# A New Classification of Risk-Reduction Options to Improve the Risk-Reduction Readiness of the Railway Industry

Eberechi Weli, Michael Todinov



***Abstract*—**The gap between the selection of risk-reduction options in the railway industry and the task of their effective implementation results in compromised safety and substantial losses. An effective risk management must necessarily integrate the evaluation phases with the implementation phase. This paper proposes an essential categorisation of risk reduction measures that best addresses a standard railway industry portfolio. By categorising the risk reduction options into design, operational, procedural and technical options, it is guaranteed that the efforts of the implementation facilitators (people, processes and supporting systems) are systematically harmonised. The classification is based on an integration of fundamental principles of risk reduction in the railway industry with the systems engineering approach.

This paper argues that the use of a similar classification approach is an attribute of organisations possessing a superior level of risk-reduction readiness. The integration of the proposed rational classification structure provides a solid ground for effective risk reduction.

***Keywords*—**Cost effectiveness, organisational readiness, risk reduction, railway, system engineering.

## I. Case for Effectively Implementing Options for Risk Reduction

A Considerable amount of effort is expended on planning, evaluation and management of potential risks prior to the selection of risk-reduction options.

The selection of risk-reduction options would normally be preceded by a process of cost and benefit evaluation. In practice, the selection of risk-reduction options is constrained by fixed budgets. The greatest challenges of introducing and effectively managing risk-reduction options are the novelty of the option; the complexity of each risk reduction option; and the integration issues. The integration issues include (i) the interaction between subsystems to achieve risk reduction, (ii) the correlation and interaction among the risk reduction options and (iii) the correlation and interaction between the risk-reduction options and the environment. A comprehensive understanding of the limitations and strengths of each option for the specific application is a prerequisite for effective overall risk reduction. For major railway projects with multiple risk reduction options, the key to effective risk reduction lies in the successful integration of the available options. During the implementation phase, the integration of several options has the potential to expose an organisation to unanticipated problems and vulnerabilities. These problems are further compounded by an inefficient organisation. This paper argues that a well-structured decision-support technique for selecting risk reduction measures must necessarily consider the organisational readiness to implement them, as an integral part of the risk options selection and evaluation. As a result, effective risk reduction during the "evaluation and selection" of risk-reduction measures benefits immensely from a systematic approach that considers the organisational readiness and structure.

There is surprisingly little research on the risks involved with the implementation of risk-reduction measures within the railway organization. Current studies, mostly organisation's internal risk management practices are limited in scope and cannot be generalised. In addition, there are no standard *measures of effectiveness* for the implementation of risk reduction options, not until an accident occurs. Most ALARP or risk management studies have been limited to identification, evaluation and options selection without any supporting analysis on the applicability of the selected options within the railway organization. Any knowledge in this area is hardly ever recorded and definitely not incorporated in existing safety and business cases, despite the potentially severe financial and safety consequences. The existing safety and business cases do not analyse the risk reduction measures in relation to their mutual correlation, suitability and impact for the organisation. Without an organisational readiness to support effective implementation of the selected risk-reduction options, the existing safety and business cases are inadequate and weak.

## II. Risk Reduction on Large-Scale Engineering Projects

To address the potential challenges posed by the implementation of the risk reduction options on the railway industry, a thorough understanding of similar challenges from large-scale engineering projects is necessary.

As established by [1], hardly any publications exist on the effect that strategy, structure, processes and projects have on one another. The paper further argues that an integration of strategy, structure, processes and projects is required to facilitate the effective development of a business. In earlier work, [2] points to the integration of organisational structure, control and prioritisation as three critical areas necessary for effective risk reduction within large and complex engineering projects.

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The key relationships between design, implementation and operational losses have been addressed in [3], [4] and [5]. Reference [6] defines risk on large engineering projects as the possibility that events, their resulting impact and dynamic interaction may turn out differently than expected. The risk of project completion is further broken down to technical, construction and operational risks. A study on how design errors can severely jeopardise safety and contribute to failures in construction and engineering projects, with devastating economic, environmental and social consequences is presented by [7]. Design errors are described as a symptom of dysfunctional organisational and managerial practices. Reference [8] states that comprehensive product description and product requirements are essential influences on the risk patterns of IT organisations.

By comparing product architecture to organisational structure, [9] describe the failures in large-scale product development processes as a misalignment of the organisation to the product and points to two fundamental challenges: (i) the assignment of people to parts and subsystems that make up the product and (ii) the effective collaboration in the performance of design tasks. This is further supported by studies on railway organisation failures, primarily as a result of the misalignment between architectural/technical interdependence and organisational communication [10]–[13].

The risk of failure of large projects is a direct function of the level of interdependency among numerous parameters such as time, cost, scope, safety, environment, security and health. Within a project, the existence of interrelated risks, naturally results in triggering one risk from another risk and creating propagation phenomena such as reaction chains, amplification chains and loops. Using the network theory-based analysis, [14] proposed a risk reduction technique for reducing the risks of failure within large projects. The paper also states that the risk of failure is caused by the lack of capacity to anticipate and control complex interactions. References [15]-[17] share the same view. However, [18] goes further by proposing that the key factors that drive complexity are project size, variety, interdependence and context.

The underpinning requirement for an effective organisation is that the organisation must successfully assimilate and implement technology and manage interactions between the source and the recipient of technology. The capacity to efficiently act on knowledge is argued to be a critical activity that determines the readiness and value of an organisation's structure [19]. To build on this point, it is important to note that any effort towards risk reduction must comprehensively consider the source of risk and the receiver, before any claims for effective risk reduction can be made. According to [20], the primary causes of failure for major engineering projects are: *the lack of understanding of users' and operational needs, poor staffing decisions, tight schedules and extensions to the functionality of an existing product without a comprehensive understanding of the technical challenges*.

The studies on the effectiveness of technology innovation, implementation and risk reduction have accumulated and advanced over a number of decades. The partitioning and interdependency of risks associated with the conceptualisation phase and the execution phase is best presented by [21]. Innovation is partitioned into an initiation phase and an implementation phase [22]. Within an organisation, high complexity, high diversity, low formalisation and low centralisation are most conducive during the initiation phase, whilst low complexity, low diversity, high formalisation and high centralisation are most conducive at the implementation stage. In line with this theory, [23] demonstrate the potential constraints arising from inadequate specific knowledge of the project and the mutual self-reinforcing relationship between organisational structure and project. Later studies by [24] also pointed out that organisational structure, corporate culture and people are primary risks.

The risk of failure during implementation is three-dimensional in project size, experience with the technology and organisational structure. [25], [26] cite amongst other factors, the lack of organisational adaptation to complement technological change. An example of inappropriate applications is introducing new trains in small tunnels when it would have been easier to introduce advanced vehicle controllers only, at a cheaper price. Other important factors contributing to the risk of failure are the lack of skills to support implementation and the lack of exploration of a wide range of options.

These studies clearly indicate that the organisational structure is impacted by the risk reduction options selected and vice versa. Consequently, for effective risk reduction, it is mandatory to establish the relationship between risk reduction at the initiation stage (i.e. the stage of identifying and assessing risk reduction options) to risk reduction at the implementation (operational) stage where there is a significant contribution from the organisation and users. Fig. 1 illustrates that weaknesses in the implementation phase could partially or fully compromise the high-level of potential risk reduction achieved at the initiation stage. In order to achieve and maintain a maximum risk reduction, the organisation must demonstrate readiness for acceptance and effective implementation of the risk reduction options identified at the initiation phase. These may include new techniques, technologies, processes etc.

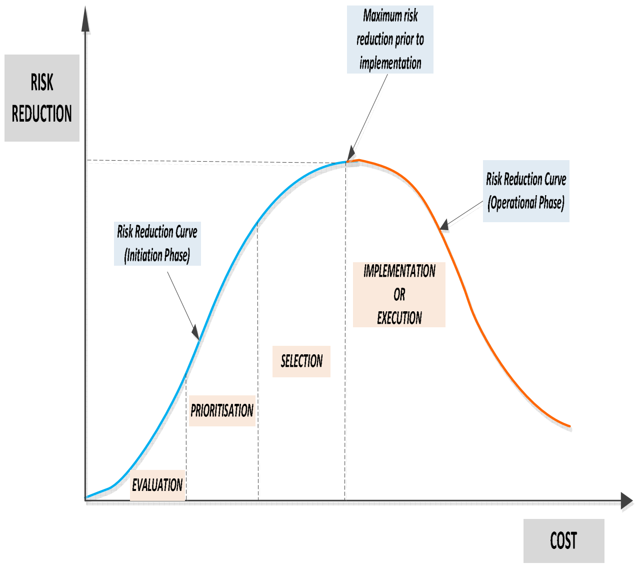


Fig. 1 A risk Reduction Curve due to a poor implementation of the risk-reduction options selected at the initiation stage

## III. Organisational Readiness – Complexities and Management

Within an organisation that controls risks, ambiguous specifications and requirements for risk reduction, lack of clarity on the inter-relationships between risks, risk reduction options and the associated functions are major factors impacting effective risk-reduction. The issues related to managing multiple projects such as project prioritisation, selection and resource allocation in multi-functional organisations, are well defined in [27]-[30]. These issues are very similar to managing and implementing multiple risk reduction measures.

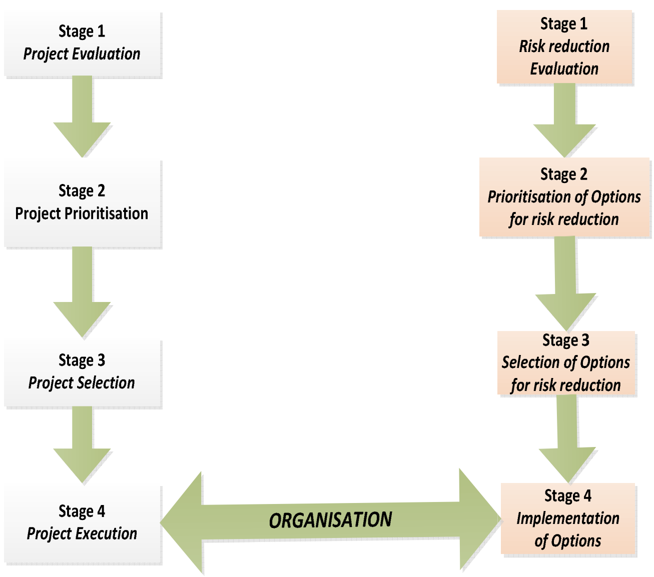


Fig. 2 Parallelism between the implementation of multi-functional projects and the implementation of risk reduction measures

The left-hand side of Fig. 2 illustrates the key stages of effective management of projects. The essential stages in the implementation of risk reduction measures are provided in parallel (the right-hand side of Fig. 2). The diagram clearly illustrates an existing parallelism between the two. The benefit from an improved organisational readiness has another, very important dimension - the capability to address unanticipated risks. Apart from operational circumstances that can be foreseen, there are also unforeseen risk events which are the product of unforeseen operational circumstances. These circumstances cannot be predicted, they are "unknown unknowns" or "black swans" [31]. We never know exactly what they are, but we do know they might occur. Improving the risk knowledge, the safety culture in the organisation and the level of general risk protection measures are effective barriers to unknown unknowns.

*A change in the organisation structure may be necessary to effectively implement particular risk reduction options.* This is for example the case when considering two options to eliminate wrong-side failures (i.e. failures leading to catastrophic consequences) for spring-applied parking brakes by (i) enhancing testing and maintenance regimes or (ii) by replacement with new braking systems. Selecting and implementing enhancing testing and maintenance regimes for example, requires specific organisation changes, (such as developing an organisation with emphasis on maintenance and testing rather than one with key expertise in design and manufacturing) if the measures are to result in maximising risk reduction. These organisational changes are driven not only by cost considerations. More importantly, these organisational changes are the only way to guarantee that effective risk reduction will be maintained through the life of the operation. In common industry practice for selection of risk-reduction options, no publication, significant work or structured guide exists beyond the standard risk evaluation methods based on cost-benefit analysis (CBA). In fact, the existing approach does not consider the organisational structure (people, processes and tools/equipment) and its preparedness for the selection, evaluation and implementation of the risk reduction measures. The consequences of the lack of appropriate structure to support and maintain the maximum risk reduction are:

- Incorrect evaluation of risk-reduction options, which subsequently resulting in:
  - Reduced safety levels
  - Increased implementation costs
  - Inaccurate prioritisation of the risk reduction measures
  - Incorrect estimation of residual risks
  - Inaccurate risk profile
- Misalignment of selected risk-reduction options with the organisational capability and management structure, which leads to
  - Increased risk of failure to gain approval for the selected risk-reduction measures
  - Increased implementation costs
  - Inadequate implementation leading to degraded safety levels

Considering these consequences and existing practices, railway organisations typically have four distinct levels of readiness for implementing risk reduction. Table I presents the Risk-reduction readiness levels for railway organizations.

TABLE I
CLASSIFICATION OF RAILWAY ORGANISATIONS ACCORDING TO THEIR LEVEL OF RISK REDUCTION READINESS

| Risk Reduction Readiness Levels | Strategy | Description |
|---|---|---|
| Level – 1 | Reactive level | No risk reduction strategy. Reactive approach to risk management (dealing with risks as they materialise) |
| Level – 2 | Basic level | Basic risk reduction based only on qualitative assessment and measures (e.g. by using risk matrix) |
| Level – 3 | Normative level | Risk reduction based on cost-benefit analysis which involves quantification of risk reduction options in terms of benefit and cost).<br>No methodology for selecting risk-reduction options. No consideration of the interaction among risk reduction options. No optimisation in selecting the risk reduction options. No consideration of the impact of the selected options on the organisation and the environment. No consideration of the required organisational changes needed for the implementation of the selected options. |
| Level – 4 | Optimal level | Risk reduction is based on a systematic approach impacting both the risk option selection, the precise quantification of removed risk and the optimal selection of risk reduction options.<br>The impact of the selected options on the organisation and the environment is part of the analysis. The required organisational changes needed for the implementation of the selected options are carefully considered and specified. |

Organisations at Levels 1 to 3 do not provide any support to maximising the risk reduction within fixed budgets. This increases the organisations' vulnerability to inaccurate assessments of risk and selecting weak and inefficient risk reduction options at escalating costs. The proposed classification, based on the fundamental principles of risk reduction and systems engineering is an initiative with the potential to provide a Level-4 framework that supports risk evaluation, optimal options selection and ultimately permits organisations to maximise risk reduction within fixed budgets. The proposed also bridges the gap between evaluation and selection of risk reduction options and specifying adequate organisational structure for their effective implementation.

## IV. SYSTEM ENGINEERING APPROACH TO RISK REDUCTION IN A RAILWAY ORGANISATION

By definition, the system engineering approach to risk management must ensure effective risk reduction for any major railway renewal or developmental project.

During the initiation or concept phase, the risk reduction evaluation effort is determined by a complete and well-defined set of safety requirements. The specification of requirements must identify potential stakeholders. This ensures that the proposed solution is not only cost effective (i.e. feasible and affordable), but also guaranteeing the required levels of safety. On a large and complex project, the primary requirement for maximum risk reduction within a fixed budget is that the selection of risk reduction measures complies with the risk reduction potential and the budget constraints. This also requires a methodology that facilitates a comprehensive evaluation of the selected options. All operating modes (normal, degraded and abnormal) and the transitions between them should be considered. The way in which the systems will be operated, including the capacity and competence of personnel involved, operational arrangements and processes need to be fully understood in order to address the full set of possible operational scenarios. The integrated systems participating in the risk reduction exercise are a complex combination of people, processes and supporting structures (i.e. equipment or tools), whose interaction must be understood in order to achieve efficient risk reduction.

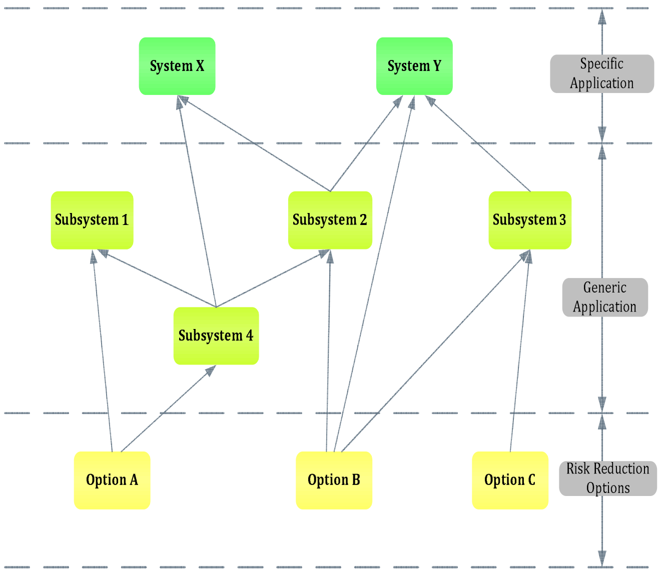


Fig. 3 Systems engineering approach to risk reduction

## V. THE INTER-RELATIONSHIP BETWEEN RISK EVALUATION AND RISK REDUCTION IMPLEMENTATION

The introduction of new techniques, technologies or processes into the railways is usually associated with complexity and uncertainty. Reference [32] qualifies projects as *dynamically* or *structurally* complex and broadly dependent on project elements and interactions that are subject to change. This results in unpredictability, uncertainty and emergent behaviours. Structural complexities on the other hand, are quantifiable and predictable which provides an opportunity for better management. Reference [33] provides insight into the complexities and uncertainties involved in the risk reduction and effective management of large railway projects, in cases where there is predictability and in-built flexibility in the organisational structure.

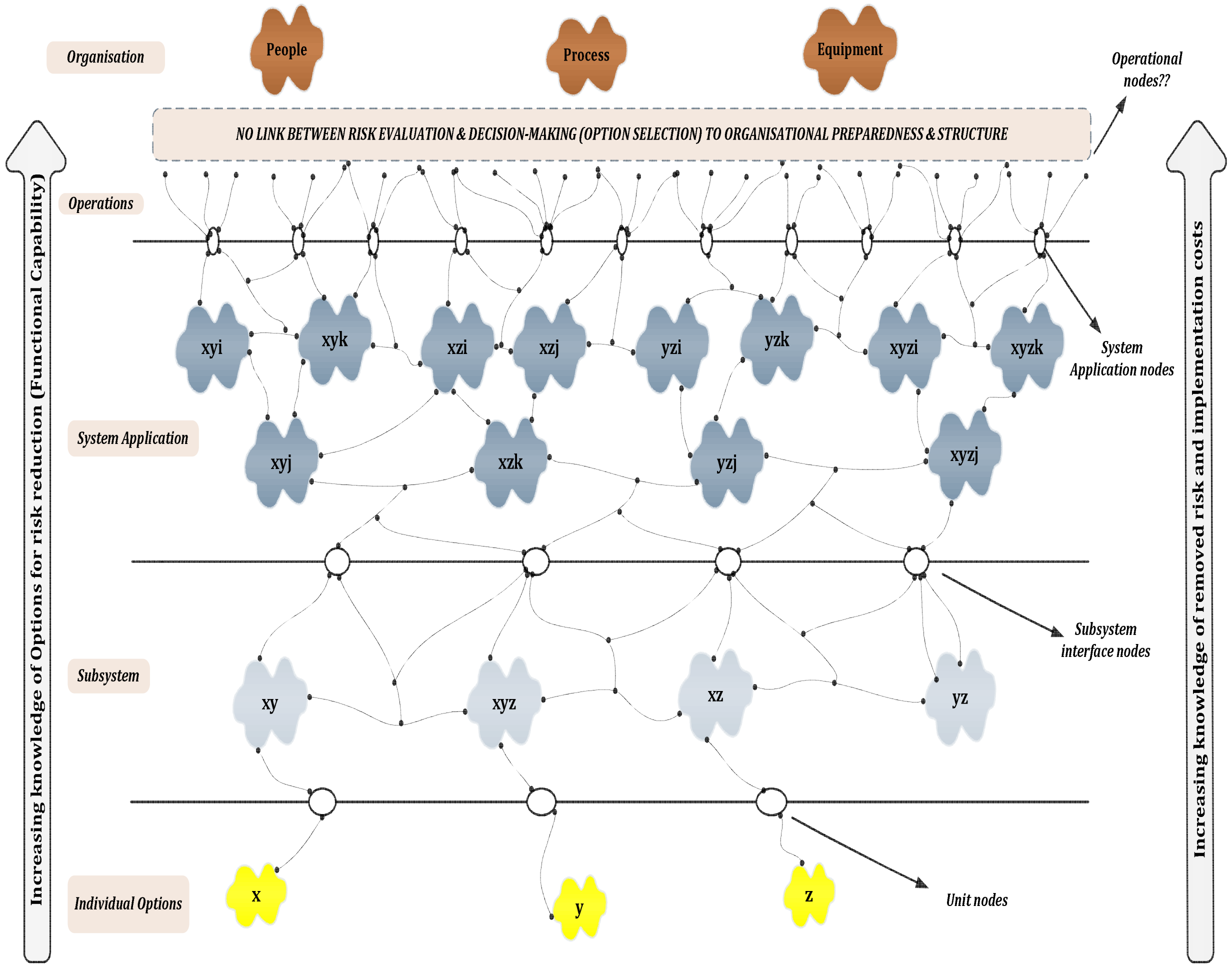


Fig. 4 A system analysis is necessary for the effective implementation of the selected risk reduction options

Fig. 4 provides a simple illustration of the interactions and dependencies between risk reduction measures and the application environment which includes people, processes and equipment necessary for effective implementation. Fig. 4 raises a fundamental question – is the railway organisation adequately prepared to facilitate the implementation of the selected risk-reduction options? In the current system, there is no link between the evaluation phase and the implementation phase of risk-reduction.

A simple practical illustration is the application of a number of risk reduction options to reduce the *Collision Between Trains* accident. The options are generally classed as (A) *brake assist systems*; (B) *collision warning systems* and (C) *intelligent speed adaptation systems*. Options A, B and C achieve the risk reduction because of their inherent operational characteristics. In practice, these options are not mutually exclusive and an investment in all options (A, B and C) is often required to achieve effective risk reduction. While for risk reduction options which are relatively independent, the application of dynamic programming techniques is fully justifiable and leads to a significant risk reduction within a fixed budget [34], additional (systems) analysis is needed for correlated risk reduction options. In cases where some of the options are incompatible (cannot be applied simultaneously) or in cases where the effective risk reduction from the application of one option requires the application of another option, the blind application of standard optimisation tools may not result in the expected risk reduction.

The limitations, the required conditions and existing interactions among the risk-reduction options should be thoroughly understood and accurately specified.

Additional risk reduction options, typically introduced in railway safety to reduce the Collision Between Trains accidents include: extension of signals, train movement rules, incident response systems, train driver training, speed restrictions, wheel-slide protection systems, In-cab design modifications, operational testing and maintenance, emergency timetables, track inspections and refurbishment, one-person (driver) operated closed circuit television, etc.

Following this understanding, a number of additional measures can be combined with the selected options A, B and C to achieve a significant risk reduction:

*Option A: Brake assist system + (operational testing and maintenance, train driver training, one person-operated closed circuit television)*

*Option B: Collision warning systems + (train driver training, in-cab design modifications, speed restrictions, emergency timetables)*

*Option C: Intelligent speed adaptation + (Train movement rules, wheel-slide protection, extension of signals, emergency timetables)*

For example, investing in brake assist systems (Option A) without investing in operational testing and maintenance does not permit obtaining a long term risk-reduction benefit from investing in expensive brake assist systems. Risk reduction Option A requires also investing in testing and maintenance if a long-term risk-reduction effect is to be achieved.

Similarly, investing solely in collision warning systems (Option B) without simultaneously investing in driver education and training does not permit obtaining the risk reduction benefit from applying solely to Option B. As a result, if Option B is to have a tangible risk-reduction effect, investment in another risk reduction option ("driver training and education") is required. In fact, without driver training and education, there may not be any risk reduction benefit from purchasing expensive collision warning systems.

By considering these interactions as important factors in the risk reduction exercise, the safety and business case claims for risk removed and cost effectiveness can be justified and further enhanced to support their acceptance and successful implementation.

By revealing the complex interrelations among the risk reduction options, the gap between risk evaluation, options selection and implementation (i.e. costs, people, process and equipment) can be effectively closed. The adoption of the systems approach provides coordination between people, processes and equipment at the implementation phase, where the organisation plays a crucial role in the risk management process. In this sense, the systems approach provides a bridge to the organisation structure.

## VI. A New Classification of Risk-Reduction Options

As established, integrating risk evaluation with the primary operational functions is a fundamental requirement for successfully making the case for the selected options. This requirement is especially applicable to industries where risk management drives investments and decisions. References [35] and [36] expound on the topic related to effective management of operational risks. These risks are defined as event risks and to effectively handle the risks of potential losses, categorisation of events is necessary. This serves as a receptacle for accident data gathering on frequencies and costs. A tentative categorisation for managing potential operational losses is further provided as People, Processes, and Systems.

The Railways and Other Guided Transport Systems (Safety) Regulations 2006 [37] require that the infrastructure operator and maintainer of the railways demonstrate how safety risks will effectively be managed and whether the infrastructure operator and maintainer have the ability, commitment and resources to comply with the regulations. This is generally addressed by *(i) demonstrating capability, commitment and availability of resources to manage safety risks; (ii) the safety case which provides a framework against which regular assessments, risk control measures and management systems are established and maintained (ii) the safety case assures regulators that the risks associated with operations have been assessed and all reasonably practicable controls have been implemented to reduce the risks.*

The areas that are considered safety-critical and have a direct impact on the successful prevention of accidents on the railways are typically *signalling and train control (communication systems); train driving and train operations; train manufacture, maintenance and refurbishment; installation, renewal and maintenance, faulting and inspection of infrastructure; safety of passengers on trains; passenger and visitor movement on stations and platforms; on-track machine manufacture, maintenance and refurbishment.* The major accidents that are to be reduced are attributed to risk of derailment, risk of collision between trains and risks related to the passenger train interface.

Following the argument that effective risk management must necessarily integrate the initiation (evaluation) phase with the implementation phase, we propose a categorisation of risk reduction measures that best addresses a standard railway industry portfolio. The introduction of a structured approach based on categorising the options for reducing major accidents, reflects the standard railway organisational structure. By categorising the risk reduction options into *design, operational, procedural and technical options*, it is guaranteed that the efforts of the implementation facilitators (people, processes and supporting systems) are systematically harmonised. The categorisation effectively simplifies a complex register of risk reduction options and combination of options into a format that reflects the typical railway organisational structure and helps reduce the gap between the evaluation and implementation phase.

The categorisation includes:

- *Design risk-reduction options (DRRO)* – Novel systems, major renewals and modifications
- *Operational risk-reduction options (ORRO)* – Communications, Supervision and Speed Restrictions or similar operational decisions
- *Technical risk-reduction options (TRRO)* – Testing, Maintenance, Inspections, Installations, Assessments / Studies informing risk reduction decisions
- *Procedural risk-reduction options (PRRO)* – Risk education, Risk training, Processes and Plans

Each risk reduction option, within each group, is based on sound engineering principles for risk reduction. The effectiveness of each of these options has been proved by theoretical considerations, reliability and risk modelling, field testing and historical track records. The introduction of these options reduces the complexity of selecting risk reduction options for different applications. At the same time, the classification guarantees that no efficient risk-reduction option is missed at the evaluation phase. Consequently, this classification will be particularly useful for major railway projects with numerous possible risk reduction options, typically reflecting all aspects of the standard railway organisational operations including: design, maintenance, testing, new technologies etc. combined with people, processes and equipment. Table II presents a structured categorisation that supports the option selection and the evaluation of individual options and combination of options. The systematic process of categorising the risk reduction options and aligning them with the existing organisational functions also supports the identification and assignment of responsibilities for effective implementation. Table II and Fig. 5 also illustrate the relationship between the major accident hazards, risk reduction measures and the direct link with the organisational instruments – people, process and equipment. Fig. 5 also depicts the role of the proposed categorisation in the relationship between these, for effective risk reduction.

The clear outline of the roles and responsibilities within the risk reduction exercise ensures that resources such as finances, technical expertise, information, systems and equipment, medical facilities etc., necessary for implementing the measures are available and appropriately targeted. In the risk reduction effort, undertaking emergency and preparedness planning, immediate post-accident actions and response is absolutely essential. The inter-relationships between departments, participating in the risk reduction operation, can be used for developing measured strategies for accident prevention and protection. Throughout the project lifecycle, the clearly defined inter-relationships between departments ensure that the railway operations also make it possible to take advantage of the many technical resources that already exist within the organisation. By reflecting the typical railway organisational structure, the proposed categorisation makes it possible to tap into the existing resources within the organisation.

TABLE II
CLASSIFICATION OF RAILWAY ORGANISATIONS ACCORDING TO THEIR LEVEL OF RISK REDUCTION READINESS

| RISK REDUCTION OPTIONS | EXAMPLES OF RISK REDUCTION OPTIONS | KEY FUNCTION(S)FOR IMPLEMENTATION |
|---|---|---|
| **DESIGN OPTIONS (DRRO)**<br>Novel Systems, Major Renewals, Design Modifications (Capital Intensive Projects) | 1. Signalling replacements and modifications - automatic signalling and control systems<br>2. Optimising cab design for driver protection | Chief Engineer, System Integration, Programme Directorate, Project Management |
| **TECHNICAL OPTIONS (TRRO)**<br>Testing, Maintenance, Inspections, Installations, Assessments/Studies | 1. Improving inspection, testing and maintenance regime for detection of wheel flat and worn wheels<br>2. Signal positioning studies and potential extension of distances between signals | Technical Assurance, Civil and Power Engineering, Signalling Systems Engineering, Train Systems Engineering, Asset Management |
| **PROCEDURAL OPTIONS (PRRO)**<br>Risk education and training, Processes and Plans. | 1. Risk education and training of key personnel<br>2. Amendments to train despatch rules<br>3. Review and improvement of recruitment and selection processes | Infrastructure and Systems Protection, Training Management or Organisational Development. |
| **OPERATIONAL OPTIONS (ORRO)**<br>Communications, Supervision and Speed restrictions | 1. Crowd Control<br>2. Speed restrictions (adhesion) | Operational Engineering, Telecommunications Systems Engineering |

The proposed classification promotes a comprehensive understanding of the risks resulting in an accident and provides a strong support to the *Lessons learned database*. It provides a direct and strong support to the comprehensive check lists related to known accident scenarios which is an important tool for identifying possible accident and failure scenarios. The proposed methodology also draws on concepts from organisational theory and optimization of risk reduction as introduced by [38]. However, by considering the intricate interrelations between risk reduction options and the organisational interdependences, it goes beyond the development in [38] and promotes a novel framework that bridges the divide between the identification and implementation of risk reduction measures within railway organisations.

## VII. Readiness for Effective Risk Reduction

A significant amount of effort towards risk reduction in the railway industry is associated with major renewal projects. The renewal projects are usually large-scale engineering undertakings which provide the railways with necessary modifications and improvements. Along with reducing particular risks, these projects introduce new risks to railway operations. Consequently, essential risk reduction measures are considered and implemented to ensure that the safety integrity of the railways is not compromised, and where possible, improved. The new risks are the result from altering fundamental operational parameters such as *increasing number of trains to cater for a greater passenger volume* or *the removal of speed limits to meet operational schedules*. The situation is complicated considering that these changes are weather-dependent – they are different during different times of the year. The challenges facing the railway industry are the unrelenting pressures to reduce cost, improvements for customers and pressure to maximise the use of the asset base.

However, the organisational changes and modifications, every time a big renovation project is initiated are very costly. A railway organisation that has not taken the necessary steps to a dynamic and flexible organisation in relation to risk reduction, easily incurs significant implementation costs. The significant increase in implementation costs usually deters the selection of appropriate risk reduction options to achieve a maximum risk reduction.

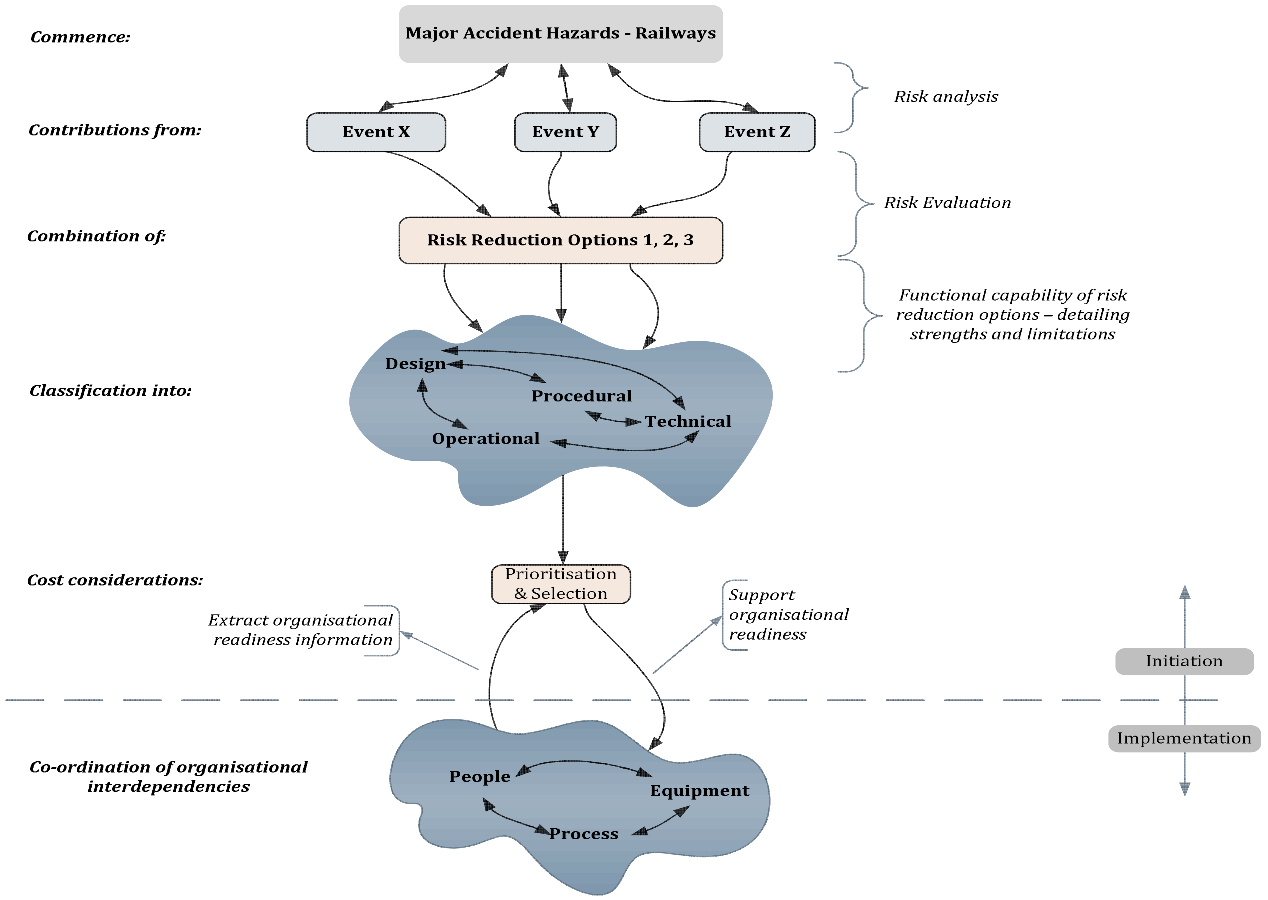


Fig. 5 Categorisation of risk-reduction options, risk management and the organisation

By adopting the proposed categorisation technique, the organisation is less likely to invest in new organisational development and re-structuring schemes that facilitate the required modifications. The assurance of organisational readiness prior to gaining approvals to operate is significantly strengthened by the comprehensive decision-support framework provided by the proposed categorisation. Essentially, it is recommended that to achieve a maximum risk reduction within financial constraints, the concept of *"Readiness for effective risk reduction"* be stipulated as a fundamental process requirement in railway safety cases.

It is essential, that modifications and potential changes to the operating parameters leading to modifications are properly assessed and do not necessarily impose fundamental changes to an existing railway organisation. Without the structure proposed, any rapid evolution of the railway organisation will absolutely result in excessive implementation costs. By improving an organisation's readiness to implement effective risk reduction, significant costs and improved safety levels can be secured.

The DOPT methodology requires a thorough understanding of the budget allocation methodology. This means that as a minimum, the capability of the measure of reducing the likelihood of the accident or the consequences following an accident to be thoroughly understood. The DOPT methodology provides the framework for reducing the duplication of effort as it supports further considerations of whether the organisation or specific departments within the organisation are better placed to implement the risk reduction measure or combination of measures for any particular risk. The DOPT concept creates also a common risk-reduction platform between departments to ensure synergy in the risk-reduction effort. It supports technical co-operation for the effective use of preventive and protective risk reduction measures to effectively achieve minimisation of railway safety risks. It facilitates establishing and implementing robust accident prevention programmes and mitigation against consequences of an accident.

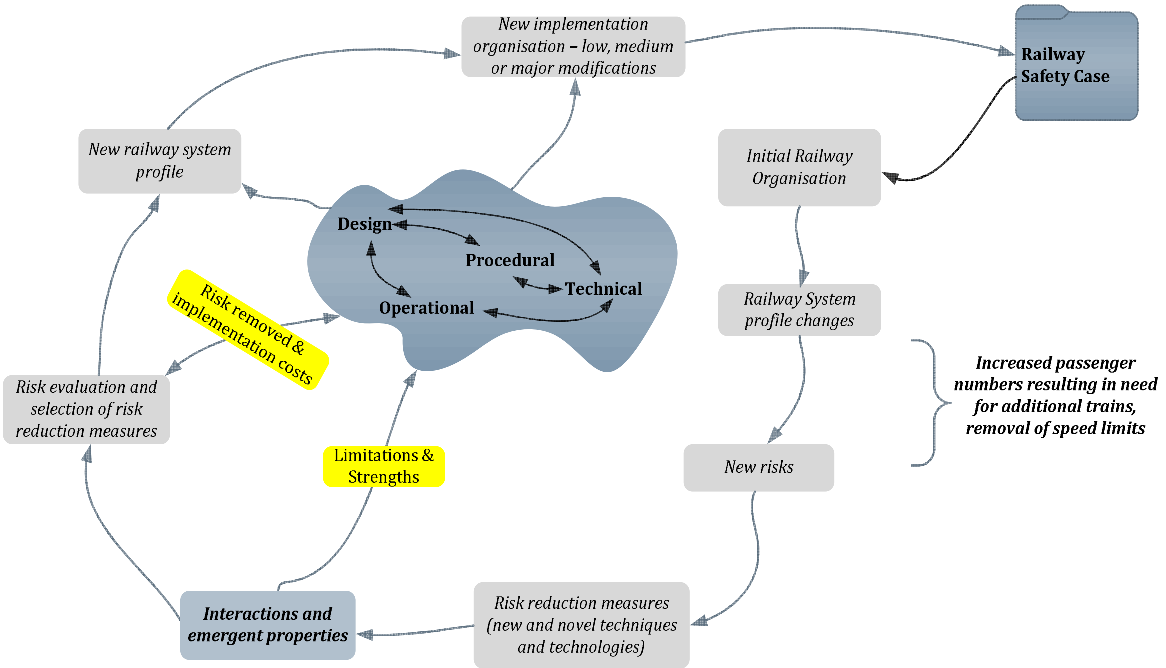


Fig. 6 New operational modifications and the process of risk reduction associated with the new risks

## VIII. Conclusions

1) The paper introduced the DOPT classification, derived from basic principles of risk reduction and systems engineering, to address the existing gap between the initiation (evaluation) phase of risk reduction options and the implementation phase. The DOPT methodology creates a common categorisation of risk reduction measures that best addresses a standard railway industry portfolio.
2) The DOPT concept permits effective planning of human resources, spheres of responsibilities and equipment engaged in the risk reduction effort, considering the capabilities of the railway organisation. The clear outline of the roles and responsibilities within the risk reduction context ensures that resources such as finances, technical expertise, information, systems and equipment, medical facilities etc., necessary for implementing the measures are available and appropriately targeted.
3) The DOPT concept promotes a comprehensive understanding of the risks resulting in an accident. It provides a strong support to the Lessons learned database and the check lists related to known accident scenarios.
4) The DOPT concept eliminates the duplication of effort and creates a common risk-reduction platform between departments to ensure synergy in the risk-reduction effort and cooperation at all levels.
5) The DOPT concept is a framework necessary to provide a Level-4 framework that supports risk evaluation, optimal options selection and ultimately permits organisations to maximise risk reduction within a fixed budget. The use of a methodology similar to the proposed DOPT methodology is a characteristic of an organisation possessing a superior level of risk-reduction readiness.
6) In order to achieve a maximum risk reduction within financial constraints, the concept of "Readiness for effective risk reduction" must be stipulated as a fundamental process requirement in railway safety cases. The integration of the proposed rational classification structure provides a robust and verifiable case for effective risk reduction.

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