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Research paper

Governance of uncertainty in implementing mobility innovations: A comparison of two Dutch cases

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A B S T R A C T

To make the supply of transport services more attractive and sustainable, mobility suppliers and governmental actors expect much from mobility innovations. When developing and realizing these innovations, they experience considerable uncertainty about the future outcomes of implementing these innovations (1), and about other actors' intentions and actions in realizing these innovations (2). Literature on governance under uncertainty often overlooks the experienced uncertainty during interactions among multiple actors. To address this gap, this paper applies a new conceptual model for understanding interacting actor behaviour under uncertainty in the context of two innovative mobility cases in the Netherlands: Mobility as a Service (a digital channel for users to plan, book, and pay for multiple mobility services) and ERTMS (a new European rail traffic control system). Our analysis reveals that actors tend to rely on traditional project management approaches for dealing with uncertainty, even when there is no shared understanding of innovation requirements and scope. However, uncertainty manifests itself most regarding actors' intentions and actions in the development phase of innovations. This gap underscores the limitations of managing innovations using project management and highlights the need for additional governance approaches to address the major uncertainties that actors face about their mutual relations.

1. Introduction

As part of making current transport systems more sustainable, public and private actors collaborate to develop and implement mobility innovations. Infrastructures mostly have a public character, vehicles mostly a private character, and services consist of a mix. Mobility innovations potentially have a great impact on stimulating a transition towards a sustainable transport system (Geels, 2012). However, by their nature realizing these innovations requires dealing with many uncertainties about e.g. technological performance, impact on traffic and transport, as well the societal conditions needed to fulfill sustainable impact (Jittrapirom et al., 2018). In this paper, uncertainty is defined as a lack of necessary knowledge needed for an individual or group to make decisions (Abbott, 2005).

What causes uncertainty in mobility innovation projects? Mobility innovations are expected to operate in the future over time and through space, linking together many actors, including travelers, transport providers (of infrastructure, vehicles, and services) and public organizations (municipalities, provinces, and national governments). As mobility innovations can have a wide spatial or even societal impact, many actors have a stake in the realization of these innovations, including funding, operation, and planning. Uncertainty exists for actors in this context in two ways. Firstly, there is uncertainty about the ways an innovation will affect the system with unknown variables and/or relationships, i.e. system or structural uncertainty (Brugnach et al., 2008; Walker et al., 2003). In the context of mobility innovations, such uncertainties translate into questions of functioning and effect of the change. For example, does a platform-supported transport service stimulate a desired result of a modal shift away from private car ownership and use in the long run? Secondly, uncertainty also relates to other actors' dynamic (future) objectives and preferences in the form of different knowledge frames (Klijn & Koppenjan, 2016; Kwakkel et al., 2010). For example, will the algorithms of a new platform-supported transport service optimize for profit, individual travelers' speed, or societal goals like modal shifts? And do actors know of each other what their preference of optimization is, or will be?

Uncertainty hampers the development of mobility innovations because actors might want to wait for more knowledge or because of a

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lack of common ground in the decision-making process. However, uncertainty is inherently part of any innovation process (Köhler et al., 2019) and it is exactly the novelty making it impossible to gather reliable information about the functioning and effect of the to-be implemented innovation. To deal with issues of uncertainty, literature about (mobility) innovations has focused on both a better *understanding* of uncertainty via systems engineering and risk management strategies (Priemus et al., 2008), as well as *managing* uncertainty between actors via trust, stakeholder management, contract management and procurement strategies (Hensher, 2010; Lenderink et al., 2022; Love et al., 2021; Mok et al., 2015).

However, there are two problems with the current focus of literature regarding uncertainty in (mobility) innovations. Firstly, uncertainty is not just an abstract absence of knowledge to all involved, but it is the patchwork of experiences of such absence by all actors as influenced by their emotions, feelings, and becoming part of who those actors are and how they act (Scoones & Stirling, 2020). In this sense, uncertainty is not just another aspect of innovations that can be measured, tamed, and managed by injecting information. Rather, uncertainty is both a normative and a descriptive lens through which actions in decision-making processes can be understood. The competence of people involved in decision-making processes, all dealing with their experience of the unavoidable lack of knowledge is underrepresented in frameworks that look into mobility innovations and uncertainty. Secondly, literature on governance under uncertainty mostly focuses on either public (Dewulf & Biesbroek, 2018) or private (Fanousse et al., 2021; Gomes et al., 2021) actors instead of the interaction under uncertainty between public and private actors. Although research has been carried out about public-private interaction in mobility innovations (Smith et al., 2018; Terrien et al., 2016), its focus was not mainly on uncertainty but on barriers and good practices in general. However, mobility innovations are developed via complex multi-actor networks, in which the role of uncertainty cannot be ignored. Therefore, the current paper addresses the following research question: How do experiences and interactions of public and private actors under uncertainty affect the introduction of mobility innovations?

As should be clear from the above, this article shifts the perspective to a multi-actor focus to provide a better understanding on why developing and implementing mobility innovations fail, by analyzing the innovation process through an uncertainty lens. Such an understanding can improve and enrich existing interventions and methodologies (Sustar et al., 2020) for dealing with uncertainty, like stakeholder management applications. Also, new interventions can be set up based on actors' uncertainty competencies through incorporating actual experiences of uncertainty.

This paper is divided into four parts. Firstly, we propose a theoretical framework of actor interactions under uncertainty in decision-making about mobility innovations in Section 2. Then, we explain the application of this framework in the methodological Section 3, by a comparative case study of two mobility innovations in a Dutch context: Mobility-as-Service (MaaS) and ERTMS (European Rail Traffic Management System), a new rail traffic control system. By analyzing the decision-making process through key moments of uncertainty, differences and similarities between both cases illustrate how uncertainty affects innovation trajectories. Results of the case study comparison are presented in Section 4 and discussed in Section 5. Finally, we end in Section 6 with a conclusion and possible future research avenues related to the governance of mobility innovations under uncertainty.

2. Theoretical underpinning and framework

The theoretical starting point of this paper is the concept of socio-technical change, which refers to co-constructing configurations of technology embedded in social user practices, that can contribute to the structural change of a societal system (Geels, 2002; Loorbach et al., 2017). There are many theoretical perspectives for analyzing and understanding socio-technical change (Sovacool & Hess, 2017), and this paper is inspired by the theory of sociotechnical transitions in the form of the Multi-Level Perspective (Geels, 2012). This perspective conceptualizes transitions as a result of the interactions between niches (protected spaces for radical innovations), socio-technical regimes (institutional structuring of current systems) and exogenous landscape developments. In our view, the interactions between the three levels are in fact formed by actors' decisions under uncertainty. Where Geels and Schot (2007, p. 401) speak of 'landscape elements putting pressure on existing regime', or 'the regime is dynamically stable', we translate such dynamics as uncertainty being perceived as relatively high and low respectively by actors. This paper therefore proposes to conceptualize transitions and the development of radical socio-technical innovations through the lens of uncertainty as experienced by actors, a gap that is acknowledged within transition theory literature (de Haan & Rotmans, 2018).

The remainder of this section presents a conceptual model that has been constructed by conducting a literature review. The model unpacks the role of uncertainty in the implementation of mobility innovations and consists of three key elements.

- Firstly, decision-making for mobility innovations occurs in an interaction arena in which multiple actors come together.
- Secondly, based on what happens in this arena, actors make decisions under uncertainty through decision-making mechanisms via a cycle of experience, response, and choice. With experience, we do not refer to a lack of experience but to the subjective perception of an individual actor of uncertainty in an innovation process.
- Thirdly, uncertainty competencies and settings are conditional factors that explain actor-specific preferences and choices for dealing with uncertainty in the form of individual and organizational characteristics (e.g. a negative attitude towards uncertainty), as well as formal and informal governance rules (e.g. contracts, predictive models, leadership), respectively.

The overall conceptual model with all three key elements is presented in Fig. 1. We will firstly explore existing models that describe multi-actor decision-making under uncertainty, and then go more deeply into each of the key elements of our proposed model.

2.1. Existing models on multi-actor interaction under uncertainty

There have been some theories and models developed to explore multi-actor decision-making behavior under uncertainty for developing innovations. Meijer et al. (2006) have proposed a framework to analyze dominant patterns of perceived uncertainties in innovation processes. They constructed a table with different sources of uncertainty and different phases of the innovation stage in which uncertainties can come up. They did not categorize however the mechanisms of why perceived uncertainties come up with specific actors. Similarly Gomes et al. (2018) focused on uncertainties of innovative products developed by businesses and constructed a framework that conceptualizes the flow of individual uncertainties (as part of one entrepreneurial firm) and collective uncertainties (as part of the ecosystem in which the entrepreneur operates). Some mechanisms of how individual uncertainties become collective uncertainties are described, but only from a business ecosystem perspective. Poeppelbuss et al. (2021) also have adopted a multi-actor perspective to study uncertainty reduction mechanisms in smart service innovation processes. Their conceptual framework is based on the microfoundations movement (Felin et al., 2015), and consists of a macro-level (institutional logic), a micro-level (actors' actions) and a meso-level that translates institutional macro logics into micro actions and vice versa. The study focused explicitly on actors' actions to reduce uncertainty (the how), but they recommend that future research should be spent on 'putting the interviewees' perceptions of uncertainty center stage' (Poeppelbuss et al., 2021, p. 623). Also,

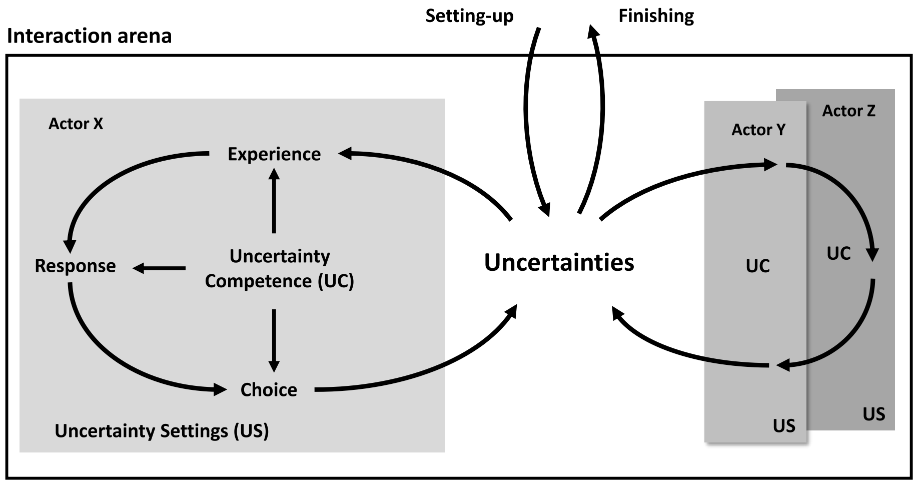

Fig. 1. Conceptual model of multi-actor interaction under uncertainty in decision-making for mobility innovations.

reducing uncertainty is not the only possible response and can be counterproductive in dealing with uncertainties (Rindova & Courtney, 2020; Van 't Klooster & Veenman, 2021). Griffin and Grote (2020) have proposed a more individualized theoretical framework that does incorporate the idea that actors manage uncertainty based on their preferred uncertainty levels. This model has not been empirically tested, however.

All in all, there are frameworks on actor interactions under uncertainty described in literature, often from a business perspective. All models have a different focus, such as the innovation phases, the interaction between collective and individual uncertainties, and the interplay between institutional logic and actors' actions. No explanatory model exists however that describes factors why actors make certain choices regarding uncertainty, dependent on their individual and subjective perspective of uncertainty. Therefore, we will elaborate on the elements of our proposed theoretical framework, displayed in Fig. 1.

2.2. The interaction arena

Decision-making can be considered as an interaction arena that consists of a set of actors, their organizational arrangements constructed with a specific goal in mind (van Bueren, 2003), namely creating and implementing a mobility innovation. Often, arenas have the form of a project that is shaped by formal and informal agreements between multiple actors. Classically, the transport domain is characterized by a high level of institutionalization in the form of tenders, contracts and common ground that form the basis of interaction arenas between public and private actors in the mobility field (Hrelja et al., 2017). However, new players like bike-sharing companies or MaaS providers cannot build on such earlier experiences and need to construct new interaction arenas, possibly with different institutions (van Waes et al., 2020). Especially in the early phase of some mobility innovations, an interaction arena does not exist yet and has to be formed by relevant actors. It can be expected that the initial agreements about the structure and arrangements of the interaction arena are highly influential in determining what type of uncertainties come up and how they are dealt with. Other frameworks refer to the interaction arena as a (service) ecosystem (Gomes et al., 2018; Poeppelbuss et al., 2021).

2.3. Decision-making mechanisms under uncertainty

Based on events and interactions in the arena, actors have a specific experience of uncertainty, either related to the innovation and the transport system or other actors and the governance of the innovation. This experience is actor-specific and subjective by definition, as each actor perceives uncertainty in different ways based on cognitive biases and earlier experiences (Meijer et al., 2007; Milliken, 1987). Consequently, actors respond to experiences of uncertainty by reducing, tolerating, or denying it (Van 't Klooster & Veenman, 2021). Finally, an actor's response to uncertainty is translated into concrete choices or strategies relevant for the interaction arena (Rindova & Courtney, 2020), often categorized in contractual and relational governance choices (Aben et al., 2021). It might also be possible that through tolerating uncertainty, nothing is done. The combination of experience, response, and choice we call a decision-making mechanism under uncertainty. For example, a governmental agency can experience uncertainty whether newly deployed e-scooters are having a sustainable effect on travel behavior. Consequently, this local government wants to reduce this uncertainty, and makes a choice to allow e-scooters for the time being by a special permit. This mechanism is a cyclical process, as choices by one actor can trigger a cascading effect of other actors' decision-making mechanisms. Eventually an actor can choose to stop the innovation project which leads to the dissolution of the temporary interaction arena. Only one framework also includes feedback loops (Griffin & Grote, 2020), whereas other frameworks are one-directional (Poeppelbuss et al., 2021) or non-directional (Meijer et al., 2006).

2.4. Uncertainty competencies and settings

Uncertainty competencies and uncertainty settings are conditional factors relevant for decision-making mechanisms and the interaction

Table 1
Uncertainty settings and competencies.

Uncertainty competencies	
Individual	Earlier experiences Capabilities Attitudes Expectations
Group	Organizational culture Routines and heuristics Earlier experiences National culture
Uncertainty settings	
Formal	Contracts and regulation standards Models and methods Funds Market form Policies and co-design strategies
Informal	Trust Common ground Responsibilities Leadership

arena. An overview of all competencies and settings is presented in Table 1, based on a review of relevant factors in decision-making and planning under uncertainty of which the results are described below.

Firstly, competencies are actor-specific characteristics either on an organizational or individual level, consisting of earlier experiences (Mauelshagen et al., 2013), attitudes (Bijlsma et al., 2011; Chung & Hensher, 2015), routines and capabilities (Dewulf & Biesbroek, 2018) to handle uncertainty. Bad previous experiences with another actor or innovation makes an actor more uncertainty avoidant, i.e., less accepting uncertainty, as illustrated by Lane et al. (2017) who found that inexperience of the regulator slowed down the progress in innovative water projects. A fixation on certainty (and a negative attitude towards uncertainty) can lead to inflexible decision-making practices, shown by a case study of water management in the Netherlands (Zandvoort et al., 2019). A sufficient level of capabilities in the form of skills are necessary to assess and evaluate uncertainties properly. For example, Bornemann et al. (2016) found that a more holistic and comprehensive planning mentality led to a higher chance of addressing uncertainties as an important topic by stakeholders for implementing local energy innovations.

Secondly, uncertainty settings are defined as the formal and informal institutional governance rules of actors and of the interaction arena. Formal governance settings are rules that are part of institutional procedures in clear contexts, whereas informal governance settings are uncodified rules within the sphere of social relationships and behavior. Uncertainty settings structure decision-making processes under uncertainty, as well as the interaction arena itself. For example, a specific set of choices is available to actors when responding to uncertainty, delimited by the availability of funds, models and methods. In the Netherlands, different scenarios are prescribed for the appraisal of national infrastructural projects. Without funds and evaluation tools, stakeholders cannot reduce uncertainty let alone introduce an adaptive planning approach (Hanna et al., 2020). Co-design strategies and adaptive planning methodologies can also be a tool for dealing with uncertainty in complex projects (Mahmoud-Jouini et al., 2016; Patrício et al., 2020). Uncertainty settings can overlap between actors, when starting the innovation by signing contracts, agreeing on regulation standards and collaboration within the rules of a specific market form. However, such formal settings can also be a source of uncertainty through interpreting them differently and proposing another set of rules suitable for that actor (Zandvoort et al., 2019). Informal governance rules can also diverge between actors, as levels of trust, common ground and leadership demands can be highly different per actor. Especially trust in other actors can increase the stability of the interaction arena under uncertainty (Aben et al., 2021; Hensher, 2010).

It is expected that negative and positive patterns exist between uncertainty competencies, formal and informal uncertainty settings (Meijer et al., 2007). For example, a positive attitude towards uncertainty may decrease the need for more funds and trust between actors in an innovation process. However, classically organizations seek to avoid uncertainties which leads to a hard focus on formal regulation settings and contract management between actors. In such cases, contracts can reduce uncertainty in unpredictable innovation projects but trust between actors might also go down. The additive effect of both competencies and settings on actors' experience of uncertainty is therefore something to keep in mind when analyzing decision-making processes under uncertainty.

3. Methodology

The aim of this study was to apply the theoretical framework as developed in Section 2 for actual innovation cases in practice, to examine the interplay between actors and innovations via the perspective of uncertainty. Such an approach increases the understanding of success and failure of mobility innovations by concretizing terms and definitions (cf. Feitelson & Salomon, 2004). Better conceptualization of what happens in practice can be input for lessons for improving innovation projects and skills of practitioners.

3.1. Process tracing methodology

This paper applied a process tracing methodology, an approach that is focused on explaining how outcomes are produced by events of action of actors and their interactions in a specific context (Bennett & Checkel, 2015). In our case, the outcome was the success or failure of introducing mobility innovations, and the actions and interactions of actors related to their uncertainty experience, response, and handling. The contextual factors in this study were uncertainty competencies and uncertainty settings. In contrast with classic process tracing adopting a within-case approach, we applied a comparative process tracing approach of two cases (Bengtsson & Ruonavaara, 2016). In doing so, we were able to systematically compare differences and similarities between the two cases, in terms of uncertainty competencies and settings and analyze its effect on the overall decision-making process. Such a methodology has already been applied for studying governance of public transport (Hansson, 2013; Hirschhorn et al., 2020), by triangulation of policy documents, interviews, and literature.

In terms of materials and analysis (see Table 2 for the full list), we did the following:

- We conducted semi-structured interviews with key actors involved in the decision-making process for developing the innovation. By comparing the interviews with document analysis, we set up a timeline of events. In the interviews, we specifically asked actors about their key-uncertainty moment, in which they felt high levels of tension and doubt in the innovation process. When it was clear what this moment was, we continued to ask about its causes and context.
- By cross analyzing the interviews and comparing multiple uncertainty moments, the most important key-moments were selected and placed on the timeline. In a second round of interviews, this timeline was presented and validated with actors by asking additional questions and reflections on the selected key-uncertainty moments.
- Through additional observations of meetings, we also got more insight in the language that actors use to speak about uncertainty,

Table 2
List of empirical materials.

Case	Type	Affiliation	Interview ID
MaaS	Interview	Radboud University	M1
MaaS	Interview	Radboud University Medical Center	M2
MaaS	Interview	Province	M3
MaaS	Interview	Municipality	M4
MaaS	Interview	MaaS Operator	M5
MaaS	Interview	Province	M6
MaaS	Interview	Radboud University	M7
MaaS	Interview	Radboud University Medical Center	M8
MaaS	Document	Project plan	
MaaS	Document	Research paper	
MaaS	Document	Presentation update	
ASAP	Interview	ProRail ASAP Project	A1
ASAP	Interview	ProRail ASAP Project	A2
ASAP	Interview	ProRail ERTMS Program	A3
ASAP	Interview	Ministry of Infrastructure and Water Management	A4
ASAP	Interview	ProRail ERTMS Program	A5
ASAP	Interview	Market innovator 1	A6
ASAP	Interview	Market innovator 2	A7
ASAP	Interview	ProRail ASAP Project	A8
ASAP	Interview	ProRail ASAP Project	A9
ASAP	Interview	ProRail ERTMS Program	A10
ASAP	Document	Implementation plan ERTMS	
ASAP	Document	Program plan ERTMS	
ASAP	Document	Project plan ASAP	
ASAP	Document	Progress presentation	

which enabled us to validate our theoretical framework and ask more specific questions in the second round of interviews.

- By deductively coding the interviews using the theoretical framework, the key-moments in the innovation process were dissected using the elements of the decision-making mechanisms (experience, response, and choice). Also, relevant uncertainty competencies and settings for the key uncertainty moments were coded using the theoretical framework and cross-compared between all interviewees. In general, actor-specific characteristics were coded as competencies, whereas settings were about the collaboration and institutional arrangement that structured the decision-making process under uncertainty.

3.2. Case study selection

Two Dutch innovation cases were selected to compare, namely Mobility as a Service (MaaS) and ERTMS (European Rail Traffic Management System), an innovation that aims to digitalize and standardize rail signaling infrastructure in Europe. These innovations have been selected for a comparative and contrasting reason. Firstly, a similarity of both innovations is the involvement of both public and private actors, which is the focus of this study. It can be expected that public and private players each perceive uncertainty differently, thereby influencing the interpretation of what needs to be done about this uncertainty (Smith et al., 2018). Secondly, a key difference between the two innovations is the type of innovation, either being technological-driven or service-driven (Van Wee et al., 2022). By empirical analysis of ICT-related automobility experiments in the Netherlands, Manders et al. (2018) have defined two niches: an automated niche focusing on technological and infrastructural measures, and a service niche focusing on travel services and business models. The two case studies chosen in this study can also be labelled accordingly. MaaS is typically a service-oriented innovation, being less asset-dependent and re-organizing access to existing travel services that are available on the transport market through integration of planning, ticketing, and payment (Jittrapirom et al., 2017). ERTMS on the other hand is all about the technological replacing of an existing rail system by a new system. Although ERTMS is an innovation in itself, the Dutch railway infrastructure manager ProRail would like to speed up the planned introduction of ERTMS in the Netherlands by new technologies and design approaches.

Based on the categorization by Manders et al. (2018), it can be expected that with ERTMS, less new entrants (i.e. start-ups) are involved than with MaaS. This might have an effect on the uncertainties that come up during the innovation process. As for the type of innovation it can be expected that with ERTMS as an automated (technological) niche innovation there are ‘large uncertainties about the potential benefits and what technologies to invest in’ (Manders et al., 2018, p. 96). Specific focus of this study was the ASAP[1] tender, set up in 2018 as a co-partnership with private actors in the field to produce new innovative solutions to speed up the ERTMS implementation. Key for this co-partnership was that after a successful test phase of the innovation, a commercial phase of buying the innovative product by ProRail was guaranteed for private actors. At the moment of writing, most innovations are in the test phase. Relevant actors were the ASAP project managers, the higher management of ProRail, the ministry and private market actors who develop innovations.

MaaS is part of the service niche with ‘many uncertainties about future markets and user needs’ (Manders et al., 2018, p. 96). How interactions between public and private actors should be structured remains open for debate (Smith et al., 2018), and it is unclear whether MaaS can achieve its promises to users (Pangbourne et al., 2020). Such questions also led to the development of a small MaaS pilot in Nijmegen in 2016, a medium-sized city of 175.000 inhabitants. The actual pilot started in September 2018 on the Heyendaal campus, where the Radboud University and Radboud UMC Hospital are situated. The pilot is still running in 2022 but preparations are made to scale up for a larger post-covid pilot. Relevant actors were the MaaS service provider, government authorities (municipality and providence), existing public transport operators (train, bus) and the pilot project management team (university and hospital managers).

4. Results

4.1. MaaS Heyendaal

4.1.1. Case events on timeline

The MaaS project started in 2016 as a collaboration between researchers from the Radboud University and ‘Duurzaam Bereikbaar Heyendaal’, a group formed by representatives from the Radboud University hospital, province, municipality, and transport operators. They were already working together to find out how to change mobility patterns on Heyendaal campus. It was in the early days of MaaS, and hardly anything was known how a MaaS app would technically work in practice and what positive effects MaaS could have for travelers and businesses. At the time, only one MaaS operator was available for developing the appropriate MaaS environment. It was not clear for actors how to define and work out the pilot, as it was one of the first times that MaaS was implemented in the Netherlands. Therefore, a project manager was hired to explore working conditions for a MaaS experiment. By conversations with all actors, it became clear that there were different interests with respect to implementing MaaS on campus (Meurs et al., 2020). The municipality and province had a clear interest in making students and employees travel more sustainably to the campus. Public transport firms wanted to extend their services. And the MaaS operator not only wanted to implement their MaaS platform, but also increase ridership of their shared vehicles that were included in the MaaS environment. Also, there was hesitance to share data between public transport agencies and the MaaS operator.

In 2017 however, a project plan was developed with a common aim to learn and experiment. It was agreed upon that funding was paid by the province for the initial development costs of the app, and the pilot would consist of 50 travelers maximum to avoid high losses. Also, travelers would use the app for free as it was unclear whether all technicalities would work. After all actors agreed on the project plan and contracts, the technical MaaS app development started. However, what should be delivered for the funding to develop the MaaS app was interpreted differently by actors, as well as who was responsible for attracting travelers. Technically, it was difficult to link public transport tickets within the MaaS app. During this time, project management leadership had shifted from the university to the province to the municipality, until a MaaS app was eventually working, and the pilot could start in September 2018. After a while, it became clear however that commuter travelers were not interested in using MaaS, and a choice was made by the hospital to switch to business travelers as the main target group. Such business travelers were obliged to use the MaaS app for their ticketing, so that costs could be integrated in the reimbursement process by the employer. The idea was to scale up to 1500 travelers in 2020, but covid-19 shut down all travel and therefore the larger pilot was postponed. Now that all travel restrictions have been lifted, a tender for a new large-scale MaaS pilot is prepared with the hospital and university mobility managers in the lead. A full timeline of events of the MaaS Heyendaal case is displayed in Fig. 2.

4.1.2. Key uncertainty moments and mechanisms

Based on comparison of all interviews with relevant actors and comparing what they experienced as key-uncertainty moment in the

[1] ASAP: Aanbesteding Snellere Aanpak ERTMS (In English: Tender Faster Approach ERTMS). See also: https://www.prorail.nl/programmas/ertms/asap-ertms.

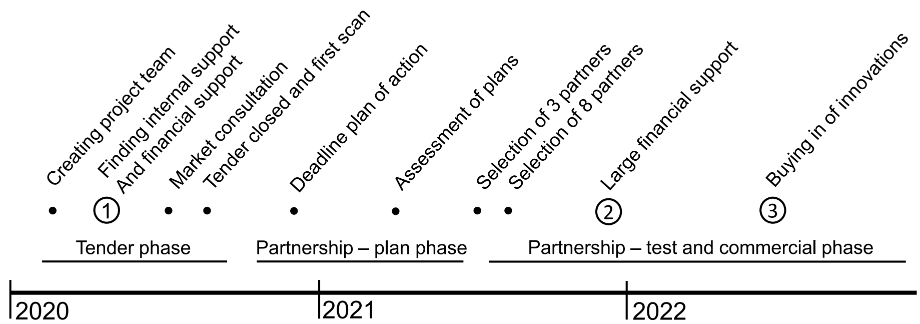

Fig. 2. Timeline of MaaS Nijmegen with key-uncertainty moments.

form of experiences, responses and choices as worked out in the theoretical framework, three most important key uncertainty moments (encircled in Fig. 2) have been defined. The fact that these moments were indeed the most important has been confirmed by another round of interviews.

Firstly, in the beginning of MaaS Heyendaal, actors did not know how MaaS could technically work in practice and whether it could stimulate sustainable travel to campus (**experience**). These uncertainties can be categorized as system uncertainties. However, there were also uncertainties about shaping the experiment and finding a proper way to collaborate with a MaaS provider, related to governance uncertainties. It was clear for all actors that these uncertainties needed to be reduced (**response**) in order to start with the pilot. This was resolved by the province and municipality through employing a neutral project leader from the university who could guide the process and assess all interests (**choice**). By interviewing all stakeholders, the project manager found that learning should be the main goal of the MaaS experiment, and a detailed project plan on what to deliver by whom, a division of budgets, agreements on marketing and a limited number of 50 travelers meant that 'risks were limited' (M1). However, the MaaS operator was pushing not to write a too detailed plan since they thought the fixed plan would not fit anyway with what they would encounter later in the development process. But, to make the pilot not too casual all parties eventually signed the initial project plan.

The second key uncertainty moment was how to work out and interpret the initial agreements in practice. As the original project leader from the university was both a consultant and a researcher, the province decided to lead the project themselves. They were not satisfied with the progress and collaboration with the MaaS operator, as the product was not finished but more funding was asked (**experience**). To get a grip on the process (**response**), contracts were checked who had to do what (**choice**). Eventually, project leadership shifted to the municipality since they were better equipped to manage the contracts tightly (**choice**). The MaaS provider on the other hand did not agree with building an extensive app as 'no one knows what the traveler wants' (M5), so not too much effort should be spent for developing an app with features that will not be used after all. Also, it was difficult for them to connect the MaaS technical interface with interface of transport operators, although that was eventually resolved. The province also stated their doubts whether the MaaS operator would be neutral since they also provided their own shared vehicles in the application (**experience**). This uncertainty was not resolved during the process.

After the app was finalized and working, it appeared that travelers were not using the app and it was unclear for actors why that was the case (**experience**). Who was responsible for attracting travelers in practice was interpreted differently, also since it was thought that 'travelers would use the app automatically because it was free' (M2). Agreements on sharing data from travelers that did travel were not kept according to the province, which led again to checking contracts. Eventually it was concluded that MaaS did not have added value for commuter travelers. Therefore, the hospital project manager decided to shift to business travelers (**choice**), as it could ease their reimbursement process via the MaaS application. On the one hand, this choice reduced systems uncertainties about the role of MaaS for travelers. On the other hand, change of scope also led to more work for the platform developer and the question was whether all this additional work was compensated by the province and municipality (**experience**). Eventually, this was the case and the MaaS business piloted was running until covid-19 shut business travel down.

4.1.3. *Interaction arena, uncertainty settings and competencies*

Initially, the interaction arena consisted of the partners of Duurzaam Bereikbaar Heyendaal, to which university researchers and the MaaS operator were added. The actors in this group were all equals, and no actors stood out in terms of power or saying. Also, other educational institutions on campus apart from the university were involved in the pilot, but they were not ready for implementing MaaS in their business schemes and left the pilot.

In terms of uncertainty settings, there was a lack of regulation standards, models, and methods to assess MaaS, and it was unclear which market form would suit MaaS. The whole point of doing an experiment was to see whether MaaS could contribute to sustainable travel on campus, or in the words of the municipality: 'We did not have any experience, but we think that MaaS could be a solution because the whole world is working on this' (M3). The learning goals were only sideways aimed at learning about collaboration and finding a suitable market form. However, the project plan did work as a catalyst for the pilot and temporarily reduced uncertainty levels. But agreements were differently interpreted by actors, and therefore project leadership shifted to an actor who was most suitable to check for agreements and contracts between the funding actor (the province) and the MaaS operator. This meant that uncertainty competencies and uncertainty settings were in fact related to each other, as one actor had more capabilities to manage uncertainty by contracts than others.

Other relevant uncertainty competencies were a lack of experience with the technological innovation itself, as well as with the new MaaS operator. Expectations about the timeline of the process also played a role, as the MaaS operator expected to go faster and make quick decisions, whereas the province thought it would take much longer to develop a working product. Different backgrounds clashed here in terms of working fast and agile versus working according to a structured decision-making process. Eventually, the MaaS pilot did find its way in the form of a new tender for business travelers. Apparently, a more classic form of structuring the decision-making process and interactions between supplier and buyer through tendering suits actors better for handling uncertainty levels. All in all, most interviewees generally evaluated the overall process as a beneficiary learning experiment.

4.2. *ASAP ERTMS*

4.2.1. *Case events on timeline*

The ASAP project started in 2020 as part of the larger 7 billion Euro

ERTMS program that will run until 2050. Since the program is so long and has an effect on the whole rail network of the Netherlands, it was expected that innovations with respect to design and construction could make the overall implementation process faster and therefore cheaper. In order to develop such innovations, project managers of ProRail developed a tender in the form of a innovation partnership, which meant that ProRail buys the actual innovation after successful tests instead of doing a classic pilot without further obligations. Also, the idea was to co-design the innovation in partnership with ProRail project managers and market actors. After finding initial support with the higher management of ProRail and the ministry, the project was launched mid 2020 by a market consultation and the tender was openend. The tender was structured around five plots: Less cables, smarter housing, faster placement of objects, smarter design, and a wild card.

After the tender closed, 88 parties had made an offer and eventually 15 parties were selected for the partnership. Each partner had to develop a business case and plan of action, which was again reviewed by a committee of ProRail (project) managers and ASAP project managers. At first, only three partners could go though to the test phase, and 8 others were put through at a lager stage based on an improved business case plan. Going into the actual test phase of plans meant that larger financial budgets had to be made available for the partners by ProRail, around 18 million Euros. Also, capacity of ProRail project managers had to be made available for co-developing innovations with the partners. After a delay of half a year, budgets were made available and partners could develop their innovations for tests. Innovations range from (intelligent) digital twins, digital axle counters, sensors for less ground work, ERTMS construction robots till an integral safety-case management system. Now, the first innovations are at the brink of finalizing the tests and going into commercial phase. However, most innovations are still in the test phase. The full timeline of events of the ASAP project is displayed in Fig. 3.

4.2.2. Key uncertainty moments and mechanisms

Based on interviews and document analysis, three moments (encircled in Fig. 3) appeared to be experienced as most uncertain for the ASAP ERTMS innovation process.

The first moment consisted of finding internal support in terms of project capacity and funding by the ASAP project managers (**experience**). Project managers who were asked to support in the project were hesitant to join as they did not know what kind of innovations they could expect, and innovations distracted them from their main duties that focused on cost minimization and increasing rail safety (**experience**). Also, higher management wanted to see official capacity requests to allocate hours to project managers. Such capacity requests were mostly ignored (**response**), and project managers were asked directly based on their personal enthusiasm to join the ASAP project (**choice**). Project management consisted here of 'taking project leaders along with the project' (A1), as well as 'just carrying on stoically' (A2). Another issue was the financial support for the ASAP project. The pressure of delivering the ERTMS project lay with the first seven railway sections, for which 2,5 billion was available. However, the scope of the ASAP innovations was intended for the other railway sections. Therefore, it was questioned by the ERTMS program management whether the innovations could be funded by the initial budget (**experience**). To avoid this scoping problem (**response**), ASAP innovations were presented as risk-mitigating measures that would use budget from the reserved risk budgets from the first seven railway sections (**choice**). So, by investing in innovations, possible future delays could be avoided. By presenting ASAP in this way to the ministry, ASAP 'was brought in as a solution for a planning problem that existed, and therefore landed very well' (A4).

In the test phase of the project, the financial funding of the innovations issue returned as a key uncertainty moment. The question was whether the ASAP project team were allowed to spend 18 million euros, or whether the program management had to make a decision (**experience**). To clear this up (**response**), contracts and original plans were checked (**choice**). It became apparent that for spending more budget than one million euro, the program management needed the ministry to give permission. The ministry on their side felt uncertainty because it was unclear whether spending 18 million euros was lawful or not, within the policy makers' mandate (**experience**). On top of the large financial budget, the question was again whether the innovations were in the scope of the first seven railway sections (**experience**). Originally, it was promised to parliament that a specific technology would be used. However, one of the innovations focused on a different type of technology, out of scope of the original plan. Therefore, to fill the scope gap (**response**), a memo was written by the ministry stating a new technology policy to make the innovation fit with the ministerial scope (**choice**). Also, just as with the first key uncertainty moment, a new cost-benefit analysis from ProRail supported the wish that savings could be made in the first seven rail sections (**choice**). In this way, the ministry could approve taking the 18 million from the ERTMS risk budget scheme so that the partnerships could carry on.

The final key moment focused on the interactions between ProRail and the innovation partners themselves. Especially smaller innovation partners mentioned that they struggle with delivering all the documents on business plans financial support (**experience**). Also, ProRail project managers were hesitant to test innovations in their project because they wanted to avoid delays, and they already had contracts with other organizations on delivering specific technologies (**experience**). To reduce this unclarity whether a new contract could be installed with an innovation partner (**response**), contracts were checked, and it was found that existing contracts might not be continued (**choice**). ASAP project managers also advised the innovation partner not to wait for the ProRail organization, but just to develop a working product and then present that to ProRail (**choice**). In this way, innovation partners were not too dependent on the bureaucracy of ProRail.

4.2.3. Interaction arena, uncertainty settings and competencies

The layered interaction arena consists of the ministry, the ASAP project team, higher ERTMS program management, other ProRail departments such as Asset Management and the innovation partners. In this arena the tandem of ministry and ProRail together structure the decision-making process with innovation partners. In terms of uncertainty settings, the whole innovation and decision-making process is

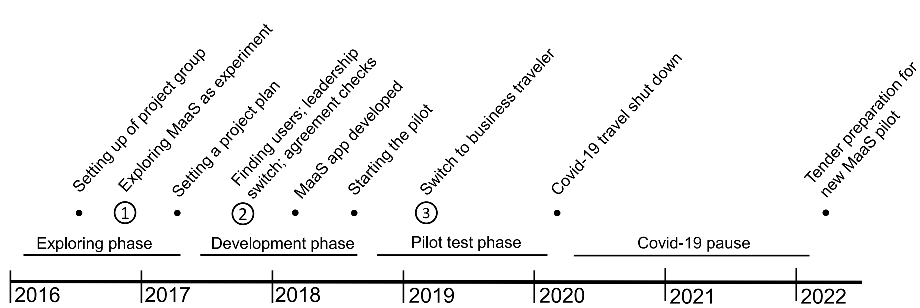

Fig. 3. Timeline of ASAP with key-uncertainty moments.

highly structured by existing visions, programs, and tender rules. Although the new innovation partnership is a new way of tendering, it appears that the outcomes of such a partnership clash with the already existing rules and interpretations of these rules. Decisions about funding of the innovation project have to go through the whole decision-making process of ProRail and the ministry, which focuses on controllability and manageability. Throughout conversations with all actors, it was remarkable that almost all experienced uncertainties were about finding support using the bureaucracy between the ministry and ProRail, and not about the new innovations themselves and technologies. It was questioned whether the partnership and investing that much money was illegitimate and out of scope in the original program. This fear can also be subscribed to uncertainty competencies of actors such as a high level of uncertainty avoidance, both with project managers at ProRail and with policymakers at the ministry. Several interviewees mentioned that taking risks is not rewarded within ProRail, and there is a lack of experience with new innovations and partnership methodology which led to a wait-and-see mentality. On a positive side, creative and informal leadership by ASAP project managers have pushed the whole project forward, thereby stimulating discussion within ProRail and keeping connections with the innovation partners.

5. Discussion

In this section, differences and similarities between both cases will be discussed with reference to the interactions between actors through uncertainties, by their competencies and settings.

With both cases, experienced uncertainties mostly were about the actions and intentions of other actors, and not about the functioning of the innovation in the system. When the MaaS pilot did not take off by focusing on commuter travel behavior, this uncertainty was handled ad hoc by shifting the pilot scope to business travelers. This decision was not contested by other actors but did raise the level of uncertainty. Was the new scope part of the original assignment for the app-developer or should more money be spent to fund the design changes of the MaaS app? In the ASAP decision making process, almost all uncertainties related to questions of legitimacy of funding, being in or out of scope of existing programs, and finding enough capacity to support the implementation of the innovation. Although these uncertainties were rooted in the unknown impact of an innovation on the rail system, being responsible for handling these uncertainties in the bureaucratic system was what caused the real tensions with actors. The context of experienced uncertainties is therefore different with both case studies. With the MaaS case, a lack of initial uncertainty settings in the form of leadership and division of responsibility created many uncertainties with actors which made them feel like inventing the wheel for the first time. With ASAP, an overload of uncertainty settings in the form of standardized processes and programs led to a high level of uncertainty experience, in combination with competencies like avoiding uncertainty and a blame culture of who is accountable when the innovations are not successful or going over budget. Similarly, to Manders et al. (2018), ERTMS actors (being part of an automated/technological niche) experienced more uncertainty about potential benefits of innovations and especially how to allocate these benefits in existing programs and budget schemes. With MaaS however, there was more uncertainty experienced about the future market design and user needs, which was indeed expected to be more relevant for service-oriented innovation niches.

A similarity between both cases is that throughout the development process, there was a tendency to move from the open experiment (MaaS) or innovative partnership (ASAP) to more classic project management approaches with respect to uncertainty handling via a client-contractor contract and relationship. This process, displayed in Fig. 4, is not per se a negative interaction pattern as observed by Meijer et al. (2007), in which one actor's experienced uncertainty results in an increase of another actor's experienced uncertainty. Rather, actors shift in their usage of uncertainty settings, by making choices that are more comfortable for them given their historic role and responsibilities in public-private interactions. With both innovation trajectories, the original idea was to co-design the innovation together with the market. As it was unclear for actors who should do what in the MaaS development, a project plan was set up to structure this uncertainty. Consequently, when there was uncertainty about the agreements made in the project plan, contracts were checked to find out what the exact responsibilities and obligations were of each actor. Likewise, ASAP project managers started off with an innovative partnership idea in mind that would stimulate the interactions between ProRail and market suppliers. Initially, project uncertainties were handled through creating risk/benefit profiles of each innovation in the form of an exploratory process between both ProRail managers and market innovators. However, ASAP project managers recently noticed that some partnerships were not partnerships anymore, as the involved project manager of ProRail just asked for a specific design based on a specified rate, like a classic supplier-demander relationship. This eliminated the partnership aspect of co-designing innovations.

A striking similarity is that both decision-making processes were driven by enthusiast actors who think innovations are necessary for ensuring sustainable futures of their organizations and the transport system in general. In literature, such an actor is referred to as a MaaS champion (Hensher, Mulley, & Nelson, 2021). Analysis of both cases make clear that this leader does not have to be from government per se. Because the most important uncertainties in both cases were about governance issues rather than system uncertainties, a more neutral actor might have the lead orchestrating the collaboration between public and private players. For example, although leadership was a problem in the

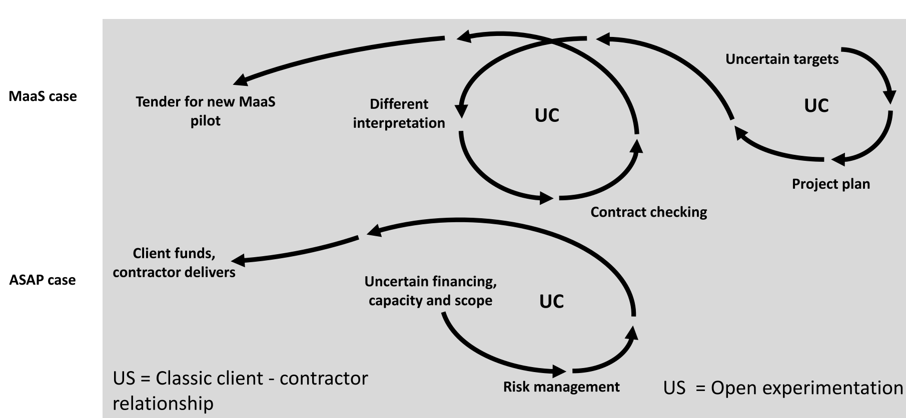

Fig. 4. Model of uncertainty handling applied for both cases, moving from co-design to classic client-contractor (US = Uncertainty Settings, UC = Uncertainty Competencies).

MaaS pilot, the hospital project manager ensured that the pilot could continue by changing the focus towards business travelers. Actors with this kind of leadership were referred to in the interviewees as 'friendly dictators' who pushed innovations and could find other willing people in their organization through relational governance mechanisms (Aben et al., 2021). Such actors had specific uncertainty competencies such as a positive view towards uncertainty and the capability to look beyond uncertainties related to the bureaucratic embedding of an innovation in the organization. If necessary, such actors did have an understanding of the bureaucratic needs of another organization like the ministry, so that the handling of uncertainty became easier via classic risk management strategies. However, it is the question whether risk management strategies as a single way of handling uncertainties bring innovations further in the long run. Focusing only on risks, benefits and their handleability seems to distract from the innovation themselves, their impact on the transport system and creating public value.

Although not in the scope of this paper, there is increasing attention for citizens contributing to the development of innovations in the form of co-production or co-creation, thereby adding to public and private actors as main players in an innovation process (Boivard & Loeffler, 2022). It is suggested in literature that citizen engagement in co-creation processes can aid 'towards understanding and grappling with the wickedness of future mobility services' (Ebbesson, 2022, p. 2). In the case analysis of this paper, co-creation could seem particularly relevant for MaaS as an innovation aimed at travelers directly. There were several user-related uncertainties experienced by actors, such as finding users that wanted to participate in the trial and knowing what they expected from a MaaS product. These uncertainties might have been resolved by broader and earlier involvement of users in the form of experiments, as was done in other MaaS trials (Hensher, Ho, & Reck, 2021). However, it cannot be expected that governance uncertainties, being the most important in the two case studies of this paper, are resolved through co-production strategies only.

6. Conclusion

Based on a comparative case study research of applying an uncertainty perspective to two Dutch mobility innovations, this research demonstrates and confirms empirically how the implementation of mobility innovations is a result of very diverse practices of uncertainty management (Dewulf & Biesbroek, 2018; Machiels et al., 2021). Through analysis of key uncertainty moments, it was found that decision-makers push innovations forward by relying on their uncertainty competencies and knowing how to work around and use uncertainty settings to their advantage. Although both innovation trajectories have not been completed fully, technological uncertainties were not experienced as most important by actors. Key uncertainties were about keeping agreements, accountability for when things go wrong and legitimacy of funding. To improve mobility innovation projects regarding uncertainty, this conclusion implies that public and private players should not predominantly focus on creating a better understanding of the functioning and effect of the innovation. Rather, this focus should be balanced with attention towards governance uncertainties in an experimental setting, by exploring different options of how public and private actors can collaborate. Obviously, functioning and effect are the end goal, but they are highly dependent on the quality of dealing with uncertainty during the decision-making, which in turn is highly dependent on the governance set up.

Throughout both innovation cases, there was a tendency to rely on classic uncertainty settings in the form of risk management and client-contractor relationships. This relatively narrow approach towards uncertainty is no guarantee for success however, as it creates more uncertainty for actors in the innovation process itself in terms of compliance. By framing uncertainties as risks, actors feel a sense of control that in a later stage proves illusory as the innovation process is, by definition, highly unpredictable. Decision-makers and their organizations should be better equipped to accept and embrace uncertainties in projects (also allowing failures) and share these uncertainties with their key-partners to create more empathy and a trusted partnership. Hypothetically, such an approach could improve the robustness of public-private collaborations for innovations that can withstand governance uncertainties in a better way.

The results of this study also make clear that leadership skills in the form of a (MaaS) champion can be crucial to navigate around uncertainties of complex bureaucratic organizations and the external environment. Implementing mobility innovations requires multi-actor engagement of new (niche) parties and older (more traditional) parties, and, ideally, the strengths of all these actors are used and canalized in an innovation process. For example, traditional actors can make use of their risk management approaches, but not in such a way that it blocks the development of innovations of which positive effects are yet hard to measure as input for these approaches. In such cases, a more exploratory approach could be pursued where the innovation focus lies on the design process and future institutional and collaborative agreements, rather than trying to push for successful innovation outcomes that fit into pre-defined criteria of success.

The uncertainty described above does not manifest itself uniformly, neither in how it presents itself to the actors involved, nor in how they deal with it. Still, the language in these processes often artificially reflects uniformity of knowledge and interests, only until major conflicts arise. Our switch to a multi-actor and experiential perspective points at different ways of managing uncertainty not by injecting more information (that by the nature of the innovation is tenuous), but by strengthening the relations of those involved to deal with the unavoidable slings and arrows of outrageous fortune. We think this is a field of research with much potential and invites to be further matured.

There are limitations to this study, related to the specific Dutch innovation context and its institutional setting (Koppenjan & de Jong, 2018). Also, because of the duration of the innovation cases, it was impossible to do right to all specific elements or factors that led to a specific decision or outcome of the decision-making process. More interviewees with actors beyond the core management team and direct stakeholders could have validated their experience of uncertainty and attitude towards the specific innovations.

Several opportunities for further research have emerged throughout this research. Firstly, the proposed conceptual model could be applied for other types of (mobility) innovations and 'general' infrastructural planning projects, to analyze how different combinations of uncertainty competencies and settings influence the handling of uncertainty. Secondly, the role of leadership and uncertainty competencies should be further explored, to find patterns that can be used for developing new governance approaches that build robust and trusting multi-actor networks, for example in the form of an evidence-based training for project managers of the future. Also, it would be worthwhile to analyze how co-production strategies for innovations could be a solution for handling uncertainty as elaborated in the discussion section. Finally, practitioners in the field could experiment with defining stages in the innovation process related to high and low levels of experienced uncertainty. The first stage could be more open to find out what to develop, whereas the second phase could be more closed, focusing on efficient partnerships in the classic sense (Lyons & Marsden, 2019). In this way, a mobility innovation process can be both about exploring new possibilities and be controllable from a managerial perspective.

Declaration of interest

The authors declare that they do not have competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Ruben Akse: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Wijnand Veeneman:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Vincent Marchau:** Conceptualization, Writing – review & editing, Supervision. **Simone Ritter:** Conceptualization, Writing – review & editing, Supervision.

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