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# FROM TRAFFIC SAFETY CULTURE KNOWLEDGE TO ACTION: A PRELIMINARY ARCHITECTURE FOR CONTEXT-SENSITIVE DECISION SUPPORT

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**Abstract:** Road Safety interventions intended to strengthen Traffic Safety Culture (TSC) may address conditions within the wider road transport system, ultimately influencing the shared values, beliefs, and norms, and motivation of road users. Selecting interventions for a particular TSC challenge requires public authorities and practitioners to consider the implementation context. This paper presents the conceptual and methodological foundations of the proposed Roads4All Decision Support Toolkit (DST). Stakeholder user stories, survey responses, and project knowledge informed a preliminary intervention catalogue, structured profiles and filters, and a TSC-oriented semantic model. The proposed DST architecture combines context-sensitive semantic matching with direct browsing of the intervention catalogue and safety impacts knowledge map. Natural language processing and machine learning are envisaged to support input interpretation and relevance assessment. The DST would present interventions' potential contributions to TSC alongside implementation considerations. Its usability and retrieval relevance remain to be evaluated.

**Keywords:** Traffic Safety Culture; Decision Support System; Semantic Modelling; Intervention Selection; Implementation Context

## 1. INTRODUCTION

Road traffic crashes remain a major social and public health challenge, causing an estimated 1.19 million deaths worldwide in 2021 (WHO, 2023). In its 2007 work, the AAA Foundation for Traffic Safety argued that societal acceptance of road deaths as inevitable could hinder the implementation of proven safety measures in the United States and made Traffic Safety Culture (TSC) a priority for sustained research and education (Kissinger, 2007). The Safe System Approach likewise treats deaths and serious injuries as preventable and emphasises shared

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responsibility among those who regulate, design, manage, and use the transport system (ITF, 2022).

Definitions of TSC emphasise values, beliefs, norms, and attitudes, although they differ in how they relate these cultural elements to formal and informal structures and observable practices and behaviours (Edwards et al., 2014; Ward et al., 2019; Nævestad et al., 2026). Behavioural theories, including the Theory of Planned Behaviour (Ajzen, 1991), the Norm Activation Model (Schwartz, 1977), and the Stage Model of Self-Regulated Behavioural Change (Bamberg, 2013), offer complementary insights into how beliefs, norms, and motivation relate to action. Multilevel TSC and organisational safety culture frameworks place these processes within interacting social, organisational, and institutional conditions (Özkan & Lajunen, 2015; Bisbey et al., 2021; Nævestad et al., 2026).

Roads4All is an ongoing Horizon Europe project (2025-2028) that aims to contribute to strengthening TSC through a holistic, multi-level and participatory approach designed to support cultural transformation. A synthesis of these behavioural, multilevel, and organisational perspectives informed the qualitative-integrative Roads4All framework, which relates shared cognition to wider system influences, behaviour, safety outcomes, and interventions (Giannakos et al., 2026; Schade et al., 2026). The Roads4All semantic model complements this scheme by structuring its concepts and relationships for future decision-support use. The qualitative-integrative framework and semantic model were examined in a consultation workshop with external experts and Roads4All partners, whose feedback informed their refinement (Giannakos et al., 2026).

Organisations and institutions shape the conditions in which road safety decisions are made. Within organisations, leadership, mobility policies, training, and reporting practices can influence safety priorities and work-related travel (Newnam et al., 2008). At the institutional level, policy coherence, clear responsibilities, and implementation capacity affect whether interventions can be delivered and sustained (ITF, 2022). These conditions may also be targets of interventions intended to strengthen TSC (Giannakos et al., 2026).

Interventions may operate across levels, from road users and communities to organisations, national institutions and transnational policy contexts. Their potential contribution may therefore depend on coordination across actors and levels (ITF, 2022; Özkan & Lajunen, 2015; Bisbey et al., 2021; Giannakos et al., 2026). An intervention may be considered potentially culture-shaping when its intended mechanism includes changing shared understandings of acceptable behaviour, responsibility for safety, and tolerance to risk (Austin et al., 2021).

Existing tools provide substantial support for road safety decisions. The iRAP Road Safety Toolkit (International Road Assessment Programme) offers guidance, treatments, and case studies spanning road users, infrastructure, vehicles, and road safety management. The SafetyCube Decision Support System (SafetyCube project) connects evidence on crash and injury risk factors with relevant countermeasures and their reported effectiveness. Although both resources address behavioural and institutional issues, they primarily organise knowledge around road safety problems and their prevention. A related methodological precedent is the SINFONICA Knowledge Map Explorer, which uses an ontology to connect stakeholder and contextual information with guidance for inclusive Cooperative, Connected, and Automated Mobility (CCAM) (Antonakopoulou et al., 2025). Adapting this knowledge mapping approach to TSC, the proposed Roads4All Decision Support Toolkit (DST) complements the road safety tools by making interventions' potential contribution to TSC an explicit organising criterion, linked to context, TSC-related factors, cognition and motivation, behaviour, and organisational and institutional practices.

This paper presents the conceptual and methodological foundations of the Roads4All DST, as developed to date. Building on stakeholder requirements and project knowledge, including an

initial Roads4All repository of TSC-relevant good practices (Antov et al., 2026), it describes a preliminary intervention catalogue, a filter scheme, a TSC-oriented semantic model, and a high-level architecture for context-sensitive intervention retrieval and direct browsing. Together, these elements provide a basis for the DST's subsequent implementation and evaluation.

## 2. METHODOLOGY

The proposed Roads4All DST architecture was developed by bringing together stakeholder requirements and existing Roads4All project knowledge on TSC. Requirements elicitation combined user stories prepared by project partners, describing intended users, decision situations, desired functions, and acceptance criteria, with an online stakeholder survey addressing intervention selection, evidence needs, practical constraints, and trust in decision support. Recurring needs were consolidated into a backlog of functional and non-functional requirements, which project partners discussed and prioritised.

Knowledge structuring was informed by the project's qualitative integrative and semantic frameworks, work on organisational and institutional TSC, an initial repository of good practices, and a taxonomy of safety impacts associated with emerging transport technologies and modes. Intervention material was organised into a preliminary catalogue of 36 interventions across five domains. Selected interventions from different domains were developed into detailed profiles to test and refine the profile structure and its mapping to basic and advanced filters. The filters combine characteristics of a user's problem and context with characteristics of interventions that might address it.

These inputs informed the TSC-oriented semantic model and the proposed functional architecture presented in this paper. The architecture provides for context-sensitive intervention retrieval as well as direct browsing of the intervention catalogue and safety impacts knowledge map. Natural Language Processing (NLP) and Machine Learning (ML) components are envisaged as supporting the interpretation of free text and assessment of relevance.

## 3. REQUIREMENTS AND KNOWLEDGE BASE

### 3.1. User and System Requirements

The requirements of the Roads4All DST were identified through a combination of internal and external stakeholder input. As an initial qualitative source, project partners developed 17 user stories representing a broad range of potential users, including public authorities, policy officers, municipal and regional planners, road safety experts, researchers, educators, NGOs and civil society representatives. The stories described concrete decision situations, expected benefits, and acceptance criteria, thereby providing insights into different perspectives on how users might interact with the DST and what information and functionality they would require. Despite the diversity of use cases, recurring needs included the ability to define a decision context, identify suitable interventions under practical constraints, access supporting evidence and indicators, and understand the rationale behind recommendations.

To complement the user stories, an online survey was distributed through project partners' networks in May-June 2026, receiving 33 responses from stakeholders working at local, regional, national, and international levels. The survey combined multiple-choice, ranking, and open questions. Respondents represented research organisations (17), public authorities (7), education (6), the private sector (2), and civil society (1). The survey explored decision-making needs, difficulties encountered when selecting or evaluating interventions, preferred information and functionalities, interface preferences, and factors affecting trust and adoption. The results

reinforced the needs identified in the user stories. Respondents highlighted difficulties related to identifying suitable interventions, adapting them to context, evaluating their effectiveness, accessing reliable evidence, coordinating across organisations, and resource constraints. Respondents were also asked to rank seven proposed DST functionalities from most to least important. The most frequent first-place choices were assessment of expected safety impacts (10 of 33 respondents), recommendations based on context (8), and search for relevant interventions (6). Guidance on implementation requirements and on monitoring and evaluation also appeared among respondents' top-three choices.

The user stories and survey findings were reviewed to identify recurring decision needs and translated into a draft requirements backlog. Overlapping needs were consolidated into functional and non-functional requirements, grouped by theme, and linked to the relevant user stories where applicable. Project partners discussed and voted on the candidate requirements, identifying proposals considered out of scope and prioritising those retained. In the resulting backlog, requirements were classified as "must have" or "nice to have".

Core functional requirements include the ability to define the decision context and relevant constraints, retrieve a focused set of suitable interventions, provide structured information on intervention characteristics and implementation requirements, and link recommendations to supporting evidence and comparable cases. Additional requirements concern monitoring indicators, knowledge exploration, research-oriented search, visualisation, and export functionalities.

The non-functional requirements emphasise usability, source traceability, accessibility, performance, modularity, and semantic consistency. In particular, the DST is intended to remain usable by practitioners without advanced technical expertise, while recommendations should be transparent and linked to supporting evidence. The requirements also recognise the importance of maintaining up-to-date information and consistent terminology across the different parts of the system.

Together, these requirements provide the basis for the knowledge representation and decision-support workflow described in the following sections.

### 3.2. Structuring Intervention Knowledge

In the current approach, interventions are the principal units of recommendation, while broader domains organise the intervention catalogue. Each intervention is represented through a structured profile organised into the information groups shown in Table 1 to support context-sensitive intervention retrieval.

These attributes serve complementary purposes within the DST. Identity and classification fields distinguish each intervention and classify it by domain, types of action, and intended level of influence. Contextual and stakeholder-related fields describe where and for whom an intervention may be relevant, as well as who may lead or support its implementation. The TSC-related fields characterise which cultural, behavioural, institutional or organisational dimensions it is intended to influence. Implementation fields capture practical considerations such as requirements, resources, time horizon, and relevant implementation conditions. Evidence-related fields provide users with supporting evidence, selected sources, and real-world examples, while suggested KPIs indicate how implementation progress and outcomes may be monitored and evaluated. The intervention profiles also distinguish between the intervention itself and the more specific measures or components through which it may be implemented. For example, a broader intervention such as a 'Young and Novice Driver Programme' can comprise risk perception training, peer-norm activities, mentor coaching, and follow-up feedback, without listing each component as a separate intervention. Finally, explicit relationships between interventions are

retained to support navigation across the knowledge base and to identify potentially complementary approaches. For example, intervention records can indicate other interventions with which they may work particularly well.

**Table 1.** Proposed intervention profile

| Group | Information included |
|---|---|
| Identity and classification | Identifier, name, domain, primary/additional types of action, level of influence, short description |
| Challenge and context | Safety or TSC challenges, target groups, implementation and territorial context |
| Stakeholders | Main implementers, other stakeholders and their roles |
| Intended TSC contribution | Narrative of the intervention's expected contribution to TSC, linked TSC dimensions with mechanisms, illustrative measures or components |
| Implementation profile | Requirements, resources, time horizon, implementation considerations |
| Evidence and monitoring | Available evidence, real-world applications and sources, suggested Key Performance Indicators (KPIs) |
| Connections | Relationships with other interventions |

### 3.3. Intervention Domains and Current Knowledge Base

The current intervention knowledge base is based on the initial repository of good practices developed within the Roads4All project (Antov et al., 2026) and comprises 36 interventions, organised into five broad domains: Educational & Learning, Awareness & Communication, Institutional & Governance, Organisational, and Culture & Creativity (Table 2). These domains provide a high-level structure for organising and navigating the catalogue.

The catalogue was developed to capture interventions acting at different levels of the road safety system and through different types of action. In addition to their primary domain, interventions may involve multiple action types and address several behavioural, cultural, organisational, or institutional dimensions. For example, the *Young and Novice Driver Norms and Risk Perception Programme* combines education and training with participatory and technology-supported elements, while the organisational *Just-Culture Incident and Near-Miss Reporting and Learning System* combines organisational management with technology, professional learning, and communication actions.

At the current stage, detailed structured profiles have been developed for a selected set of interventions representing different domains. These profiles are being used to test and refine the profile structure and its filter mappings before extending them across the wider catalogue.

**Table 2.** Intervention domains and indicative examples

| Domain | No. of interventions | Indicative example |
|---|---|---|
| Educational & Learning | 8 | Young and Novice Driver Norms and Risk Perception Programme |
| Awareness & Communication | 4 | Positive Social Norms and Shared Responsibility Campaign |
| Institutional & Governance | 10 | Vision Zero and Safe System Adoption and Implementation Programme |
| Organisational | 10 | Just-Culture Incident and Near-Miss Reporting and Learning System |
| Culture & Creativity | 4 | Road Safety Stand-Up Comedy and Facilitated Dialogue Programme |

### 3.4. Context and Filters

The current design uses two levels of filter. Basic filters capture information that users are likely to know at the beginning of a search, including the intervention domain, type of action, safety or TSC challenge, target group, implementation setting, and available resources. Advanced filters allow users to refine the search further by specifying the TSC dimensions to be addressed, intended level of influence, how the intervention is expected to work, the protective or responsible behaviour to be promoted, transport mode, territorial context, main implementer, and time horizon.

Since these characteristics are not mutually exclusive, an intervention may be associated with several values for the same dimension. For example, the *Positive Social Norms and Shared Responsibility Campaign* may address multiple target groups and TSC dimensions and can be implemented across different territorial and organisational contexts, while the *Just-Culture Incident and Near-Miss Reporting and Learning System* is primarily associated with organisational settings, professional road users, and dimensions such as leadership, trust, fair accountability, and organisational learning.

## 4. PROPOSED DST ARCHITECTURE AND WORKFLOW

### 4.1. Semantic Model

The proposed DST uses a semantic model to connect a user's road safety problem or TSC challenge with relevant intervention knowledge. The model (Fig. 1) is organised into six related areas: Context, Manifestations, Cognition and Motivation, Behaviour and Practice, Safety Outcomes, and Interventions. Together, these areas represent selected relationships within the wider road transport system and provide the conceptual structure behind the DST's filters and intervention profiles.

*Context* describes the circumstances in which a TSC challenge is identified and informs the fit and interpretation of potential interventions. The model also distinguishes four analytical levels of influence: micro (individual), meso (groups, organisations, and communities), macro (societal and national systems), and magna (transnational). An intervention may act at more than one level.

The *Manifestations* area captures conditions that may shape TSC and be modified by interventions, including infrastructure, strategies, regulatory and enforcement arrangements, education systems, socialisation environments, organisational work design and reporting systems, and organisational or institutional leadership and capacity.

*Cognition and Motivation* brings together related but distinct concepts at individual and collective levels. Shared cognitions include collective safety values and priorities, social norms and expectations. Beliefs, attitudes, risk perception, trust and perceived legitimacy may be held individually and/or shared within a group. Motivational processes concern why actors undertake or avoid safety-related actions, including perceived responsibility, motivation to act, and expected consequences. Perceived enforcement may also influence these decisions.

*Behaviour and Practice* distinguishes between individual risky and protective behaviours and safety-related practices within organisations and institutions, such as reporting a near miss, responding to a safety concern, or setting safe work schedules.

*Safety Outcomes* covers events, such as near-misses and crashes, and their consequences, including injuries and fatalities. Indicators may track intermediate changes in manifestations, cognition and motivation, and behaviour and practice, alongside safety outcomes.

*Interventions* are matched to an identified TSC challenge and its context. In the simplified model in Fig.1, they are represented primarily as modifying manifestations or influencing cognition and motivation, with possible implications for behaviour and practice. The recommendation logic therefore considers an intervention's expected contribution to TSC, rather than treating improvement in safety outcomes as the primary criterion.

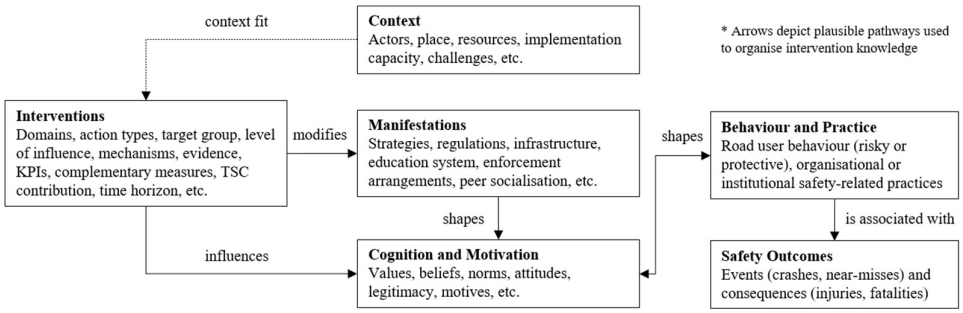



**Fig. 1.** Simplified semantic model for the Roads4All DST

### 4.2. Roads4All DST Architecture

The proposed Roads4All DST follows a hybrid semantic-ML (machine learning) architecture. The semantic model provides the structured basis for decision support, while natural language processing (NLP) and ML may assist with interpreting user input and assessing relevance. At a functional level, the architecture comprises user interaction, context interpretation, intervention matching, and presentation of results, supported by the DST knowledge base. A high-level representation of the architecture is presented in Fig. 2.

The user interaction component allows a decision-maker to describe a road safety problem or TSC challenge using free text, the structured filters presented in Section 3.4, or a combination of both. The context interpretation component maps these inputs to the concepts and controlled terminology of the semantic model. NLP is envisaged to help identify relevant concepts in free-text descriptions, while explicitly selected filters remain part of the user's stated decision context.

The DST knowledge base brings together the preliminary intervention catalogue and its structured profiles with links to TSC concepts, implementation information, available evidence and examples, and suggested KPIs. The semantic model described in Section 4.1 defines the concepts and relationships used to organise this knowledge, while a formal ontology will operationalise these relationships for consistent querying and reasoning. The DST knowledge base will also incorporate a safety impact knowledge map based on the taxonomy of safety impacts already developed within Roads4All project, allowing users to explore potential safety challenges and opportunities of emerging mobility technologies, services, and modes (Giannakos et al., 2026a; Giannakos et al., 2026b).

The decision-support component uses the interpreted problem and constraints to identify interventions relevant to the TSC challenge and compatible with the specified context. Semantic retrieval and matching provide the principal basis for this process, while ML-based similarity provides additional support when related ideas are expressed in different terms. A request-specific matching score is envisaged to summarise the relevance of each candidate intervention. The method for calculating this score remains to be specified.

The DST output is envisaged as a focused set of interventions, each accompanied by a matching score, a short description, and its expected TSC contribution. The description and expected TSC contribution support users in assessing each result, while the score summarises its request-specific relevance. Users could access the full intervention profiles for implementation information, evidence and source links, suggested KPIs, and related interventions. An additional planned function would allow users to assemble complementary interventions into a portfolio linked to a specific issue and save it for future reference. Figure 2 also shows direct browsing of the intervention catalogue and safety impacts knowledge map as an alternative to query-based intervention matching.

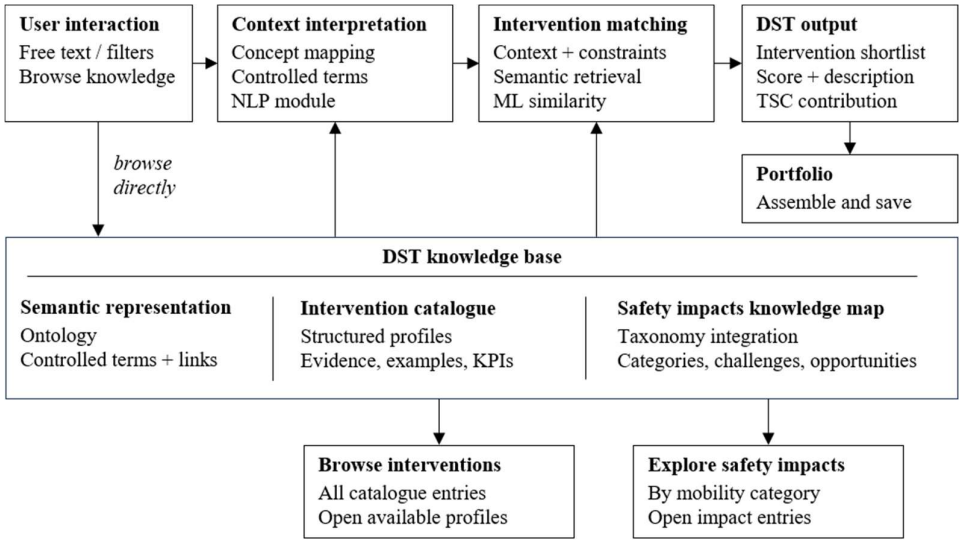



**Fig. 2.** Proposed Roads4All DST architecture: recommendation and browsing routes

For example, a municipal road safety officer might seek to address speeding and peer pressure among novice drivers through a school-based initiative with medium resources. The officer could enter a short description and select filters for “Young people and novice drivers”,

"Unsafe speed and rule violations", "School or educational setting", and "Medium" resources. Context interpretation would map peer pressure to the model's "Social norms and expectations" concept while retaining the selected filters as constraints. Semantic retrieval could then identify the *Young and Novice Driver Norms and Risk Perception Programme*, whose profile is linked to these characteristics. The result would show its description and expected TSC contribution, with access to its implementation requirements, selected evidence, and suggested KPIs, including changes in risk perception and perceived peer norms. The profile also links to a *Positive Social Norms and Shared Responsibility Campaign*, which the officer could inspect as a complementary option.

## 5. DISCUSSION

This paper proposes a structured approach for using TSC knowledge and stakeholder needs to support context-sensitive intervention selection and documents the conceptual and methodological choices made during the DST's development. It does not present a finalised tool. The proposed DST explicitly considers an intervention's potential contribution to TSC as part of decision support. Its semantic model and structured profiles connect TSC challenges with context, manifestations at different system levels, cognition and motivation, behaviour and practice, and implementation conditions. This would allow users to examine interventions in relation to the circumstances in which they might be applied. The complementary browsing route would also support exploration when users have not yet defined a specific problem.

Challenges include the broad and evolving nature of TSC, the definition of TSC-relevant interventions, the multi-faceted nature of several interventions, limited direct evidence of their effect on TSC, and the difficulty of linking interventions to measurable TSC change over time. The semantic model necessarily simplifies relationships within a complex transport system. Indicators can monitor changes in TSC-related constructs over time, but attributing those changes to a particular intervention requires an appropriate evaluation design. Currently, only selected interventions have detailed profiles. Intervention profiles should articulate, where possible, a theory-informed rationale for their potential TSC contribution and the contexts in which they may apply. Indirect evidence may inform that rationale when direct evidence is unavailable, but should not be treated as proof of TSC transformation.

The user stories and stakeholder survey informed the requirements but do not establish the relevance or usability of the proposed DST. In particular, the survey findings should be interpreted as indicative rather than representative of prospective DST users, since recruitment relied on project partners' networks and 17 of the 33 respondents were affiliated with research organisations. Although assessment of expected safety impacts was the most frequent first-place survey choice, the proposed safety impacts knowledge map would support browsing of impacts associated with emerging mobility, rather than predict the effects of individual interventions. The envisaged matching score would indicate relevance to a request, not intervention effectiveness or predicted safety impact. Its calculation and interpretation remain open design issues.

Future work will focus on completing intervention profiles and testing the consistency of semantic mappings. It will also determine how evidence quality and uncertainty will be represented. Testing with practitioners in varied decision contexts is needed to assess the relevance, usability, and interpretation of both matched results and browsed knowledge. Future extensions of the DST may also consider a more granular representation in which individual interventions' measures or components are modelled and analysed separately.

## 6. CONCLUSIONS

This paper proposes a way to translate TSC knowledge into context-sensitive intervention selection. A user's challenge and context are related to intervention profiles describing target actors, potential TSC contributions, implementation conditions, and available evidence. Stakeholder input and Roads4All knowledge informed a preliminary intervention catalogue, selected detailed intervention profiles, and a filter scheme, while the semantic model and architecture define how these elements could support decision-making. Intervention matching, direct browsing, and portfolio creation remain envisaged DST functions. This work has not yet demonstrated the workflow's usability or retrieval relevance, nor does it establish the effectiveness of the catalogue interventions. The immediate priorities are to complete the intervention profiles, specify transparent matching rules, and evaluate the proposed workflow with practitioners.

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