CulturalRoad: A Five-Pillar Framework for Equitable CCAM Implementation Across Europe

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Abstract. As Connected, Cooperative and Automated Mobility (CCAM) systems evolve, ensuring their equitable deployment across diverse European contexts becomes increasingly critical. This work introduces the Five-Pointed Star Rating System (FPSRS), a novel evaluation framework that integrates cultural and geographic diversity into the assessment of CCAM equity. The FPSRS is structured around five key pillars. Inclusivity assesses spatial, physical, digital, and economic access to mobility services, focusing on underserved groups, including individuals with disabilities, limited digital literacy, or financial constraints. Network optimisation applies analytical and simulation-based models to evaluate CCAM integration within multimodal transport systems, aiming to ensure efficient and equitable service provision. Safety addresses disparities in crash risk and infrastructure readiness, using surrogate indicators to examine safety outcomes across user groups. Acceptance investigates willingness to adopt CCAM, particularly among disadvantaged populations, through stated preference methods that capture socio-demographic and attitudinal factors. Psychological factors explore trust, technophobia, and cultural attitudes toward automation to identify barriers and enablers of adoption. Together, these dimensions inform a holistic, user-centred equity assessment tool applicable across diverse contexts. Preliminary findings show FPSRS can support policymakers in creating CCAM systems that are technologically innovative and socially equitable.

Keywords: CCAM, equity, inclusivity, acceptance, safety.

1 Introduction

CCAM is a key pathway toward more efficient, safe, and sustainable transport systems in Europe. Equity ensures fair outcomes by accounting for socio-economic, geographic, and demographic differences [1]. Without intervention, CCAM may reinforce transport poverty.

The European Common Evaluation Methodology (EU-CEM) provides a structured approach for assessing CCAM impacts across domains such as society, mobility, environment, and economy, including aspects of accessibility, safety perception, and user acceptance. The framework presented here complements EU-CEM by focusing specifically on cultural, behavioural, and psychological dimensions of equity.

The CulturalRoad project addresses the challenge of ensuring equity in CCAM across Europe and beyond by introducing the Five-Pointed Star Rating System (FPSRS). It provides a structured framework for evaluating equity, integrating diverse cultural, geographical, and social factors into a comprehensive assessment methodology. FPSRS is built on five interdependent pillars, namely Inclusivity, Network Optimization, Safety, Acceptance, and Psychological Factors, each capturing essential dimensions of equity in CCAM. This framework provides a practical tool for designing equitable CCAM systems.

2 Methodological Framework

The CulturalRoad project adopts a mixed-methods approach combining quantitative modelling with participatory engagement to operationalize equity in CCAM.

2.1 Mixed-Methods Design

At the system level, outcomes are assessed using measures such as affordability ratios, accessibility indices, and simulation-based analyses [2]. User-level insights are collected through surveys, interviews, focus groups, and workshops exploring perceptions of safety, trust, and attitudes toward automation [3].

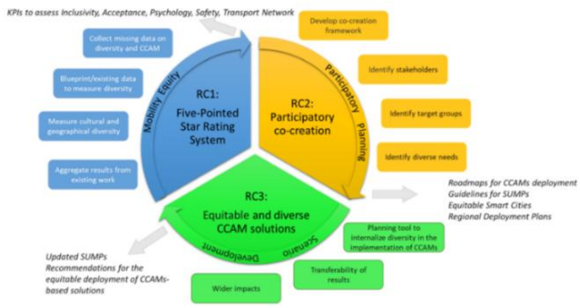

Figure 1. CulturalRoad Research Concepts, derived from a mixed-methods approach

As illustrated in Figure 1, one of the framework's central research concepts is the FPSRS. This tool is designed to evaluate equity within any CCAM (Connected, Cooperative and Automated Mobility) project or implementation. In doing so, it accounts for how well specific cultural or geographical needs are addressed, ensuring that local characteristics and user requirements are meaningfully reflected in project outcomes. The five pillars were selected to capture both structural and behavioural dimensions of equity in CCAM.

The Cultural Road framework is envisioned as an accompaniment to the prevailing European approaches for the evaluation of CCAM, particularly the EU-CEM approach. The EU-CEM approach provides an overarching framework for evaluation that comprises various impact areas, while the FPSRS approach focuses on equity (see Table 1).

Table 1. Conceptual alignment between FPSRS pillars and EU-CEM evaluation dimensions

FPSRS Pillar	Related EU-CEM Evaluation Areas	Contribution of CulturalRoad
Inclusivity	Accessibility, reachable activities, societal impacts	Focuses on digital inclusion, affordability, physical accessibility across diverse user groups and other ethical issues
Network Optimisation	Traffic efficiency, multimodal integration	Examines the balance between operational efficiency and equitable service distribution
Safety	Road safety, infrastructure readiness	Evaluates safety disparities across regions and user groups using surrogate indicators
Acceptance	User acceptance and behavioural response	Measures willingness to adopt CCAM technologies across socio-demographic groups
Psychological Factors	Social perception and behavioural aspects	Introduces trust, technophobia, and cultural attitudes toward automation as equity determinants

2.2 Stakeholder Engagement and Co-Creation

Stakeholder engagement is a key component of CulturalRoad's methodology. Stakeholder engagement includes workshops with experts and focus groups with users. These participatory activities make sure that the FPSRS considers the values and concerns of people who have historically been underrepresented in transport planning [4].

2.3 Pillar Integration into CCAM Assessment

The five pillars are operationalized as Key Performance Indicators (KPIs) by the FPSRS, and these KPIs are then combined to create a composite equity score. Every pillar contributes one or more KPIs. This approach permits flexibility to account for cultural and geographic variances while ensuring that CCAM equity can be evaluated uniformly across a range of contexts. It also supports comparative evaluations across sites and user groups.

3 Pillar-Specific Approaches

This section provides particular insights into the methodologies and indicators used by each pillar. The indicators represent preliminary examples of measurable variables that can operationalize each pillar. The specific indicators applied in practice may vary depending on data availability, local context, and the characteristics of the CCAM deployment being assessed.

3.1 Inclusivity

To achieve equitable CCAM, the economic, digital, physical, and spatio-temporal barriers that influence mobility must be addressed. Transport systems often overlook underserved groups like women, low-income households, and people with disabilities [5], [6]. Inclusivity is fundamental for preventing transport poverty and facilitating equitable opportunities in automated mobility contexts.

In turn, physical and digital accessibility, as well as in-vehicle security systems and respect for data privacy, are tackled using advanced multicriteria analysis techniques. Physical accessibility ensures that users with mobility limitations can use CCAM services. Digital accessibility draws attention to the risks of exclusion in app-based mobility systems and aims to integrate people with low digital capabilities as CCAM users. Finally, security and data privacy aspects are tackled from the point of view of the systems' actual design (i.e., which measures they offer), leaving perceptions for the Acceptance or Psychological factors pillars. Cumulative opportunities, barrier coverage, as well as equity indexes such as Foster-Greer-Thorbecke (FGT_2) are some of the KPIs of this pillar.

3.2 Network Optimization

The Network Optimisation pillar examines how CCAM can be integrated into multimodal transport systems while balancing efficiency and equity. Although automation may improve travel time and system capacity, studies suggest that these benefits may disproportionately favour dense urban corridors unless the needs of peripheral and rural areas are explicitly addressed [7].

This pillar applies analytical models, such as frequency-based coordination, to optimise scheduling and service integration [8]. The approach considers heterogeneous user groups and geographic diversity, enabling the analysis of shared automated services within CCAM scenarios. The problem is formulated as a constrained optimization framework that evaluates operational trade-offs between efficiency and equity. Key KPIs include the level of CCAM integration with public transport, coverage in underserved areas, equitable fleet allocation, and travel time savings across population groups.

3.3 Safety

Safety equity is essential for CCAM deployment, as crash risks, infrastructure readiness, and exposure to hazardous conditions are often unevenly distributed across socioeconomic and geographic groups. Previous research shows that inadequate infrastructure and unequal safety investments increase risks for vulnerable users such as pedestrians, cyclists, and low-income communities [9]. While CCAM technologies may reduce overall crash rates, disparities may persist if deployment prioritizes well-equipped areas and neglects regions with poorer infrastructure.

Given the early stage of CCAM deployment, the Safety pillar relies on safety indicators rather than crash data alone. Surrogate measures such as conflict points, speed variance, and near-miss frequencies provide predictive insights into safety outcomes. These are complemented by simulation models analyzing interactions between automated vehicles and vulnerable road users, as well as assessments of infrastructure readiness and risk exposure across user groups [10]. Key KPIs include the frequency of surrogate safety conflicts, infrastructure readiness scores by region, risk exposure by transport mode and socioeconomic group, and public perceptions of safety.

3.4 Acceptance

The Acceptance pillar examines willingness to adopt CCAM technologies, focusing on socio-demographic and attitudinal differences. Literature indicates that factors such as age, gender, income, education, and vehicle ownership, as well as attitudes toward technology and social norms, influence acceptance. Previous studies show that disadvantaged groups may be more hesitant to adopt automation due to concerns related to trust, privacy, and affordability, highlighting the need to consider both social and technical barriers to equitable deployment.

According to [11], acceptance of new travel modes can be assessed through stated preference surveys that capture user choices among alternative travel options. Psychometric and attitudinal measures are also used to evaluate perceptions of safety, trust in automation, and environmental benefits [12]. In this project, a travel survey combining stated preference and psychological measures is used to assess acceptance of CCAM modes across socio-demographic groups in the pilot cities. Key KPIs include acceptance trends over time, perceived barriers (e.g., cost and data security), and willingness to adopt across age, gender, and income groups.

3.5 Psychological Factors

The Psychological Factors pillar examines how user interactions with CCAM systems are shaped by cultural perceptions, affinity for technology, and trust. These psychological dimensions highlight underlying attitudes and cognitive responses that determine whether adoption is sustained over time, whereas the Acceptance pillar focuses more narrowly on willingness to adopt. According to research, risk perceptions, fear of losing control, and trust in automation are critical factors that influence the use of CCAM [13].

To investigate these aspects, the pillar employs validated survey instruments designed to evaluate key psychological constructs such as trust in automation and affinity for technology across different European contexts [14]. Structural equation modelling will be used to analyse the data and identify correlation and weighting factors in the variables. Initial KPIs include perceived risk across demographic groups, the prevalence of technophobia, the degree of trust in automated systems, and the shift in attitudes following exposure to CCAM. The FPSRS incorporates these psychological indicators to identify emotional and cultural barriers that could impede adoption, ensuring strategies build user confidence.

4 Integration into the FPSRS

The value of the FPSRS lies in its ability to integrate multiple indicators into a composite framework for equity assessment. Although each pillar captures a distinct dimension of equity, indicators are standardized to ensure comparability across pillars and contexts. Through normalization and aggregation, the framework generates composite scores that highlight the relative performance of different sites, projects, or user groups. These standardized outputs help policymakers identify strengths, weaknesses, and trade-offs, supporting more informed and context-sensitive decision-making.

Following normalization, FPSRS aggregates indicators into pillar-level and overall equity scores. Aggregation can follow equal weighting or policy-sensitive weighting schemes, allowing greater emphasis on dimensions such as inclusivity where access or affordability are critical. This flexibility enables both methodological consistency and responsiveness to policy priorities. The Equity Star (Fig. 2) provides a visual representation of system performance, allowing stakeholders to assess results across all pillars simultaneously. This multidimensional view supports comparisons across urban, suburban, and rural contexts, where different trade-offs may occur.

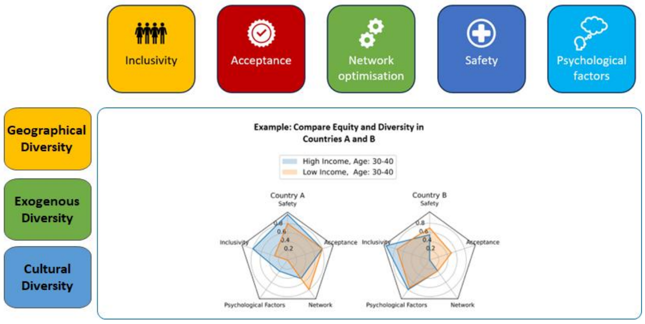

Figure 2. Equity evaluation and comparison through the FPSRS.

Finally, the modular architecture of the FPSRS ensures flexibility and scalability. Indicators can be adapted to local conditions, enabling applications ranging from local pilots to cross-national benchmarking and supporting the equitable deployment of CCAM across Europe.

5 Results and Discussion

Initial applications offer early evidence that FPSRS can capture equity dimensions in CCAM environments, even though it is still in the development stage. Two important insights are highlighted by preliminary findings. First, there is an easy observation of trade-offs between the pillars. Urban areas perform well in network optimization but show weaker inclusivity outcomes in affordability. On the other hand, because of better spatial coverage, inclusivity scores were relatively high in urban or peripheral areas, but safety indicators fell behind due to inadequate infrastructure preparedness. These results align with research highlighting the unequal geographic distribution of mobility equity. Second, the importance of psychological and acceptance factors has been highlighted by stakeholder engagement. Even when technical accessibility is guaranteed, focus groups showed that cultural attitudes and trust mediate the willingness to adopt CCAM services. This emphasises the need for infrastructure, pricing, and policy interventions that focus on perceptions. These observations suggest that the FPSRS can serve as a diagnostic and comparative tool, helping identify gaps across contexts and user groups.

The FPSRS provides a more comprehensive equity assessment than approaches focused only on accessibility or affordability. Limitations include reliance on proxy measures, early-stage development, regional data inconsistencies, and unvalidated weighting schemes. Nonetheless, FPSRS shows strong potential as a decision-support tool for policymakers.

6 Conclusion

The FPSRS provides a comprehensive framework for assessing equity in CCAM. By integrating structural, cultural, and psychological factors, it extends beyond traditional accessibility or cost-based metrics, offering methodological rigor and enabling cross-context benchmarking. While current applications rely on proxies and face challenges such as data heterogeneity and unvalidated weighting schemes, FPSRS remains flexible and scalable as technologies evolve. Despite limitations, it contributes a valuable tool for policymakers and planners by highlighting cultural and psychological adoption factors, visualizing trade-offs, and identifying disparities, thereby supporting more inclusive and equitable mobility transitions.

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