

# Safety when implementing digital Technology and Infrastructure

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Increasing critical infrastructure (CI) resilience is a European strategy to enhance safety and security. A digital radio standard for the rail have been developed by The International Union of Railways (UIC) - The Global System for Mobile Communication in Railways (GSM-R). In Norway, GSM-R was implemented on the total rail network in the period 2003 – 2007. The system replaced all existing analogue communication systems and should also meet future requirements regarding radio communication.

Implementation of the new CI digital platform is related to communication between train leaders at control centers and train drivers, especially regarding train conveyance, incidents and emergencies. Main arguments for implementing the GSM-R project was that it would support safe and efficient rail communication.

In Norway several major public investments are evaluated. The Concept Research Program have developed a model for evaluating of long-term effects of CI projects.

This paper present evaluation of the implementation of GSM-R using this model. The evaluation model comprises goal achievement (results, effects and society) and unintended effects, in addition to relevance, sustainability and socio-economic value. The study is based on documentation analysis and interviews of key stakeholders. The results are discussed considering resilience engineering perspectives on safety and measurement guidelines.

**Keywords:** Safety, efficiency, resilience, rail, infrastructure, evaluation.

## 1 Introduction

Increasing critical infrastructure (CI) resilience is a European strategy to enhance safety and security. Resilience is a response to the increased complexity in interconnected and interdependent complex socio-technical systems, organizations and society. The resilience concept is broad, a variety of definitions are used, and it is applied in different research areas. It addresses the ability of a system/organization to continue operations both under expected and unexpected conditions. Resilience can be defined as the ability of a system to maintain and adapt its operational performance in the face of failures and other adverse conditions (Laprie 2005; Strigini 2012). A current EU project define resilience of an infrastructure as (Vollmer et al, 2016): *"the ability to understand risks, anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruption"*. The main aspects of similar definitions are 'absorb shocks', 'ability to adapt', and 'ability to recover' or 'bounce-back'. Another definition focusing on safety management to cope with complexity under pressure to achieve dependability, safety, continuity and regularity are *"the intrinsic ability of a system to adjust its functioning prior to or following changes and disturbances, so that it can sustain operations even after a major mishap or in the presence of continuous stress"* (Hollnagel, Woods & Leveson 2006). According to Westrum (2006), the main aspects are the ability to 'foresee and avoid' – incident/ accident prevention, 'cope with ongoing trouble' – to prevent an incidence from becoming worse, 'repairing after catastrophe' – to recover once it has happened.

This paper focuses on digitalization of a critical infrastructure in the rail transport sector - GSM-R (Global System for Mobile Communication-Railway) which is radio communication between infrastructure system, engine and control centers. A Norwegian case study illustrates experiences from a resilience perspective and focuses on both the implementation phase and long-term effects of the innovation.

### 1.1 Resilient guidelines

OECD (2014) resilience guidelines focus on developing countries. It is a step-by-step guidance on how to analyze risk and build a roadmap to resilience. However, OECD support development of similar guidelines in contexts prone to e.g. natural, climate, economic and/or geo-political shocks. The purpose of guidelines is to enable effective development.

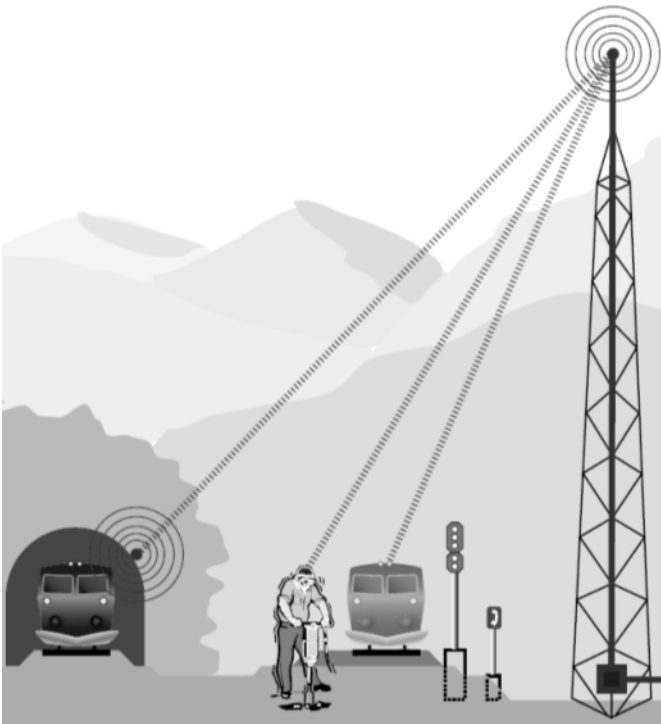
The argument for clarifying resilient perspectives and using resilient principles is that people, institutions and states need the right tools, assets and skills to deal with an increasingly complex, interconnected and evolving risk landscape, while retaining the ability to seize opportunities to increase overall well-being (OECD, Ibid).

However, it is noticed that translation of the idea into good practice has not been easy. One problem is to have the right tools to systematically analyze resilience, and then integrate resilience aspects into strategical and operative programs.

### 1.2 Standardization of rail critical infrastructure

One argument for implementing European standards in the rail sector is the enablement of common trans-

border railway transport allows trains to travel in any European country. The difference between national systems in European railway has been significant. A standardized system should improve the interoperability between networks and systems.



bility between networks and systems.

Figure 1. GSM-R infrastructure. (Norwegian National Rail Administration, 2005)

Today, a European standard regarding a common signaling system - ERTMS (European Railway Traffic Management System) - is to be introduced in all EU countries by 2030. This paper focuses on a component of ERTMS, that is GSM-R (Global System for Mobile Communication-Railway). GSM-R is a radio communication system for direct communication between engine and network operator. In addition to GSM-R, ERTMS includes ETCS (European Train Control System) and common European traffic regulation.

Standardization of GSM-R was designed to replace an analogue communication system with a digital system.

## 2 The Rail Case Study

The study presented in this paper is implementation of GSM-R in Norway in the period 2003 – 2006, and an evaluation of the effects. Norway was one of the first countries in Europe implementing an operative GSM-R system on the total rail network (Bane NOR, 2007).

The GSM-R infrastructure replaced the analogue system with a new digital emergency warning installation. The system shall ensure radio communication in both emergencies and ordinary operation. The in-

frastructure includes both voice and data communication via antennas and fiber (see Figure 1). GSM-R is based on the mobile standard GSM.

It is argued that a joint rail communication system would satisfy a list of rail specific requirements regarding safety and availability.

### 2.1 Implementation of GSM-R in Norway

The GSM-R project covers totally 3,900 km railway lines and 650 base stations, inclusive transmission. The infrastructure cover one pole with antenna and a radio box on each 6 km rail line. To ensure radio communication in about 600 tunnels was considered one of the biggest challenges (Bane NOR, *ibid*).

The implementation was done in two stages. Lines without authorized emergency communication, as requested by The Norwegian Railway Authority, was prioritized first. At the time being, these lines were operating on time limited permission. Trains, working machinery and Traffic Control Centers was equipped with new user equipment when GSM-R was put into operation on a section.

The most important GSM-R function is safe communication between train driver and traffic controller. A controller should always get quickly in contact with the right train. Further, the net is closed and limited to rail related radio communication. Thus, nor was travelers' mobile communication improved, nor should public mobile communication interrupt the rail communication. On the other hand, commercial tele operators would be allowed to use the infrastructure to improve mobile coverage onboard trains.

## 3 Evaluation of Infrastructure Projects

The Concept Research Program in Norway covers research related to effects of major public investments. Concept is founded by the Norwegian Ministry of Finance. Most Concept evaluations of investment in new critical infrastructure projects have measured effects like cost, time and quality. These are defined goals as an immediate result of the implementation project. In addition, several recent research projects also include ex post evaluations of investments projects.

### 3.1 Three levels of success

Projects successful may be evaluated in different ways. Effects may be classified along a continuum from short- to long-term. Samset & Volden (2013) distinguish between three levels of success: (1) Operational success: The delivery of the project is as promised and is both time- and cost efficient. (2) Tactical success: The project produces the maximum utility/benefit for the users at the lowest possible cost. (3) Strategic success: The project contributes to a desired societal development (as expressed by its long-term objective), at the lowest possible cost and

in a financially sustainable manner. The three levels of achievements correspond to the project management literature, i.e. (1) the outputs (project delivery), (2) the outcome (first-order effects for users), and (3) societal objective (wide and long-term effect for society (see Figure 2).

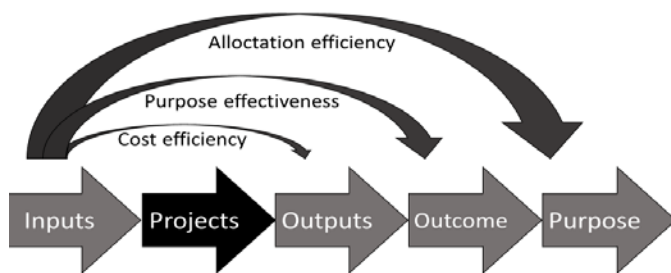


Figure 2. Three levels of efficiency. (Samset & Volden, 2013)

In practice, most of the focus has been on operational success. However, since major public investments typically have a broad societal perspective, the assessment of tactical and strategic performance may be vital aspects of the assessment of their success.

### 3.2 Evaluation model

The objective of the evaluation of the GSM-R project is to measure long-term effects of investment in changes of a critical rail infrastructure. The Concept program has developed and tested a model for post-evaluation on several CI projects. This evaluation model is used as guidelines when evaluating the GSM-R implementation. The evaluation model is a broad, goal-oriented evaluation model recommended by international organizations, including the OECD, in combination with economic analysis (Volden & Samset, 2017).

The model covers six general evaluation criteria (see Figure 3): (1) Efficiency. This is a measure of the project's implementation: how effectively the project organization has converted resources to deliveries. This includes an assessment of the project's outputs in terms of cost, time and quality. (2) Effectiveness. This concerns whether the agreed outcomes (or first-order effects) were reached and to what extent the project contributed to this outcome. (3) Other impacts. This includes all effects beyond the intended effects (the outcome) that can be attributed as the result of the project, positive and negative, short-term and long-term, and for different stakeholders and affected parties. (4) Relevance. A project is relevant if there is a need for it. Project relevance is measured in relation to needs and priorities as expressed politically and by stakeholders and affected parties. (5) Sustainability. A project is sustainable if its positive effects are likely to persist throughout its lifetime. (6) Socio-economic efficiency. This can be measured in terms of either the users' willingness to pay in relation to cost (profitability) or the outcome

in relation to cost (often denoted as cost-effectiveness).

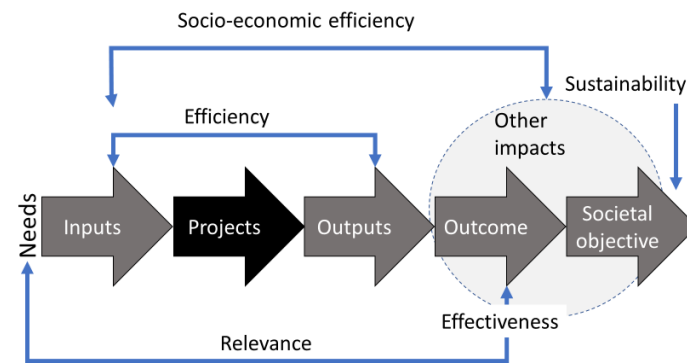


Figure 3. Concept Post-evaluation model. (Volden & Samset, 2017)

### 3.3 GSM-R - Evaluation method

The evaluation is based on document analysis and interviews of key stakeholders with central roles in the planning, implementation and operation of GSM-R.

Totally three individual and three focus in depth interviews were accomplished in the period from September 2018 to January 2019. Most were face-to-face interviews, and one was using Skype. Each lasted from one to two hours. A semi-structured guideline based on the Concept Post-evaluation model was used to ensure all aspects were taken into consideration.

The documents include descriptions of the GSM-R project, an up-front report based on external quality assurance, inquiry and statistical reports, meeting protocols etc.

## 4 Results

### 4.1 Safety – A central argument for the CI implementation

Documents and interviews indicate that safety is the main argument and objective for implementing GSM-R in Norway. The Åsta rail accident in 2000 are attributed as a triggering factor for deciding to replace the old and analogue system with a new and digital rail infrastructure in Norway. Because of the collision between two trains, 19 persons died, and several was seriously injured.

The accident had major influence on rail safety development and several safety measures were implemented, including GSM-R. The system should ensure communication in both emergencies and daily operations.

### 4.2 Operational success of GSM-R implementation

Efficiency is a measure of operational success and covers the project's outputs in terms of (1) time, (2)

cost and (3) quality. Documents and interviews indicate that these were within the estimated indications.

The documents and interviews indicate two main challenges during the implementation phase. First, before the implementation some lines were operated without any authorized emergency communication systems. These operated on time-limited license. This challenge was regarded as safety critical.

The interviews indicate that the quality of the analogue system was old and outdated and had to be replaced by a digital platform.

Regarding time, the implementation was planned as a two-step process. Phase 1 – sections without prior train radio communication – was completed as planned in 2005. Phase 2 – the rest of Norwegian rail net – was completed by 2007. This was also completed within the planned time period.

Another challenge was related to costs and quality; the absence of radio connection in tunnels. Some additional costs related to radio communication in tunnels and installations were anticipated. These costs were slightly overrun, compared to prior estimates.

### 4.3 Tactical success

Tactical success covers two criteria of the Concept Post-evaluation model – Effectiveness and Socio-economic efficiency.

(1) Effectiveness is the criteria that is of most interest in this paper. The main agreed outcomes (or first-order effects) of GSM-R implementation was safe and efficient train conveying. The question is if these objectives were reached and to what extent the project contributed to this outcome.

Train collisions are the third most severe rail accidents type in Europe, after Rolling stock in motion and Level-crossings (Stene, 2018). These are the accidents with highest number of persons killed or injured. The most frequent cause of fatal train accidents is signal passed at danger. This is also the case for the Åsta accident. Further, the infrastructure system neither included any alarm about the critical situation prior to the accident, nor functioned as an emergency communication support after it took place.

One question is whether the infrastructure serves as a barrier. A barrier may be defined as "measure which reduces the probability of realizing a hazards potential for harm and reducing its consequence. Barriers may be physical or non-physical (procedures, inspection, training or drill)" (ISO 17776 2000). According to Elvenes (2013) GSM-R may function as a safety measure in combination to other systems. However, alone this is not a safety barrier preventing fatal accidents. In the pre-crash period GSM-R may be a significant medium for warning if undesirable situation is evolving. Train driver and

train operation manager will have the possibility to alert and communicate directly with each other.

As one safety element, GSM-R may have a significant function in the post-crash period (Elvenes, Ibid). As a prevention measure, it is argued that the most relevant accident type is collisions between trains. It may also have a minor safety effect regarding derailments, collisions with objects, and persons at the platform or on the track.

To what extent GSM-R has contributed to fewer rail incidents and accidents are not clear. One reason is that accidents are rarely occurring. Thus, it is statistically hard to validate a reduction.

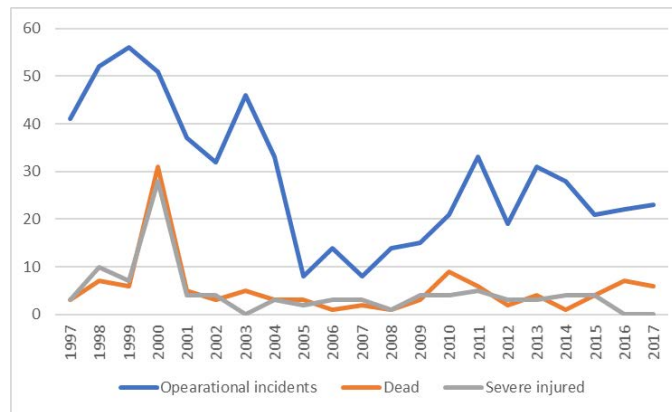


Figure 4: Number of accidents and injured/ killed in Norwegian rail in the period 1997 – 2017. (Source: The Norwegian Rail Authority)

Figure 4 show a clear decline in the number of reported operational accidents after 2003, but with an increase trend after 2008. The number of injured and dead is relatively constant. Each severe incident/ accident was reported, and an inquiry completed. In GSM-R the implementation phase 2003 – 2006, no severe accidents are reported. After this, the figure indicates an increase of accidents. One reason given for this is the emphasis on registration routines.

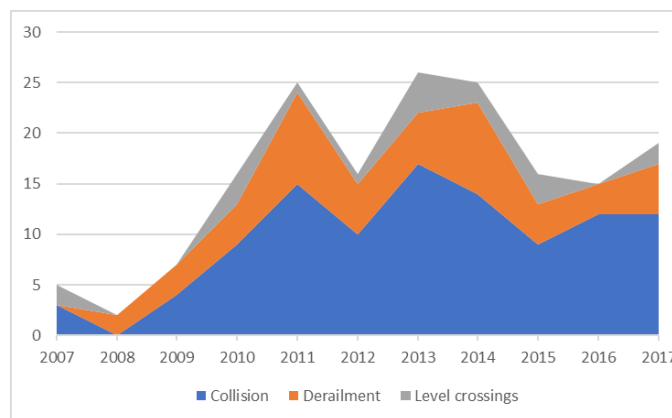


Figure 5. Operational accidents 2007 – 2017 – The three most frequent incidents. (Source: The Norwegian Rail Authority)

Figure 5 illustrates the three most frequent incidents categories after 2007. Incidents and near misses may

indicate a trend. However, incident reporting was not mandatory and systematic in Norway before the Åsta accident. One of the measures afterwards is a mandatory registration of severe incidents from 2006. These are undesirable rail incidents that (under other conditions) may have resulted in an accident. The argument was learning and improvement from these, contributing to prevention, lessons learned and improved safety.

However, the focus interview with the operational personnel (engine drivers) indicates that GSM-R includes communication artefacts (internal mobile phones, emergency button etc.) have contributed to accident prevention, and thus being a safety barrier. One example was a car stuck on a level crossing. This was reported to the control center, which switched on an emergency button and informed the train approaching the crossing. The emergency button automatically - and at once - slows down the speed of the trains in the area to 40 km/h.

In addition to technical and physical elements, the barrier definition also covers non-physical elements as procedures, inspection, training or drill. Both the quality assurance report as a basis for deciding to implement GSM-R and the interviews point at the need for developing and adjusting work processes and education. This was relevant for staff both at the GSM-R communication center, the traffic management center and the engine drivers. Several adjustments, modifications and development of new procedures were necessary after the implementation phase finishing in 2007.

One of the informants mentions the need for developing a new operational organization related to the digitalization in parallel with maintaining the old one serving the analogue infrastructure. Gradually the new organization took over the operation with responsibility for new equipment, procedures etc.

(2) Socio-economic efficiency (measured in terms of either profitability or cost-effectiveness). As prior mentioned, it was no option to keep the old analogue system. It was essential to replace it by a digital system. Thus, the willingness to pay was relatively high. In addition, accidents like the Åsta involve both high financial costs in addition to human losses and suffering.

Regularity and safety may be interrelated. Incidents and accidents often imply traffic delays. The front-end operators – the engine drivers – report that the new communication equipment onboard the trains results in fewer stops and delays. One reason is that the now don't have to go outside to call the operation central. Another reason is that they daily, especially at wintertime, call and report about obstacles like animals and snow/ ice on the track. This prevents accidents and may be solved faster than earlier. The train drivers report some cases of accident prevention, where the radio is used to report cars, persons or animals on the track.

Another aspect of socio-economic efficiency is related to the train passengers, service and regularity. To be resilient, GSM-R was decided to be a closed system, meaning that it should be restricted to solely rail communication and rail operators. The new system was limited to rail communication between train, rail communication network operators and traffic controls centers. The reason was to ensure contact in emergency situations and the priority of calls between traffic manager and engine driver. Commercial communication operators were offered the possibility to use the infrastructure to install their own antennas. However, this offer has not been utilized.

#### 4.4 *Strategical success*

Strategical success comprises aspects like sustainability and relevance.

(1) Sustainability. After the implementation of GSM-R in 2007, some challenges are faced. Generally, this is related to resilience. One central aspect of resilience is redundancy. The interviews identified the fact that the existence of one GSM-R control center was too vulnerable in case of breakdown of the center. This resulted in building an additional center (after the GSM-R implementation period) to be used in such cases.

Further, the engine drivers report that they daily have used the same phones onboard since the implementation of GSM-R. They are solid and sustainable.

In order to be resilient, implementation of new technical equipment, GSM-R also had to be accompanied by organizational and cultural changes. New working processes implied specification of changed communication procedures. The engine drivers mention procedures like dialogue with the management center before every departure or reports about maintenance due to equipment errors or collision. Education and operational training in introduced to handle deviations and emergency situations.

(2) Relevance. Affected parties are for instance user of the infrastructure – traffic managers and train drivers. Related to safety, the traffic manager can immediately stop all trains by one keyboard pressure in case of a reported risk. In case of an emergency call from a train driver, the speed automatically reduces to maximum 40 km/h at the affected distance.

Further, the equipment is suitable to handle situations in case of signal errors. Redundancy is achieved by using the GSM-R communication equipment onboard. Instead of stopping at assumed signal failure, dialogue with the traffic management center is helping to clarify whether it is safe to proceed or whether an incident has occurred.

One drawback related to regularity is the need for maintenance. Five times per year the GSM-R center discontinue traffic due to maintenance. Some night trains must be cancelled. Another vulnerability is

disappearance of local electric power. Then the base station breaks down. Fortunately, this seldom occurs.

Relevance is also related to political decisions and priorities. GSM-R is a central as a basis in subsequent digitalization of the rail.

## 5 Discussion

The increasing use of resilience approach also imply an additional perspective to traditional risk management. In the definition presented in session 1, This section starts by some comments on this shift. Then the three main aspects of resilience are discussed; to 'absorb shocks', 'ability to adapt', and 'ability to recover'.

### 5.1 Resilience understanding – A shift from reactive and linear to a proactive and holistic approach

During the last decade the use of the resilience concept has increased enormously. The concept of resilience has roots in many disciplines, and over 300 definitions are identified. However, these are phases or dimensions in most common definitions. European Commission (2018) tries to present an overview and classification of resilience understanding. The definitions may be classified relation to level of complexity (reductionism vs. holism) and conceptual orientation (outcome and capacity vs. process and capacity). For example, some definitions represent more linear models of actions in face of a challenging situation, while others address a view of holism and complexity.

Further, three separated, albeit partially overlapping domains of CI resilience have emerged: organizational, technological and societal (European Commission, 2018). The discussion in this paper relies on a definition emphasizing increased societal complexity. Hollnagel et. al (2015) argue that a resilient system should be related to performance and whether it can *"adjust its functioning prior to, during, or following events (changes, disturbances, and opportunities), and thereby sustain required operations under both expected and unexpected conditions"*.

The resilience paradigm implies a shift from a reactive to a proactive approach to safety. The message is to look for what goes well as well as what goes wrong (Hollnagel, 2015). We cannot make sure thing go right just by preventing them from going wrong.

### 5.2 Resilience - To what degree may GSM-R absorb shocks?

This aspect includes reactive and proactive barrier elements, and may be describes as: *"The ability of a system to prepare for, mitigate or prevent negative impacts, using predetermined coping responses in order to preserve and restore essential basic structures and functions"* (OECD, 2014).

GSM-R is a critical infrastructure, and as as a technical system, resilience are related to e.g. the ability for physical absorption of energy. In a sense we can say it does. The equipnet make it possible to slow down the engine speed at once in the case of an alarm or information of obstacles on the track.

Further, GSM-R may prevent one fatal accident type – train collisions. The most frequent cause of fatal train accidents is signal passed at danger. This was also the case in the Åsta accident. GSM-R may serve as a barrier element.

In addition to technical resilience, resilience should also include organizational and societal perspectives. Organizational resilience includes the question regarding prevention and the ability to foresee and avoid incident/ accident. In addition to being physical, barriers may be non-physical including organizational and human elements. During the implementation phase of the GSM-R, the project organization met this challenge by building a parallel organization to handling the new, digital infrastructure. Gradually this replaced the old organization responsible for the old and analogue system.

The results further indicate that adjustments were needed after the implementation phase. Procedures, work processes, inspection and training had to be gradually adjusted and developed during and afterwards.

### 5.3 Resilience – How are the ability to adapt?

This question regards the ability to prevent an incidence from becoming worse, or 'cope with ongoing trouble'.

The results indicate that this to some extent may the case for technical resilience. The traffic manager may communicate with the engine driver and call attention to obstacles like animals, people or obstacles on the track. Further, pushing the emergency button automatically slows down the speed of trains in the actual located area.

According to Hollnagel et al (2015) in order to improve it must be legitimate to within an organizational culture to allocate resources to reflect, to share experiences and to learn. The GSM-R organization has created educational and operational training arenas for this. As society and technical changes are common, such arenas should develop further and cover reflection both on past, current and future safety challenges. Operational measures should consider, prepare for and adjust everyday performance to expected and unexpected condition, including so-called 'black swans'. Black swans refer to rare and unpredictable events (Taleb, 2007). The preparation to cope with black swans will require a holistic, interdisciplinary and intercultural approach (Stene et al, 2016).

#### 5.4 Resilience – To what degree have GSM-R improved the ability to recover?

This question is related to the ability recover once an incident/ accident has happened, or 'repairing after a catastrophe'.

The results indicate that the infrastructure is well functioning in case of emergencies. One challenge to many CI infrastructures is that privately owned and operated information ITC companies get the responsibility to for services (European Commission, 2018). The government will not have the control while private industry has access to necessary technical capabilities and information pertaining to the CI. Government then either has to provide necessary resources itself or to increase regulation. In case of the GSM-R implementation, operation and maintenance, the government chose to have control. In this sense they can control access and be more resilient. The communication network is strictly used by train operators. This means that the control centers and engine drivers are interconnected and may easily come in contact and communicate directly with each other. They will not be disturbed by passenger calls or overload by other phone calls.

Sustainability requires regular and safe operations under both expected and unexpected conditions. However, to recover and to bounce back. Challenges in case of a train accident to respond and recover is related to the consequences and what is damaged. This is the case of key personnel and technical equipment. The train have to be able to handle the situation, and it is critical or difficult if e.g. the engine driver is badly hurt or killed. The same is the case if the train itself or the communication equipment is damaged in an accident.

## 6 Conclusion

### 6.1 The evaluation model of CI implementation

The evaluation is based on a Norwegian model for post-evaluation on CI projects. Based on the experiences from this project, the model is regarded a useful evaluation tool. It is important that the evaluation is carried out some time after the implementation phase is finished.

The model covers six general evaluation criteria: (1) Efficiency covers the project's outputs in terms of cost, time and quality. (2) Effectiveness includes whether the project has contributed to these outcomes. (3) Other impacts include all effects beyond the intended effects (the outcome). (4) Relevance concerns the need for it. (5) Sustainability calls attention to whether positive effects are likely to persist throughout the expected lifetime of the infrastructure. (6) Socio-economic efficiency.

One question is whether this model is suitable and adequate to measure resilience, or if new resilience guidelines, measurements and tools should be added.

Resilience focus on safety management to cope with complexity under pressure, and where the purpose is to achieve dependability, safety, continuity and regularity.

### 6.2 Resilience assessment and the Concept evaluation model

The resilience concept has become increasingly used in relation to CI safety in several domains and management levels. However, still it is necessary to develop a framework systematically relating concepts and methods to their relevant scope and domain of application (European Commission, 2018).

The Concept Post-evaluation model is relatively new. It focuses on effects of CI investments. The model could benefit from expanding the scope to a greater extent include questions regarding why effects are reached or not. The work environment is becoming increasingly complex and unpredictable. One should pay attention to how they work. Performance adjustment and performance variability - 'work as done' - are thus both normal and necessary for a system to function. It is important to pay attention to how routines and procedures work in everyday practice at the front-end.

Regulations, standardization and procedures describe 'work as imagined' and when things function and/or as expected. In addition to focus solely on severity, a resilience approach would recommend to study frequent and normal performance which go right, and to learn from them. Risk management focus on maintaining capacity to control and deal with adverse events. Innovations are required to deal with new types of crises (European Commission, 2018). These innovations may complement existing capabilities. Thus, plans and procedures should address both expected and unexpected situations that challenge established responses.

Disaster management addresses both prevention, preparedness, response and recovery (Hollnagel et al, 2015). In addition to the crash phase, resilience covers both the pre- and post-crash phases, and accordingly proactive and reactive barriers.

GSM-R may increase the safety of the technical system, safety culture and human operators. However, implementation of the new technical, digital system was not enough in itself. Additional measures were necessary, including development of a new operation organization, work processes and procedures, in addition to education programs and operational training.

The GSM-R infrastructure has contributed to increased resilience. Especially this seems to be the case in in order to reduce the consequences in the emergency phase. However, the infrastructure and the associated organization also seems to have increased the ability to prevent incidents and to recover from dangerous situations.

### 6.3 Safety and regularity - Future digitalization of the rail

The GSM-R is one of the basic components and communication base in the recent implementation of ERTMS (European Rail Traffic Management System) which is a common signaling system standard. One aim is that GSM-R is used to send and receive all information (inclusive safety critical information) necessary to keep train traffic schedules. Based on a study after the implementation of GSM-R, the resilience of the system has improved including both safety and regularity (Johnsen & Veen 2013). Risk assessment was performed in 2008 and 2010, and here resilience was explored as a strategy to improve safety, security and quality of service. The results indicated improved knowledge of emergency responses. In addition, high stability of the GSM-R system supported safety of operations, despite a fire incident in 2010. Delays had been minimal, and no accidents had happened due to GSM-R.

One requirement of implementation of new CI rail systems is that increased regularity shall not reduce safety. On the contrary, safety should not be sacrificed in the need for increased regularity.

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