyses the two tasks continued in an iterative process where they contributed with knowledge to each other. The main function of the risk analyses became to contribute as decision support, ensure quality and validate existing or new rules.
- The Superstructure case started the rule writing and finished this task before the decision to apply risk analyses was made. Therefore, the conversion of rules into triggering requirement was done on the basis of existing rules and railway knowledge. The risk analyses were performed after the rule development. Accordingly, they had no direct influence upon the rule writing. As the risk analytic results did not come in conflict with the modified rules they got a validating function.

The participants of the two iterative processes found it useful to take advantage of knowledge that evolved during the work of both risk analyses and rule development. Of the same reason, the participants of the two other processes regretted that in their work the two tasks had not been integrated.

Even though the cases demonstrated four rather different processes, there were some common features:

- The risk analyses were used as a supplement to the existing modification tradition.

- Out of concerns for safety the risk analytic results were evaluated. Railway knowledge served as reference. The issue at stake was whether they covered known risks and in particular risks associated with complex interactions.
- If contradictions occurred, the common pattern was to suspect failures in the risk analyses. Hence they became reviewed. Accordingly, railway knowledge overruled risk analytic results.
- Confidence in risk analytic results was dependent upon confidence in the competence of the risk analyzers with respect to both railway- and risk analytic knowledge, the experienced suitability of the scope and preconditions settled for the analyses and the experienced appropriateness of the chosen risk analytic methods for the actual context.
- The risk analyses stimulated inquiries and systematized and documented selected railway knowledge that fit into the analytic framework.

Also in the use of risk analyses the cases get much support by theory:

- The chosen use of risk analyses can be associated with the so called risk informed approach discussed by Chapman & Dimitrijev (1999)
- Like the cases, Aven (2003) is concerned about the suitability of the chosen risk analytic method for the actual context
- This concern can also be associated with the participants' ownership to the chosen method as discussed by Rausand & Øien (2004)
- The concerns of the cases for both railway- and risk analytic competency of those performing the analytic work are also supported (Aven, 2003; European Comission, 2004; Rausand & Øien, 2004)
- This implies support to their cautious attitude towards risk analytical results
- Furthermore, literature criticizing the rationalistic tradition that risk analyses represent gives support to the worries that the analyses did not cover known risk of complex interactions (See for instance Jaeger & al.,2001; Perrow, 1999)

3.3 The strategy of reverse invention

The result of the hierarchical and risk based approaches can be summarized into a strategy given the name "Reverse invention". Here these approaches were explored and evaluated with railway knowledge as reference. When conflicts between the approaches and this knowledge occurred, railway knowledge held the strongest position. Rules were developed with railway knowledge, including existing prescriptive rules as the core fundament. Risk analyses served as supplement and had different functions in the developmental work.

The strategy of reverse invention with the strong position of existing rules and railway knowledge might face problems when the preconditions for these rules and railway knowledge are changing; the rules might be developed on outdated preconditions. This implies that the strategy requires judgments of the relevance of existing rules and knowledge for the actual context, that rule developers hold updated railway knowledge and that future rule modification processes have access to knowledge of the preconditions for existing rules.

3.4 Revived but endangered railway-knowledge?

The cases revealed that the exploration and evaluation of the hierarchical and risk-based approaches initiated inquiries into railway knowledge and discussions of the retrieved knowledge. This made existing railway knowledge more explicit and collective and knowledge from different sources became combined, i.e. railway knowledge became revived. The processes also contained elements that validated the revived knowledge and evolving results. This increased the confidence in the actual rules and associated railway knowledge.

However, the revived railway knowledge was evaluated, sorted out, systematized and translated into the written frameworks of risk analyses, new rules and project documents. Hence, the approaches also contributed to a reduction of this knowledge. This raises the question whether the rich revived railway knowledge is saved for the future.

3.5 Practical implications

The results and discussions presented above have some practical implications:

- If railway systems want to change their rule principles the rule context must be brought in accordance with requirements of the actual rule principle.
- In railway systems with a prescriptive rule tradition, outcome oriented rules can be developed with an inductive "bottom up" approach instead of a deductive "top down" approach. This will bring forward the railway knowledge associated with existing rules. However, the relevance of existing rules and associated knowledge for the actual context must be judged.
- Risk analyses can be combined with rule development in different ways. Different solutions give the analyses different functions. Interactions between the two tasks provide possibilities for taking advantage of knowledge evolving in both.
- Confidence in risk analytic conclusions depends on a number of factors. Many of these are settled in the initial phase of the work. Accordingly, this phase appears particularly important for the influence of analyses in modification processes.
- Hierarchical and risk based approaches can contribute to a revival of railway knowledge. However, they might also exclude knowledge that does not fit into the frameworks of the new approaches. Hence, this knowledge might be in danger.

4. Conclusion

The four studied modification processes abandoned the intentions of hierarchical and risk-based approaches; outcome-oriented rules were not developed on the background of risk analyses and prescriptive rules were not derived from such rules and analyses. Furthermore, the hierarchy of rule solutions were not linked to the positions of rule-imposers in the organizational hierarchy as expected.

The main reason was that the new approaches did not take the existing railway knowledge that had been found to be important for safe performance sufficiently into account. Instead, the modification work of all cases turned into processes that are given the name "reverse invention" in the study. Here existing railway knowledge and prescriptive rules were used as fundament for the work. Accordingly, existing knowledge was brought forth. This strategy requires that rule developers posit knowledge of preconditions for the existing rules and updated knowledge of the rules' actual context.

The risk analyses supplemented railway knowledge. The cases integrated risk analyses in the modification processes in four different ways. This gave the analyses different functions in the rule development. The evolving work was evaluated with railway knowledge as a reference and brought in accordance with this knowledge.

The cases favoured solutions that took advantage of different types of rules. Existing railway knowledge, including existing prescriptive rules, appeared remarkably persistent compared to the expectations for the work and one case had to leave the plan to develop outcome oriented formulations. Furthermore, the modification processes contained mechanisms that validated this knowledge.

The new approaches and the processes of reverse invention raised questions that initiated inquiries into railway knowledge. These inquiries revived this knowledge. The revived knowledge was reduced and systematized according to the chosen rule solutions, risk analytic methods and written documents from the work. This reduction might endanger some of the revived knowledge.

The practical implications of these findings are that attention should be given to the compatibility of chosen rule solutions for the rules' context, outcome oriented rules can be developed from existing prescriptive rules, risk analyses can serve different functions in rule development, confidence in risk analytic results depends on factors settled in the early stage of the analytic work and that hierarchical and risk based approaches can revive but also endanger railway knowledge.

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