Mindsets of Risk Acceptance in the Light of Vision Zero and Tunnel Safety

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Previous road tunnel fires in Europe have demonstrated the potential for major accidents. The main management principles for the Norwegian Public Roads Administration are founded on Vision Zero and Directive 2004/54/EC. As a road safety philosophy, Vision Zero states that nobody shall be killed or seriously injured in road traffic. Directive 2004/54/EC is implemented in the Norwegian regulatory framework, providing certain minimum requirements and the use of risk assessment to enhance tunnel safety. By building so-called 'prescriptive regulations', the degree of flexibility allowed is limited, additionally being in conflict with Vision Zero and dynamic development. In this paper, we explore different mindsets of risk acceptance and assess the suitability of these in the light of Vision Zero. We have identified three main risk acceptance perspectives: a mechanistic approach to the use of risk acceptance criteria, risk acceptance criteria as a guide or reference in the judgement of acceptance, and a dynamic approach to risk acceptance and safety. Our findings indicate that regulation of tunnel safety in Norway is more in line with a mechanistic approach than a dynamic approach. The Norwegian tunnel safety management approach thus requires a change in the way of thinking about risk acceptance, in order to take Vision Zero seriously.

Keywords: Tunnel safety, Vision Zero, systems safety, risk acceptance criteria, ALARP, safety constraints.

1. Introduction

The road infrastructure of Norway consists of more than 1130 tunnels. Among these, there are several long, steeply sloping tunnels, which are overrepresented when it comes to vehicle fires (Nævestad et al., 2016). In the event of a tunnel fire, road users may experience life-threatening issues, such as dense smoke and inhalation of toxic gases (Njå and Kuran, 2014). Even so, the construction of road tunnels is regarded as important to meet the growing transportation needs of most people and the business community. Thus, risk acceptance is an important aspect within tunnel safety management.

In 1999, the Norwegian Public Roads Administration (NPRA) adopted the concept of Vision Zero (Langeland, 2009). During recent decades, this concept has gained increased importance in the contemporary safety debate regarding regulation of road traffic safety.

As a road safety philosophy, Vision Zero is rooted in three values: the ethical principle, scientific-based knowledge and shared responsibility (Langeland, 2009). The scope of Vision Zero is to prevent future accidents, and, through the ethical principle, the vision states that the loss of human life and health in road traffic is not acceptable. In this, there is a commitment to a dynamic development of measures and new approaches to improve the traffic safety.

Additionally, Directive 2004/54/EC (European Commission, 2004) is implemented in the Norwegian regulatory framework, providing certain minimum safety requirements for tunnels in the Trans-European road network. The directive was developed in the aftermath of several devastating tunnel fire accidents in Europe.

Both the NPRA and Directive 2004/54/EC require the use of risk assessment to enhance tunnel safety. Traditionally, this is done by learning directly from experience and building so-called 'prescriptive regulations', which are intended to be universally or generally applied (European Technology Assessment Group, 2007). The problem with such regulatory systems is, however, that the degree of flexibility allowed is limited, in addition to being in conflict with Vision Zero's pillars and dynamic development.

Fischhoff et al. (1981) claim that acceptable-risk problems are decision problems, which require a choice among alternatives. There are no universally acceptable options. The choice of an

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option depends on the decision maker's set of options, consequences, values and knowledge. In the context of tunnel safety, where road tunnel fire is the main critical event, essential questions are: How do we determine acceptable risk? What risks do we evaluate as acceptable?

The objective of this paper is to explore different mindsets of risk acceptance. Thereby, and in the light of the Vision Zero principles, the goal is to identify dominating mindsets of risk acceptance in the context of the Norwegian approach to tunnel safety. By *mindset* we mean a way of thinking which may promote change.

The paper is organized as follows. In chapter two, we describe different risk acceptance perspectives, i.e. choice of method or measures to solve a problem. Then, we look more closely into the concept of Vision Zero in chapter three and the Norwegian approach to tunnel safety in chapter four. In chapter five, we assess the different mindsets of risk acceptance in the light of Vision Zero and the Norwegian approach; finally, in chapter six, we conclude.

2. Perspectives of risk acceptance

Risk is often used as a term to express our lack of knowledge about the future, indicating how we value the possible outcomes of our choices (Solberg and Njå, 2012). Risk acceptance, then, is related to the choices we make about possible future states. We have identified three main perspectives of risk acceptance.

The following sections of this chapter describe mechanistic approaches to the use of risk acceptance criteria, risk acceptance criteria as a guide or reference in the judgement of acceptance, and dynamic approaches to risk acceptance and safety, respectively.

2.1. Mechanistic approaches to the use of risk acceptance criteria

A mechanistic approach to the use of risk acceptance criteria means that the focus in risk evaluation is often limited to satisfying risk acceptance limits, usually with no or small margin (Aven and Vinnem, 2005; Aven, 2007). Two mechanistic approaches to the use of risk acceptance criteria are presented here.

2.1.1 Satisfying risk acceptance limits

It is common to make the distinction between individual and societal risk acceptance criteria (Aven, 2007; Aven et al., 2011; Vanem, 2012). Depending on the system under consideration, both might apply.

Risk acceptance criteria related to individual risk (IR) will determine the limits between acceptable and unacceptable probabilities of accidents causing death, injuries and ill health (Vanem, 2012). The level of risk is described by the probability of such an outcome per some appropriate measure of exposure, e.g. year, workhours, travelled distances, etc. For example, the individual probability that a person is killed in an accident for one year should not exceed 0.1% (Aven, 2007).

Societal risk acceptance criteria are used for large systems exposing a large number of people to risks, and where a large number of people are affected by possible accidents (Vanem, 2012). For example, the FAR (Fatal Accidental Rate) value should be less than 10 for all personnel of the group, where the FAR value is defined as the expected number of fatalities per 100 million (10^8) exposed hours (or any other relevant reference unit) (Aven, 2007).

The two most commonly used methods for describing such risks are risk matrices and FN-curves (Aven, 2007; Aven et al., 2011; Vanem, 2012).

If interpretation is encouraged, the mechanistic approach to the use of risk acceptance criteria may be taken, implying that the stated limit is regarded as an exact limit to judge acceptability or not (Aven and Vinnem, 2005). Thus, further risk reduction is not encouraged, neither does it consider later design changes which may result in risk increase, due to little or no margin in an early phase of a development project.

2.1.2 Satisfying risk acceptance limits anchored in cost

To encourage further risk reduction, an ALARP evaluation is widely applied, in addition to the use of risk acceptance criteria (Aven and Vinnem, 2005). The ALARP principle dictates that risks should be managed to be as low as reasonably practicable.

A standard approach when applying the ALARP principle is to consider three regions: (1) the risk is so low that it is considered negligible, (2) the risk is so high that it is intolerable, (3) an intermediate level, where the ALARP principle applies (Aven and Vinnem, 2005). These regions are often expressed in risk matrices or an FN-diagram, with criterion lines representing values for intolerable and negligible risks (Vanem, 2012). The area between these lines is commonly identified as the ALARP area, where cost-effectiveness criteria apply.

Two alternative criteria are often used to determine limits of what is reasonably practicable, in combination with the ALARP principle: the Gross Cost of Averting a Fatality (GCAF) and the Net Cost of Averting a Fatality (NCAF). These are cost-effectiveness measures used to evaluate risk control options in terms of the ratio of additional cost to the reduction in risk in terms of fatalities averted (Vanem, 2012). The ‘gross disproportion’ test is required for ALARP in the UK, which allows authorities to demand the achievement of risk levels much lower than the specified risk criteria (Abrahamsen et al., 2018).

Consequently, both risk levels and the cost associated with mitigating the risk are considered in the ALARP process, and risk reduction measures are implemented, as long as the cost of implementing them is within the reasonably practicable, according to cost-effectiveness considerations. However, according to Aven and Vinnem (2005), the ALARP evaluation is often carried out with a mechanistic approach. During this process, possible improvements may be identified but immediately disregarded, based on a cost/benefit (cost/effectiveness) analysis (CBA).

2.2. Risk acceptance criteria as a guide or reference in judgement of acceptance

Risk acceptance criteria are widely used to evaluate the results of quantitative risk assessment (QRA). In QRA, risk is typically described using probabilities and expected values.

Flage and Aven (2009) claim that probabilities are expressions of uncertainty based on a particular background knowledge. Moreover, if the background knowledge changes, then the probability assignment might also change. The probability-based perspective on risk, used as a measure of uncertainty or degree of belief, is not able to reflect the strength of the knowledge that the probabilities are based on (Aven, 2013). The strength or weakness of this knowledge may be related to (1) assumptions, (2) data, (3) expert statements, (4) phenomena involved and (5) models. It may also be related to the use of (6) historical data (Aven, 2013). Here, uncertainty is a factor related to the degree to which the historical data are representative for the future.

If the knowledge is poor, and assumptions and suppositions turn out to be erroneous, the probabilities assigned may lead to poor predictions. Watson (1994) argues that probabilities in probabilistic safety analysis (PSA) may be seen as a tool for argument, rather than an objective representation of truth. According to Watson, this argument is open to question, but the openness of the analysis should allow clear questions. Ale et al. (2015) claim that using CBA reduces the question of acceptability to the question of profitability, which in turn raises ethical questions concerning the value of human life. However, since QRA, PSA and CBA are supposed to be “factual” and “objective”, there is not much room for ethics in these exercises.

As a result, the perspectives of Flage and Aven (2009), Aven (2013), Watson (1994) and Ale et al. (2015) indicate that the use of risk acceptance criteria can be regarded more as a guide or reference in the judgement of what is acceptable or not, and not as absolute limits for what is acceptable.

2.3. Dynamic approaches to safety

A mechanistic approach to risk acceptance assumes that systems are static throughout their lifetime, which gives little or no margin to adapt to changes in the system. Such changes may result in risk increase and exceedance of acceptance limits and cause operational difficulties.

Changes in the environment thus seem to be a factor that demands a more dynamic approach to safety. Here, we present two approaches.

2.3.1 Different criteria for different types of decision situations

Aven and Vinnem (2005) claim that the ALARP evaluation may change. If new information from research is available, experiences from accidents or incidents are gained, and/or changes in performance standards are made, then the ALARP evaluation should be regarded as a dynamic process that needs to be reconsidered regularly.

Abrahamsen et al. (2018) and Selvik et al. (2020) emphasize the use of ALARP as a dynamic decision-making principle. They argue that the ALARP principle can be considered an appropriate principle in safety management only if the grossly disproportionate criterion is interpreted differently for different decision-making contexts. According to Abrahamsen et al. (2018), this perspective is based on a layered approach, which better takes uncertainties into consideration, by emphasizing the cautionary principle. They describe three different perspectives that could be applied in decision-making under uncertainty:

The first perspective is based on the use of a traditional cost-benefit (cost-effectiveness) analysis, where decisions are made with reference to expected values. This way of interpreting the ALARP principle is regarded as an ‘extreme economic perspective’. When the attention remains on expected values, uncertainty is not properly considered. Little weight is placed on the potential for major accidents. Thus, expected values are not appropriate as a general decision-making principle in safety management.

In contrast, rather than focusing on expected values, the second perspective gives strong weight to the cautionary principle, without any references to cost benefit (cost-effectiveness) analysis. According to Aven (2019), the cautionary principle expresses that *if the consequences of an activity could be serious and subject to uncertainties, then cautionary measures should be taken, or the activity should not be carried out.* This extreme safety perspective is, however, not considered an appropriate way to manage risk in general, as it does not turn out to be cost-effective.

Somewhere, in between these two extremes, lies a third perspective. This perspective refers to costs and benefits when decisions are made on investments in risk reducing measures. However, stronger weight is placed on uncertainties and the cautionary principle than is the case with expected values.

The main point of this perspective is that no single perspective would be appropriate for use in all decision-making contexts. The level of uncertainty, the strength of knowledge and the potential for major accidents vary from one context to another. In other words, different decision-making contexts may require different decision-making support. Consequently, the ALARP principle cannot be appropriate as a general decision-making principle, unless it is interpreted in a dynamic way. Abrahamsen et al. (2018) claim that the appropriateness of the ALARP principle must be seen in relation to how it is implemented, as the way the principle is implemented strongly influences how dynamic it is. This is more in line with the R2P2 perspective (HSE, 2001), which, in the interpretation of ALARP, gives more weight to uncertainties and a cautionary mindset when risk is closer to a non-tolerable region.

2.3.2 Safety as control and enforcement of safety constraints

Leveson (2011) states that an accident is an unplanned and undesired loss event. In systems safety engineering, safety is regarded as a control problem (enforcing safety constraints) rather than a failure or reliability problem. Leveson (2011) state that *systems are not static, but that change is a constant for all systems* (p. 176). Over time, there will be changes in physical equipment, human behavior and organizations, due, for example, to degrading of equipment, people's priorities and organizational development. Changes may also occur in the physical and social environment in which the system operates and interacts. Consequently, accident causality models must include the concept of change, in order to handle social and human aspects of safety.

Systems safety theory challenges traditional decision-making research, which views decisions as discrete processes that can be separated from the context in which the decisions are made and studied as an isolated phenomenon (Leveson, 2011). Many critical factors in accidents are often omitted from risk assessments because analysts do not know how to obtain a 'failure' probability of e.g. organizational and human factors. A basic assumption in system safety engineering is that risk and safety may be best understood and communicated in ways other than probabilistic risk analysis.

Rasmussen (1997) emphasized the dynamic part of systems and accidents, describing how systems migrate towards states of high risk under competitive and economic pressures. Leveson (2011) has extended Rasmussen's model further and created a new model of accident causation called STAMP (System-Theoretic Accident Model and Processes). STAMP could provide a new basis for understanding and evaluating safety and, more generally, risk.

In systems theory, safety is regarded as an emergent property that arises when system components interact within an environment (Leveson, 2011). Safety is controlled or enforced by a set of constraints (control laws) related to the behavior of the system. Constraints, then, represent acceptable ways the system or organization can achieve the mission goals. Accidents are a result of flawed processes, involving interactions among people, societal and organizational structures, engineering activities and physical system components that lead to violation of the system safety constraints. Effective communication channels, both downward and upward, are needed between the hierarchical levels of a system. Feedback is critical for providing adaptive control, which makes the controls more active and flexible, rather than passive. Control and enforcement of safety constraints in the entire sociotechnical system is then needed to ensure safety.

In order to include new causal factors identified in STAMP, a new approach to hazard analysis, called STPA (System Theoretic Process Analysis), has been developed. STPA can be used at any stage of the system life cycle. STPA has two main steps: (1) Identify the potential for inadequate control of the system that could lead to a hazardous state. (2) Determine how each potentially hazardous control action identified in step 1 could occur.

3. The concept of Vision Zero

Vision Zero, stating that, in the long run, no person should be killed or seriously injured in road traffic, is rooted in the three pillars: an *ethical principle*, *scientific based knowledge*, and *shared responsibility* (Langeland, 2009). The vision differs from a more traditional traffic safety policy, regarding (1) problem formulation, (2) its view on responsibility, (3) its requirements for the safety of road users, and (4) the ultimate objective of road safety work (Belin et al., 2012). According to Vision Zero, safety is supposed to be the main objective in the transport sector, meaning that safety comes before the other goals. This may challenge other values and interests in the organizations.

3.1. What is the parameter for an acceptable level of safety?

Some have raised criticism against Vision Zero as unrealistic or as an irrational goal (Rosencrantz et al., 2007; Belin et al., 2012). Belin et al. (2012) claim that it appears to be a theory (if only implicitly) that there is a limit to how far safety can go. According to this view, there is an optimal level of deaths and serious injuries, defined by the point at which the costs of intervention exceed the benefits (Elvik, 1999).

However, Vision Zero is not only a long-term goal; it also becomes a means for driving the development of new measures and new approaches that may be both less expensive and more effective than those available today (Belin et al., 2012). Vision Zero does not presume that all accidents that result in personal property damage or in less serious injuries must be eliminated (Johansson, 2009; Belin et al., 2012). Rather, the connection between Vision Zero and the public health perspective directs attention towards incidents that lead to people being killed or seriously injured. This implies that, in all road traffic safety issues and processes, *the level of violence that the human body can tolerate without being killed or seriously injured* shall be the basic parameter in the design of the road transport system (Johansson, 2009).

In contrast to traditional road traffic safety policy, where *accidents* are the problem that must be solved, Vision Zero focuses on *deaths and serious injuries* as the problem to be solved (Belin et al., 2012). In order to create a safe road transport system, this change of perspective alters the question from '*what can we do?*' to '*what must we do?*' (Johansson, 2009; Belin et al., 2012). It also recognizes that road users make mistakes that have catastrophic consequences; thus, the road traffic authorities need to make demands on all system designers and their work, in order to prevent catastrophes.

Based upon its ethical principle, Vision Zero entails a shift in the road safety planning paradigm (Johansson, 2009; Belin et al., 2012). This means that, through designing and constructing roads, etc. and through effective contribution of different support systems, such as rules and regulations, education, information, surveillance, rescue services, etc., there will be a positive demand for new and effective solutions that can contribute to a road transport system where human needs, prerequisites and demands are in focus. Consequently, Vision Zero requires a dynamic approach to determining what is an acceptable risk and level of safety.

4. The Norwegian approach to tunnel safety

The NPRA adopted the concept of Vision Zero in 1999 (Langeland, 2009). Since then, the number of fatalities and severe injuries in road traffic has been significantly reduced, from 1593 to 791 by the year 2016 (Norwegian Ministry of Transport and Communication, 2017). The National Transport Plan 2018-2029 sets a further impetus for Vision Zero, by the interim target of a maximum of 350 fatalities and serious injuries by 2030.

4.1. Tunnel safety regulation in Norway

Although Norway does not have full membership of the European Union, the *Regulation of Minimum Safety Requirements of Certain Road Tunnels* links Norway to the Trans-European road network (Norwegian Ministry of Transport and Communication, 2007).

The regulation aims at ensuring a minimum level of safety for road users in tunnels, by the prevention of critical events that may endanger human life, the environment and tunnel installations, as well as by the provision of protection in the case of accidents. Thus, in a hierarchical perspective, both EU policy and Vision Zero consequently regulate tunnel safety management in Norway.

Handbook N500 (Norwegian Directorate of Public Roads, 2016) is another main regulating document. The handbook comprises issues related to designing and engineering tunnels and describes general safety measures in compliance with the tunnel safety regulations. The handbook also describes the provisions given by the regulation for carrying out risk analysis.

4.2. Risk evaluation and judgement

Both the EU Directive and the Norwegian tunnel safety regulation highlight the use of risk analysis. Risk analysis shall be carried out to establish whether additional safety measures and/or supplementary equipment is necessary to ensure a high level of tunnel safety.

The Norwegian Directorate of Public Roads (2007) has developed a guideline for risk analysis of road tunnels, aimed at project managers, planners, safety controllers, regional risk analysts and the supervisory authority. The guidance is also useful for external consultants who carry out risk analysis.

The guideline describes three methods: preliminary risk analysis, detailed risk analysis and statistical risk calculation. Criteria for the choice of method are described in the guideline. Before conducting a risk analysis, there must always be a tunnel safety (TUSI) calculation, which is based on experiences from various sources in Europe and Norway. The choice of method will depend on safety parameters, such as slope, length, traffic volume and type of tunnel.

4.3. Risk acceptance

According to the guideline, the results of the risk analysis are typically presented as the difference in the number of killed and severely injured by different tunnel solutions and measures. The choice of final solution can then be made, based on four different criteria: (1) Change in risk, (2) Cost-effectiveness, (3) Boundary cost/Boundary utility, (4) Cost-benefit analysis.

5. Assessing different mindsets of risk acceptance in the light of Vision Zero

To be effective, the Vision Zero policy needs to be operational in tunnel safety management. The objective of this chapter is, thus, to assess the perspectives of risk acceptance in the light of Vision Zero and in the context of the Norwegian approach to tunnel safety, thereby identifying dominating mindsets. However, some reservations are made. The analysis is based upon information from official documents. A study of real projects could have revealed other aspects.

In this context, two questions are asked: (1) What perspective of risk acceptance is applicable, in order to make Vision Zero operational? (2) What perspective of risk acceptance is applied in the Norwegian approach to tunnel safety?

5.1. What risk acceptance perspective is applicable, in order to make Vision Zero operational?

To assess this question, each of the risk acceptance perspectives are considered in the context of Vision Zero.

5.1.1 Mechanistic approaches to the use of risk acceptance criteria

This approach assesses the need for risk reducing measures, with reference to (1) Satisfying risk acceptance limits related to individual and societal risk or (2) Satisfying risk acceptance limits anchored in cost-effectiveness considerations. In contrast, Vision Zero directs attention towards the level of violence that the human body can tolerate without being killed or seriously injured, as the basic parameter in the design of the road transport system, leaving little or no margin in an early phase of a project; later design changes may result in risk increase. Thus, a mechanistic approach to the use of risk acceptance criteria is not found applicable, in order to operationalize Vision Zero.

5.1.2 Risk acceptance criteria as a guide or reference in judgement of acceptance

Probabilities assigned may lead to poor predictions, due to poor knowledge. This leaves probabilities as arguments open to question. Thus, the use of risk acceptance criteria is regarded more as a guide in the evaluation of what is acceptable or not and not as absolute limits for what is acceptable. However, the ethical principle of Vision Zero encourages and creates a positive demand for knowledge, in order to find new and effective solutions that can contribute to a system where human needs, prerequisites and demands are in focus. Thus, using the risk acceptance criteria as a guide or reference in the judgement of acceptance is considered as closer to a mechanistic approach than a dynamic approach, and not applicable in order to operationalize Vision Zero.

5.1.3 Dynamic approaches to safety – (I) Different criteria for different types of decision situations

Balancing between the two extremes, *an extreme economic perspective* and *a strong weight on the cautionary principle*, this perspective suggests different criteria for different types of decision situations. However, decisions upon risk reducing measures direct attention towards cost and benefits – not towards incidents that lead to people being killed or seriously injured. The difference between these two perspectives lies in the dichotomy between the questions: *what <u>can</u> we do?* and *what <u>must</u> we do?* By placing more weight on the cautionary principle, through an ALARP principle that adapts to changes, this perspective is partly in line with Vision Zero.

5.1.4 Dynamic approaches to safety – (II) Safety as control and enforcement of safety constraints

Like Vision Zero, the mindset of systems safety theory places attention on the question – *what <u>must</u> we do* in order to keep the system safe? The recognition that accidents and catastrophic events happen triggers actions to prevent such a state. By STPA, hazardous states of the system can be identified, and necessary constraints to prevent this state may be designed. This process may be regarded as applicable, in order to make Vision Zero operational.

5.2. What risk acceptance perspective is applied in the Norwegian approach to tunnel safety?

To assess this question, each of the risk acceptance perspectives is considered in relation to information given by the *Guideline for risk analysis of road tunnels* (Norwegian Directorate of Public Roads, 2007).

5.2.1 Mechanistic approaches to the use of risk acceptance criteria

Typically, risk analysis results are presented as the difference in the number of killed and severely injured by various tunnel solutions and measures. The choice of solution is based on the four different criteria: (1) Change in risk, (2) Cost-effectiveness, (3) Boundary cost=boundary utility, and (4) Cost-benefit analysis.

In general, risk reduction investments are related to the statistical value of a lost life or a severe injury and cost-benefit analyses. If the outcome of these analyses is used as the risk acceptance limit, then the Norwegian approach to tunnel safety can be regarded as being in line with the mindset of a mechanistic use of risk acceptance criteria.

5.2.2 Risk acceptance criteria as a guide or reference in judgement of acceptance

Like the perspective of using risk acceptance criteria as a guide or reference in the judgement of acceptance, the guideline highlights that the probability-based perspective on risk is not able to reflect the preconditions and assumptions made by the risk assessment group. However, risk analysis is generally used as a basis for comparing problems and prioritizing measures. The priorities and recommendations are then used as a basis against the four decision criteria mentioned in the section above. Consequently, the Norwegian approach is partly in line with the mindset of using risk acceptance criteria as a guide or reference in the judgement of acceptance.

5.2.3 Dynamic approaches to safety – (I) Different criteria for different types of decision situations

As already discussed in the sections above, risk analysis results are typically presented as the difference in the number of killed and severely injured by various tunnel solutions and measures. The choice of solution is based on criteria, which can be regarded as in line with an 'extreme economic perspective'. Little attention is placed on uncertainties and the cautionary principle. Thus, the Norwegian approach to tunnel safety seems to have more in common with the mindset of a mechanistic use of risk acceptance criteria than the dynamic approach using different criteria for different types of decision situations.

5.2.4 Dynamic approaches to safety – (II) Safety as control and enforcement of safety constraints

The guideline for risk analysis emphasizes that *Handbook N500* in principle is in line with Vision Zero. The handbook highlights *self-rescue* as the authorities' expectations for evacuation behavior in the event of a tunnel fire. This means that people, affected by a tunnel fire, must evacuate the tunnel by themselves – they cannot rely on rescue. Past experiences have shown that people's survivability during a tunnel fire depends on how far they are from the exits, their health, condition and endurance, their tolerance of toxic gases, or simply lucky circumstances. Such conditions represent a system state, which in the event of a tunnel fire may lead to a major accident. In order to control this state and keep the system safe, a dynamic approach to knowledge and measures is required.

5.3. Summary

The table presents a summary of the assessment in this chapter:

Category of risk acceptance	**Vision Zero**	**The Norwegian approach**
Mechanistic approaches to the use of risk acceptance criteria	No	Yes
Risk acceptance criteria as a guide or reference in judgement of acceptance	No	Partly
Dynamic approach (I) Different criteria for different types of decision situations	Partly	No
Dynamic approach (II) Safety as control and enforcement of safety constraints	Yes	No

6. Conclusion

A tunnel fire has the potential for a major accident. In this context, Vision Zero highlights that the level of violence that the human body can tolerate without being killed or seriously injured represents a clear and explicit criterion or a parameter for what is to be regarded as 'acceptable' in the design of the road transport system. The question – *What must we do in order to keep the system safe?* – emphasizes that Vision Zero needs a dynamic approach, in order to be effective and contribute to continuous improvement in tunnel safety. Our findings indicate that the Norwegian approach to tunnel safety is more in line with a mechanistic approach and thus in conflict with Vision Zero and dynamic development. However, empirical studies are required, in order to explore the practical implications of this approach.

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