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SmartRail Living Lab Concept and Supporting Technical Environment

SmartTram1 WP4 and WP5

Project Report

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Contents

1 Introduction

Urbanization is one of the most significant megatrends of our time. It will accumulate many sustainability problems to cities and arranging the people's mobility in a sustainable way is one of the largest one. Transport is one of the fastest growing industries in the world and is also influenced by many megatrends such as climate change, urbanization, servitization, networking and moving towards autonomous operations. Transport represents almost a quarter of Europe's greenhouse gas emissions and is the main cause of air pollution in cities[1]. Since extending road network is not a viable option, intelligent traffic solutions based on more efficient use of current infrastructure are important part of potential solution. Traffic in cities causes not only CO_2 emissions but also other detrimental emissions that are harmful for nature and people's health. Furthermore, for example accidents, congestion, land use, and noise cause significant losses.

In people transportation, increasing the share of public transport combined with walking and cycling is seen the most efficient way to advance sustainable urban mobility. Since data-driven digital services and solutions have become an integral part of the optimization of transport as well as customer experience, their importance is paramount when looking for more sustainable solutions.

The European Union boosts electric mobility to reach its 2050 climate-neutrality target, which means emissions from transport will have to fall by about 90 percent. In many cities across the Europe, reviving or building new tram networks are seen as good way to meet the climate-neutrality target and cut transport emissions. One of those cities is Tampere in Finland where a modern tramway system is being built to meet the needs of the city.

The city of Tampere is growing rapidly. The average population growth has been more than 2,000 annually. The city centre is already congested with buses, and the narrow neck of land cannot support any more bus traffic. In addition to the ecological benefits, key goals of the Tampere tramway system include making the everyday life and transportation easier in the municipality, supporting the growth and development of the urban area, and increasing the appeal of the city. According to report from City of Tampere[2], a tramline reduces the energy consumption and emissions of traffic. Taking into account the working life and capacity of the equipment, 225 buses are required for every 25 tram cars to achieve the same service level. In addition, with the tramline option, the particle, nitric oxide and carbon dioxide emissions are slightly smaller than those of the bus option.[3]

In Tampere, climate emissions from transport are mainly caused by road traffic. The city's goal is to increase the modal share of sustainable options strongly. The tramway is the most significant single project in the development of the public transport system, as it reduces the climate load by reducing energy consumption in transport and using electricity instead of oil. In addition, the tramway creates a framework for sustainable land use and promotes smart mobility that develops smooth travel chains and new transport services.

The development of a sustainable public transport system with smooth travel chains requires a good integration of smart tram environment into the overall transport and mobility ecosystem. Especially new mobility services, such as car-sharing, demand-responsive transport, and city bikes, complement

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[1] https://ec.europa.eu/clima/policies/transport_en

[2] https://www.tampere.fi/tiedostot/c/n1quv1hoN/Carbon_Neutral_Tampere_2030_Roadmap.pdf

3 https://www.tampere.fi/tiedostot/t/M9WqiR3nP/Tampere_Tramway_Environmental_Impacts.pdf

sustainable mobility, and needs to be connected to the smart tram environment. The development of smooth travel chains and new mobility services, as well as an overall improvement of services will boost the increase the modal share of public transport in line with the target set.

Digitalisation, advanced technologies, human-centric design and new operating models are key tools in responding to the challenges of climate change and transport demand increase. The availability and interoperability of data is a key factor to support the creation of new mobility services and ecosystems. According to the United Nations report on Frontier Technology[4], “data is shaping the future of humanity”.

In Tampere, the activities related to the new tramway has given birth to the SmartRail ecosystem led by tram manufacturer Škoda Transtech. Its work, together with Tampere Tramway ltd. (Tampereen Raitiotie Oy), City of Tampere and numerous companies and research groups, aims at user centric mobility services, sustainable mobility and new business opportunities in the context where the new Tampere tramway lies. In this document, we start in Chapter 2 from the aforementioned ecosystem consisting of the stakeholders involved in the development of the Tampere tramway, trams and their operation, public transportation as well as services to the citizens in the context of public transportation. Chapter 3 presents the Living Lab concept adapted to support both the participative development of the city services related to the new tramway and to the public transportation as a whole according to the ecosystem goals. In Chapter 4, selected use cases related to the ecosystem targets as well as living lab operation are analysed in order to deduce requirements for the technical system required to support the R&D&I work in the ecosystem. Chapter 5 elaborates the use cases analysed in the previous chapter to the specification of the Urban Mobility Data Space (UMDS) along with its overall system architecture. The specified technical environment serves at the same time as a part of the SmartRail Living Lab (Living Lab ICT) and more generally as a mobility research data environment serving also other R&D&I activities. In addition, Chapter 5 presents first round of proof-of-concept implementation of the systems and some remarks. Chapter 6 concludes the work presented in this document connecting it to other ongoing and upcoming activities as well as required further research. Figure 1 depicts the relationships of the topics presented in this document.

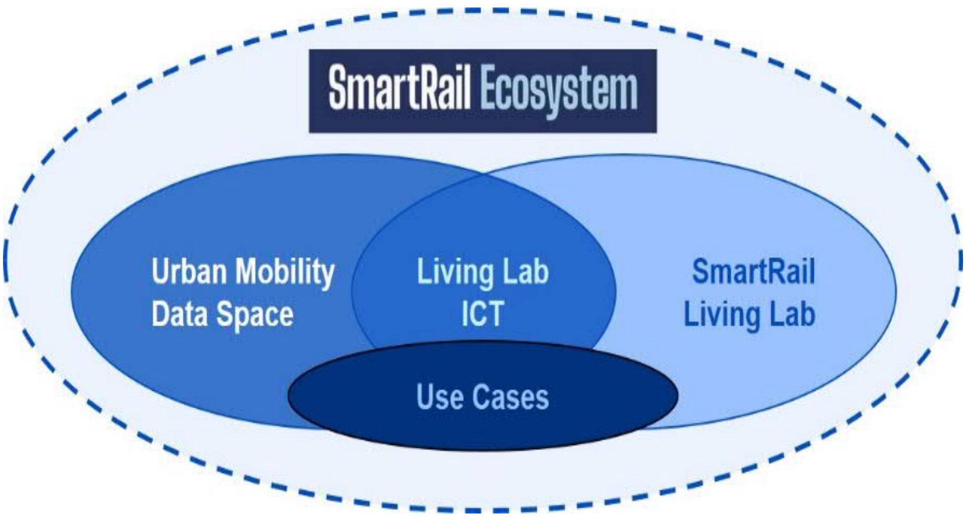

Figure 1. Relationships between the topics presented in this document.

4 https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/FTQ_1_Jan_2019.pdf

2 SmartRail Ecosystem

Increasing competition, global climate challenge and growing demands of the customers are basic examples of the forces that are changing operational environment of transport sector. To rise the challenges, companies and other organisations have to find ways to effectively change their operations, products and services. One proposed way to restructure operations and products is to change company's focus from internal value creation to innovation and business ecosystems and value networks (Lüftenegger et al. 2013).

There are many types of ecosystems in the business and innovation context, and there is no one right definition, but one very good definition describes an ecosystem to be "both a structure and an interactive process, in which actors complementing each other join forces to create value" (Valkokari et al. 2021). Goals of ecosystems can vary, and business ecosystems usually are focused on growing business results around identified customer needs and strengthening competitive position of the ecosystem in global markets (Apilo et al. 2014). In innovation ecosystems the goal usually is related to solving large, systemic challenges and combining different industries to direct operations towards common objectives (Valkokari et al. 2021). To solve systemic challenges of urban mobility and developing autonomous solutions for urban rail environments, SmartRail Ecosystem was established.

SmartRail Ecosystem is, by its own definition, "an industry-driven innovation ecosystem for developing next generation tram transport concepts increasing the competitiveness of both individual companies and the whole consortium in international transport solution markets" (SmartRail Ecosystem 2021a). Ecosystem initiative was established 2017 by Škoda Transtech in collaboration with selected partners. Goal of SmartRail Ecosystem is "to move from traditional engineering and manufacturing towards all-encompassing service and business ecosystem (Rail-as-a-Service) that is able to provide a technologically superior tram as well as digital, integrated services for its whole lifecycle" (SmartRail Ecosystem 2021b). SmartRail is an open ecosystem and currently engages over 20 members in collaborative actions and projects, while expansion through next innovation phases is currently under development. Members consist of large companies, SMEs, universities, research organisations, public authorities and customers (rail operators).

SmartRail Ecosystem is not tied to any specific location like most innovation clusters, but its members are scattered around Finland. However, there are high activity areas such as Helsinki and Tampere areas, where ecosystem members have operative business around urban rail environment. These locations are thus exploited in the ecosystem as use-cases.

2.1 Tampere Urban Rail

City of Tampere decided in 2014 to implement a tramway to Tampere and construction work of the tramway started in 2017. Plan is to start operation of tramway in August 2021. As Tampere is implementing and building a completely new tramway, it served as an opportunity for tram manufacturer and its partners to develop something new in collaboration with their customers. SmartRail Ecosystem members are the ones that are building the new tramway as a part of their daily operations, but the ecosystem activities are aimed towards developing future solutions (such as autonomous tram) that are built in phases piece by piece.

Building new products, services and solutions requires lots of resources and know-who, and ecosystemic collaboration brings together multiple actors that can share the resources and development activities to boost the speed of development and creation of new products. Ecosystemic operation model allows actors to find new ways and methods to collaborate between each other and with other stakeholders. However, it was witnessed during SmartRail Ecosystem's first innovation phase, ecosystemic way of work is not always enough, but processes and methods for collaboration are also needed to facilitate the work. It was also seen that concrete development goals (e.g. specific product) and testbeds would be beneficial in R&D&I work. City of Tampere is known for its innovativeness and testing culture especially related to intelligent transport systems. Thus, Tampere tramway is a logical choice for testing new development concepts and methods.

2.2 Co-creation as a working method for ecosystem-based product development

In last two decades, co-creation has become common buzz word and course of action that public organisations, cities and companies have taken to realize new value through customer insights. Citizens and customers are actively participating development processes through different kind of channels that facilitating organisations create and make available. Furthermore, co-creation is happening more and more between companies, public organisations and third sector. Even competitors are trying to find possibilities to co-create products and services together.

In literature, the term co-creation has multiple definitions. Despite the fact that it has been used for over two decades to describe collaborative development activities, there is still no unified perspective what co-creation term includes or excludes (De Koning et al. 2016). In common, co-creation is vaguely defined to be a cooperative development or production activity, in which two or more persons, actors or stakeholders participate. In co-creation process participants have active roles and solutions are created in collaboration (Rasmussen 2003). Objective of the development activity can be anything from new knowledge creation to business development or New Product Development (NPD). However, there are some different aspects to the definition of co-creation. For example, in business and product development literature, view to co-creation seems to be value- and customer-centric (cf. Kohlbacher 2008, Prahalad & Ramaswamy 2004, Hakanen 2014). On the other hand, in design literature, co-creation can be considered as a design method where users are developers (in guidance) or a design process where users and other stakeholders are continuously consulted (Mattelmäki & Sleeswijk Visser 2011), or any collective creative activity that at least two persons participate (Sanders & Stappers 2008). So, it can be said that the definition of co-creation is indeed vague and broadly interpreted.

Thus, there has been attempts to unify the terminology. For example, De Koning et al. (2016) analysed 50 models of co-creation and defined the term co-creation as follows: "Co-creation is the process of mutual firm-customer value creation. This facilitated (creative) process generates an active form of interaction and sharing between firm and end consumer, instead of the active firm, passive consumer interaction. One of the results of co-creation is that the contact between firm and customer moves away from transactional and becomes an experience."

Later literature proposes that there are three different approaches to co-creation: supplier-driven, customer-driven and firm-driven (Bettiga & Ciccullo 2019). In supplier-driven approach the co-creation activity is done by the firm and supplier in multiple NPD phases, while customers are included only in one phase. In customer-driven approach the firm co-creates with its customers in multiple NPD phases and includes suppliers only in one phase. Firm-driven approach includes both customers and suppliers to the process, but only in one phase (Bettiga & Ciccullo 2019). Bettiga & Ciccullo (2019) highlight the fact that none of the analysed companies co-created with customers and suppliers in all NPD phases.

Most of the aforementioned definitions have common elements: view to co-creation is customer- and/or user-centric, co-creation is considered to be a method or a process, and co-creation is used to create value. The most common approach seems to be that co-creation is seen a way to integrate consumers, end-users or customers to the creation or development process at some extent. Some also include suppliers and partners in the development process. It is also noted that starting points and capabilities to develop and create can vary vastly among participants and thus, it is needed to ease this gap between participants by facilitating the co-creation (Rasmussen 2003).

Most of the literature identify multiple benefits resulting from co-creation. For example, in design literature, co-creation can benefit 1) project itself by increasing knowledge of user needs and giving birth to new ideas, 2) customers of the service by giving birth to services that are better suited for their needs, or 3) participating organisations by advancing cooperation between humans and scientific disciplines or by accelerating innovation practices (Steen et al. 2011). On the other hand, more business-oriented literature argues that by co-creating it is possible to achieve greater value for customers and society, and thus for the developers as well (Prahalad & Ramaswamy 2004, Lusikka et al. 2020).

In SmartRail Ecosystem co-creation is considered to be a key element of ecosystemic way of work. Co-creation that has been done in the ecosystem is however extraordinary, when compared to the literature. As Bettiga & Ciccullo (2019) highlighted there were no companies in their study that included customers and suppliers in all NPD phases. SmartRail Ecosystem has succeeded in establishing co-creation approach that includes customers and suppliers (*who are, as a matter of fact, ecosystem actors*) in multiple NPD phases. In fact, the co-creation has been very profound, and participants have viewed that this working method has been both cost-effective and rapid when compared to traditional NPD process.

To transform development activities from user or supplier centric co-creation to network-like multi-stakeholder cooperation, as SmartRail Ecosystem has been able to do, demands continuous docility and adaptability from the actors (Hyvärinen et al. 2015). However, most important aspects in developing this type of ecosystemic co-creation is right team, setting up clear objectives, open technical tools (as open as possible) and setting up standards used in co-creation (Lyytikäinen 2020).

As mentioned, in SmartRail Ecosystem co-creation is a holistic working method and collaboration can take place in different NPD phases. It was also identified that concrete development goals and testbeds could boost collaboration and co-creation done in the ecosystem. In addition, shared and compatible tools and pre-determined interfaces would ease the co-creation especially in initial stage of collaboration activities. Thus, it was seen that there is a need for an innovation platform that would give participants the concrete goals to guide the work, and a place to test and co-create their products, services and solutions in the way that customers and end-users could be involved in the process as much as possible.

It was recognized based on previous experiments that Living Lab -method offers possibility to joint development and experimenting in real operative environment (Lusikka et al. 2020). So, it can be said that Living Lab is a kind of concrete innovation platform that enables co-creation and collaboration between ecosystem actors, including customers and end-users. Thus, it was decided that in order to develop SmartRail Ecosystem and to improve co-creation opportunities of ecosystem actors, Living Lab for urban rail environment needs to be developed.

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3 SmartRail Living Lab Concept

3.1 Background and motivation

The new Tampere tramway is a significant investment to sustainable public transportation and enhanced passenger experience. It has a great impact to whole public transportation system that will use tram lines as trunk lines fed by bus transportation. Furthermore, the impacts spread to urban structure, city economy and new business for companies involved in the ecosystems built around the developing city. To realize the benefits of the new tramway, it is crucial to attract people to adopt the full potential of public transportation into their use. The services making public transportation easier and more attractive to everyone (including people with special needs) have a special role in driving the shift towards more sustainable city transport. Furthermore, public transportation is connected to city environment, services, events and peoples' life in many ways but only fraction of these connections has been realized as innovative services that not only make travelling easier but improve living in the city on the larger scale.

The benefits of the Living Lab approach come from the several sources:

- *Citizen involvement.* The Living Lab approach (introduced shortly in Section 3.2) brings citizens to the development of city services. In living labs citizens are allowed to co-create services and solutions to their use. The resulting services, in this way, gain faster and improved acceptance. At the same time, citizens get the feeling of empowerment and ownership in their living environment.
- *Ecosystem enabler.* The Living Lab approach brings stakeholders from different sectors together enabling the city to drive their policies together with other stakeholders and citizens as a large ecosystem (see Living Labs as ecosystem enablers in Section 3.3). In this ecosystem, stakeholders share knowledge and know-how, and can together co-create better solutions for the needs of the city.
- *Marketing asset.* As a concrete innovation environment, Living Lab makes innovation activities visible to every stakeholder, attracting increasing number of stakeholders to join the ecosystem and invest to the city. With determined work for keeping Living Lab active and continuously developing it, will make it attractive asset for marketing the city and creating economic innovation activities.

3.2 Introduction to Living Labs

During the last two decades, living labs have gained great interest as a tool for participatory development of solutions. During its existence, the term of 'living lab' – or earlier sometimes used term: 'living laboratory' – has had number of definitions depending on the period of time, the setup and context. Common to the definitions are the real-world context (or imitation of it) for testing or co-creation and involvement of end-users in this work.

In addition to some occasional phrasing, the term 'living laboratory' or 'living lab' can be traced back to early 1990s in the United States where Tarricone (1990) referred the term 'living lab' to a concept house for testing new materials and construction methods and Lasher et al. (1991) used the term 'living laboratory' for the field trial setup involving workers to the development of the image processing system. Eriksson et al. (2005) consider the very concept of the living lab originate from William J. Mitchell at the MIT Labs and realized the concept first in the studies of emerging technologies by observing people in home like environments.

In Europe, living labs started blossoming in 2006 when European Commission put significant funding for projects (*Corelabs* & *Clocks*) realizing common European innovation system based on living labs. In this year, the pan-European network *ENoLL (European Network of Living Labs)* was also founded[5]. In this European context Living labs started to evolve towards a multiparty co-creation ecosystem. In the beginning of the European Living lab movement Niitamo et al. (2006) defined the Living lab as a Public Private Partnership concept rather than mere testing or co-creation with end-users. Leminen (2013) elaborate this definition to the form which we adopt as a basis of the SmartRail Living Lab:

"[Living labs are] physical regions or virtual realities, or interaction spaces, in which stakeholders form public-private-people partnerships (4Ps) of companies, public agencies, universities, users, and other stakeholders, all collaborating for creation, prototyping, validating, and testing of new technologies, services, products, and systems in real-life contexts.

Schuurman (2015) see three major precursors contributing to the development of Living labs:

1. Scandinavian tradition of the co-operative design and user involvement in information technology (IT) development started already in 1970s,
2. European social experiments with IT in 1980s, and
3. the digital cities initiatives in 1990s.

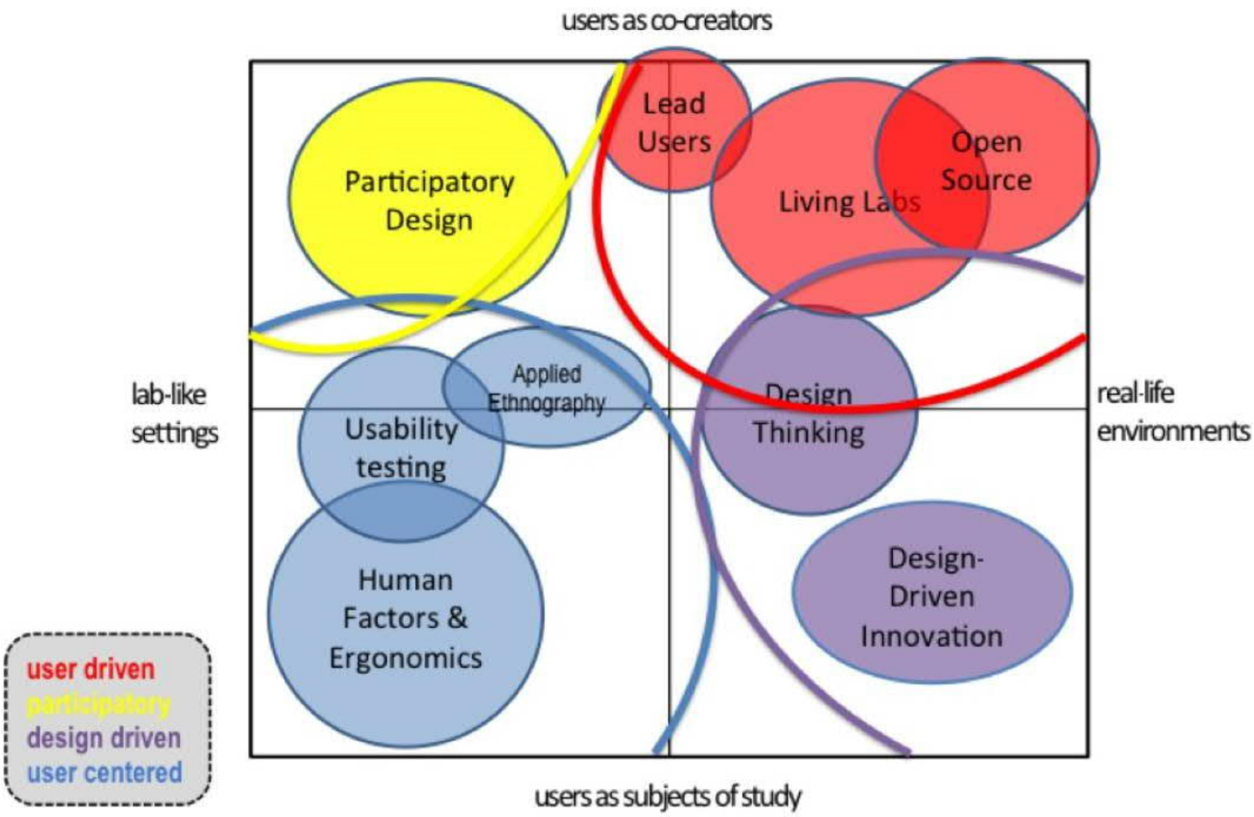

Figure 2. Mapping R&D methodologies involving end-users (From: Allmiral et al. 2012)

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[5] https://enoll.org/

Scandinavian way of co-operative design has brought in the user-centred aspect and the real-life context as well as participatory design. European social experiments, funded for example by European Commission drove experiments from laboratories to outside world, promoted multi-stakeholder aspect as well as end-user involvement. Digital city (later on, smart city) initiatives called explicitly multiple stakeholders from different sectors into co-operation providing the city infrastructure for the real-life context for experiments.

Living labs have also been seen as a R&D approach that is closely related to it. Allmiral et al. (2012) categorize these approaches with respect to degree of user involvement as co-creators and degree of real life in the R&D context (Figure 2). In their work living labs are categorized into the *user driven* approach where users drive the innovation process. Other user driven approaches are *lead user* method originally introduced by von Hippel (1986) involving users that are ahead of average users in their needs and open source communities that have taken the development to their own hands. Other approaches either do not involve so much users as drivers of innovation and/or bring the innovation process to real-world context.

Ballon et al. (2005) distinguishes different kinds of test and experimentation platforms with respect to the maturity of the solutions (to be tested or experimented) and the focus of the activity in the experimentation in Figure 2. Their categorization includes also the degree of openness (on top of the figure) as certain activities are done as in-house R&D and others are done with the help of open platforms or public pilots.

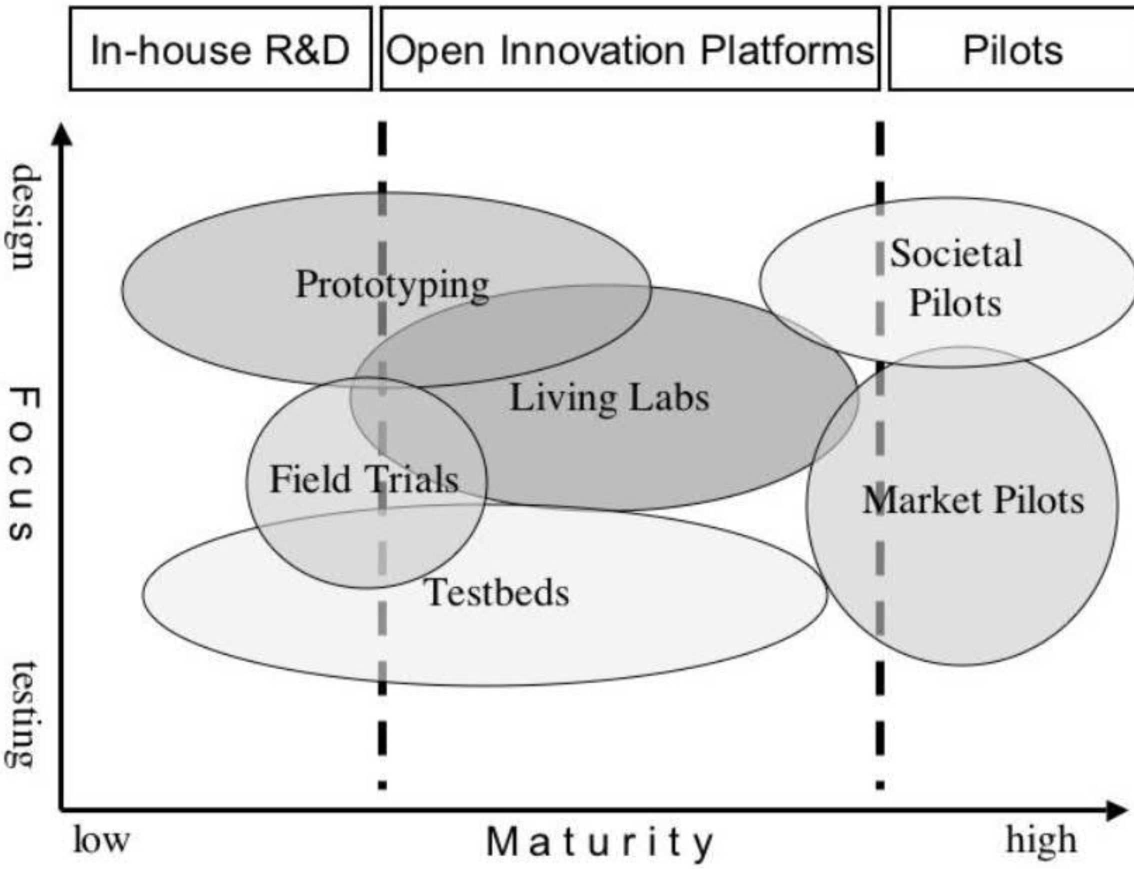

Figure 2. Different kinds of test and experimentation platforms (From: Ballon et al., 2005)

In SmartRail, living lab as a concept or R&D&I approach, is not categorized too rigidly according to the well-known classifications but will offer tools for a large set of activities and various kinds of stakeholder involvement, as seen later in this document.

The living lab approach is seen to bring benefits to all involved actors (Leminen 2015). Companies benefit from the end-user involvement by hands on data about needs and wishes. Furthermore, being able to avoid wrong paths in the development and being directed by user wishes already in the early stages of the development saves companies' money. In the long run, end-user involvement also binds end-users to the company and its activities.

End-users benefits from their involvement as better products where end-users' real-life needs are taken into account. Being involved itself makes the production process more inclusive and is often also contributing to peoples' needs.

Public sector, often financing living labs, in turn get benefits through directing the activities according to their policies. On the other hand, involving citizens gives the invaluable information how to make their lives and living-environment better. Leminen (2015a, 2015b) provides a long list of other advantages of living labs (with references to other publications). In addition, Section 3.3 introduces the Open Innovation paradigm related to living labs and the benefits coming from that.

3.3 Living labs fostering open innovation in ecosystems

This first wave of Living labs concentrated (especially in USA) to end-user involvement in the development of new products. The European approach (see Section 3.2) included multiple stakeholders to share the knowledge and know-how in the living lab-based development. This approach goes hand in hand with the Open Innovation paradigm first coined by Chesbrough (2003). Open Innovation is based on the idea that companies blend external ideas and solutions from other stakeholders in their development. Furthermore, they do utilize both internal and external paths to the market (Chesbrough 2003). The idea is that in the open innovation ecosystem companies gain more opportunities by sharing knowledge and know-how (to certain extent) with each other and utilizing the rich pool of resources in their development instead each having their own pipelines from their internal ideas to the market. Chesbrough (2003) depicted the differences between closed and open innovation with two kinds of innovation funnels: first with firm boundaries and the latter with boundaries "leaking" ideas in and out from the innovation process (Figure 3).

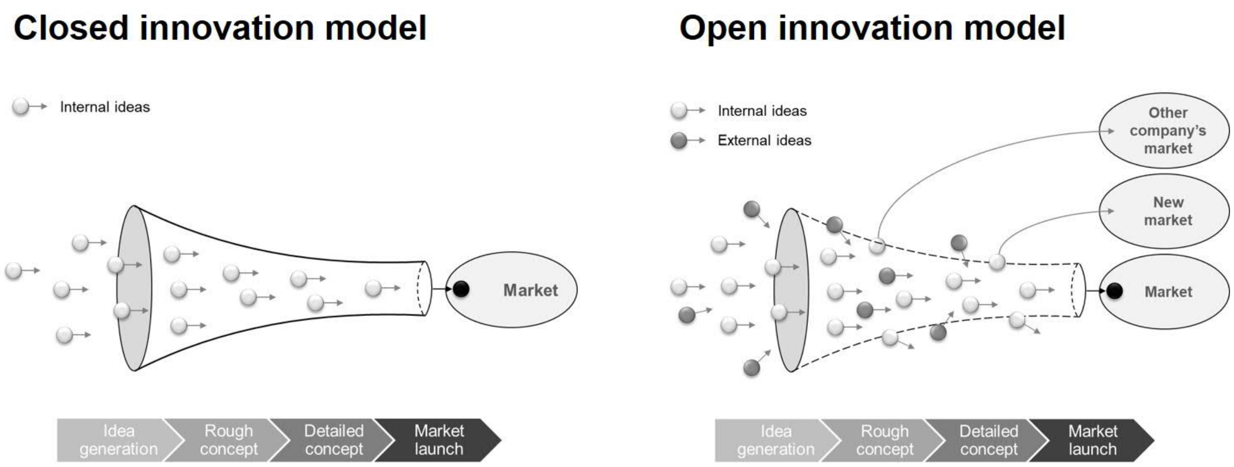

Figure 3. Closed and open innovation funnels (Chesbrough 2003).

The benefits of Open Innovation come from (Chesbrough 2007, Hagy 2017):

- cost and time savings in the development and therefore reduced time to market,
- reaching previously untapped market,
- creating new market, and
- finding new ways to reach market (e.g., by licensing, joint ventures and spinoffs).

The ideas of Open Innovation underlying European Living lab concept does not only bring in the end user involvement but also ecosystems comprising stakeholders from different sectors of the society. Living labs are adapted to serve open innovation (Hagy 2017) or Helix models for innovation ecosystems (Baccarne et al. 2015).

The SmartRail ecosystem involves stakeholders from public sector, business, academy and citizens in order to exchange knowledge and knowhow for enhancing its offering in the spirit of Open Innovation. According to Quadruple Helix Model by Carayannis & Campbell (2009) each of these parties belong to a societal subsystem that has different kinds of relevant intellectual capital to share. The parties accumulate it to the common pool of knowledge and know-how and in this way foster the helical innovation process. Later on, Carayannis et al. (2012) updated their helix model to Quintuple Helix Model adding the fifth subsystem, Natural Environment. With this addition they aimed at bringing in the necessity of taking into account environmental sustainability as a driver of the knowledge production and innovation.

3.4 SmartRail Living Lab Concept

The high-level SmartRail Living Lab concept is based on the Quintuple Helix type Open Innovation ecosystem where the innovations are co-created with the help of living lab environment and methodology. The natural environment in the Quintuple Helix is extended to include different aspects of sustainability (social and economic sustainability in addition to ecological). In this concept, the living lab is offered as a service giving a set of co-creation tools for all ecosystem members working towards innovations supporting the ecosystem goals whereas sustainability targets guide the work. (*Figure 4*)

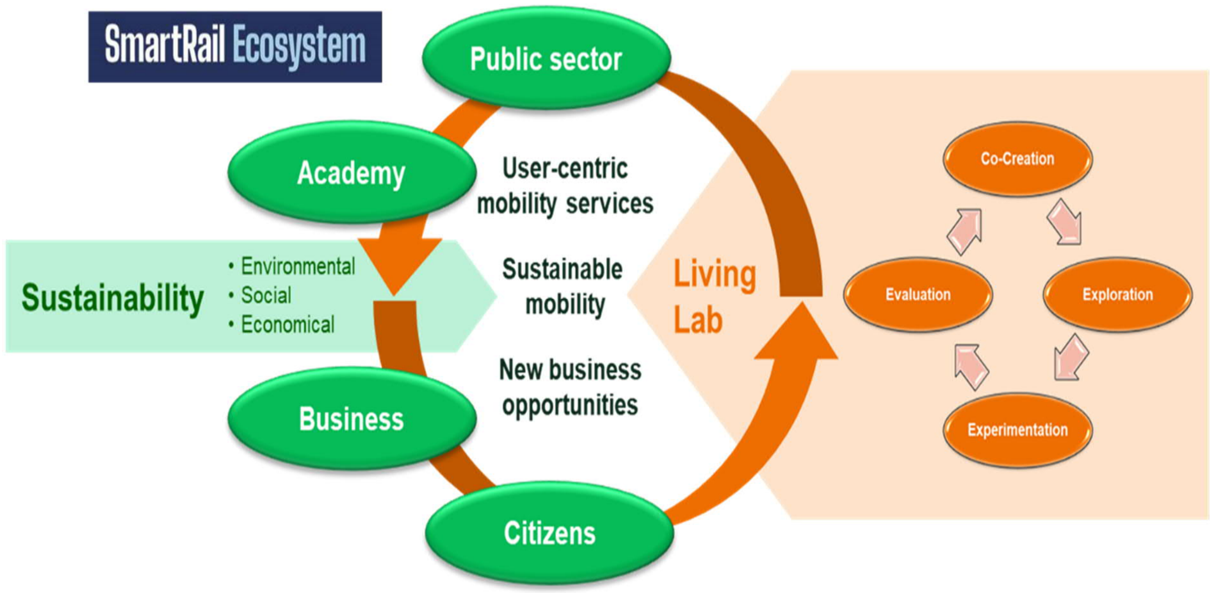

Figure 4. Living Lab as an Open Innovation enabler in SmartRail ecosystem.

The emphasis of the innovation support in the SmartRail Living Lab is on digital solutions and services serving the overall SmartRail ecosystem goals listed in *Figure 4*. This has its impact to the central elements of the SmartRail Living Lab consisting of several interlinked elements depicted in *Figure 5*:

- *Real-life Environment* where the innovation and living lab experiments take place.
- *Living Lab ICT* providing next generation technological environment for experimenting innovative digital solutions.
- *Living Lab Co-creations Tools* providing digital environment and tools for organized and efficient interaction, realization of the real-life experiments, collection of data and feedback and collaborative development.
- *Living Lab Methodology* that supports cyclic open innovation co-creation in different phases of the innovation process.
- *Living Lab Operation* that is based on pre-determined roles, rules, processes and financial model.

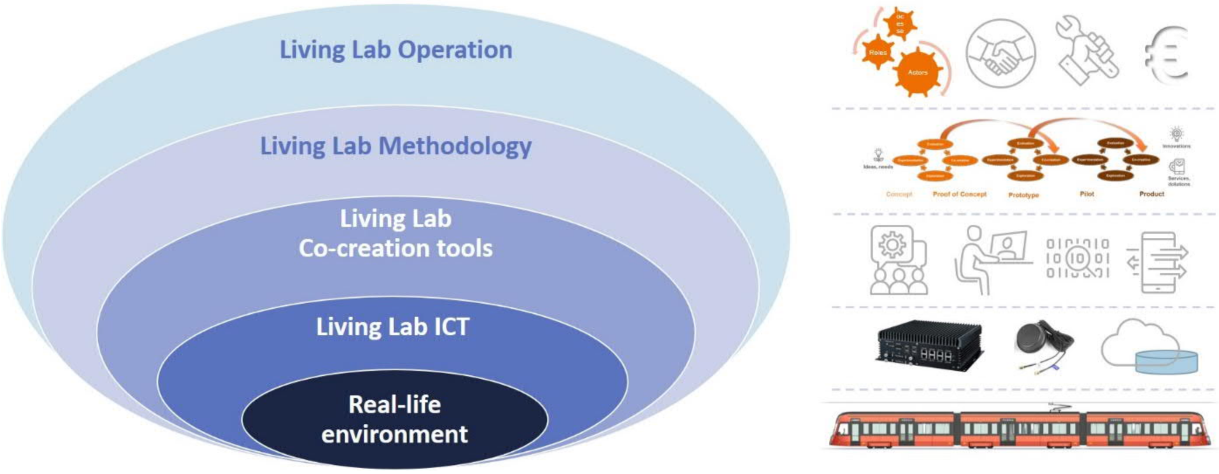

Figure 5. The elements of Living Lab.

3.4.1 Real-life Environment

Test tram

In the core of the SmartRail Living Lab is an operative tram that is dedicated to living lab experiments. It is an extra test tram manufactured by Škoda Transtech belonging to the operative fleet of 20 trams (including the extra tram) in Tampere's new tramway (*Figure 6*). The test tram as a real-life environment provides the context for the living lab experiments. It is therefore crucial that this test environment can be utilized and altered to enable the experiments. From the living lab point of view the test tram provides:

- Tram car and its interior
- Electricity supply
- Tram subsystems like lighting, air conditioning and door operation

- Tram ICT subsystems like info display system, CAN bus, security camera system, driver's services and connection to fleet management and travel information systems

Figure 6. SmartRail Living Lab real-life environment: operative tram. (Photos: Samu Rytkönen / Tampereen Raitiotie Oy & Wille Nyyssönen / Raitiotieallianssi)

The tram car and its interior (like passenger space) provide mounting points to physical equipment and user interfaces. Depending on the cases, the mounting may be on purpose visible and possibly accessible for passengers or hidden in the physical structure (Figure 7). In most cases choosing the visible option is preferable to show the special nature of the test tram for everyone. In this way, passengers, media as well as other stakeholders get interested in the living lab and good publicity is gained for the investments for the future oriented development in the tram context – simplifying: **the more visible and accessible the living lab installations are, the better it is to the publicity.**

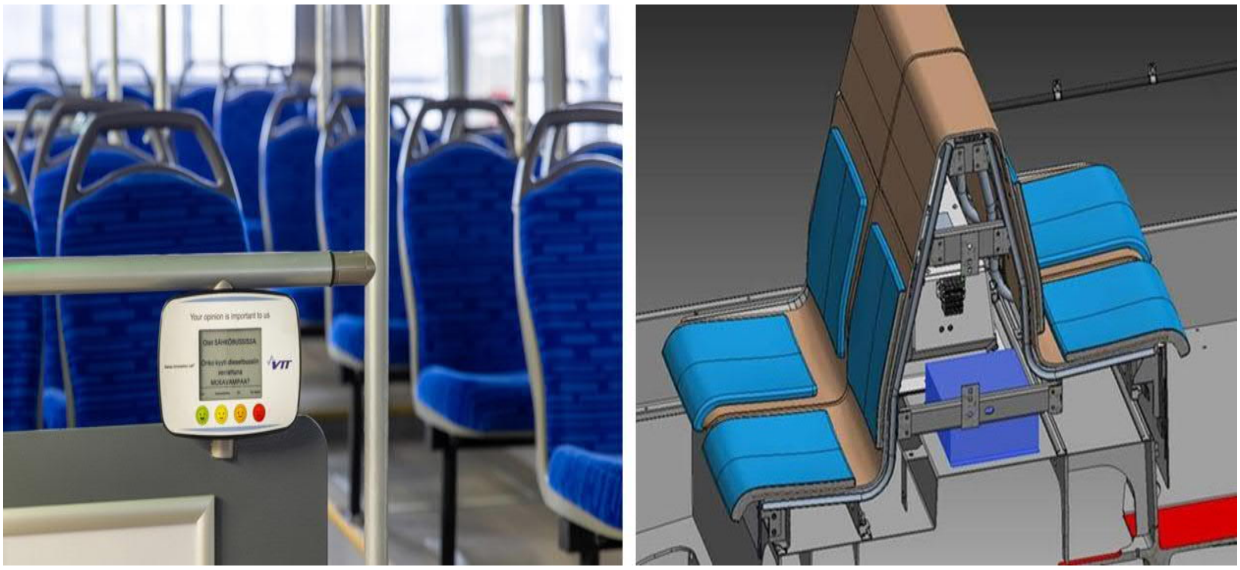

Figure 7. Visible and accessible device – an example from the Living Lab Bus experiment (Kostiainen et al. 2019) vs. hidden device (possible location of a device in a tram).

Living Lab ICT (see Section 3.4.2) as well as those living lab experiments that include physical devices often require electricity. The tram itself provides 24 V (DC) electricity supply coming from the batteries of the tram for the devices. This power option should be available for all experiments that do not have their own standalone power supply (like own battery, solar cells or energy harvesting solutions).

Utilizing the power supply provided by the test tram needs the specifications of the devices (especially power consumption and its peak values) to be inspected by an expert for required safety measures (like fuses). Furthermore, in some cases there is a need for delayed shutdown of the installed devices after the shutdown of tram power and therefore the use of so-called ignition signal might be preferred.

In the test tram, it would be also beneficial to get connected in a controlled way to the tram subsystems. In many cases, non-invasive, read only connection to the status and events of the subsystems is enough. The CAN bus is an invaluable source of information for many solutions and applications. Similarly, information about tram's location and binding to the travel information (i.e. on which trip in the planned timetable tram is bound to) are typically needed information, for example, for experiments related to advanced travel information systems.

Connection to the closed subsystems like security cameras, might require delicate balancing between regulations and maximizing the benefits for the experiments. However, for R&D&I purposes even these systems should be opened at least for restricted experimentations and see how it can be done without violating rules and regulations – for example GDPR.

In some cases, experiments might be expanded from non-invasive subsystem connection to restricted control of the subsystems. For example, the interior lighting or air conditioning of the tram could by controlled by some experimental solution experimented in the living lab.

Other SmartRail Living Lab environments

While the core of the SmartRail Living Lab as a real-life environment is the test tram, the SmartRail Living Lab is complemented with several other environments supporting different cases and phases of the development (*Figure 8*). The idea is that the living lab process (see Section 3.4.4) can always provide the most suitable environment for the development of the idea towards a product depending on its maturity, nature of the solution, required controllability of the environment, desired publicity etc.

Figure 8. Different kinds of environments in the SmartRail Living Lab.

The most controllable and closed environment is *Laboratory* that contains a replica of the Living lab ICT environment, possibly with simulated connections to the tram environment. This environment is suitable for testing, for example, the early phases of ICT and content solutions.

Light-Maketti is lighter version of the rough imitation of some part of the tram. It offers an environment for explorations of the solutions in their early phases that needing to take into account the physical tram environment. This environment is easily accessible and modifiable environment offered by Tampere University and can be used in student projects and quick experiments without greater planning.

Maketti is more heavy-duty tram replica made imitating very closely one part of the Transtech's tram and an example of the stop area. In its cab, there is sophisticated simulation environment for driver training providing realistic virtual reality view through its screens imitating the windshield. Maketti resides in the tram depot that has restricted access and visiting requires preparations in advance. This environment fits well for more detailed planning and experiments which need near exact tram environment but not real-life end-user involvement.

Test tram described earlier in this section provides real operative tram and real passengers for the living lab experiments.

Finally, in some cases experiments can be extended to the whole 20 tram *Operative fleet*, which requires production level solution that has been seen interesting or useful enough to be tested in the large scale.

One interesting addition to living lab environments, can be offered by *Simulation Environments*. The SmartRail ecosystem has produced sophisticated simulation models and tools with realistic looking 3D graphics (Figure 9). Certain experiments, for example ones involving tram drivers, would benefit from this approach.

Figure 9. SmartLab simulation tools. (Photos: Škoda Transtech)

3.4.2 Living Lab ICT

The Living Lab ICT in the SmartRail context consists of extra ICT infrastructure, devices and software solutions allowing easy experimentation without disturbing operational ICT subsystems. Furthermore, Living Lab ICT exceeds the operational tram ICT solutions and is thus allowing experimentation of the solutions that may not be possible with the tram ICT dedicated to the everyday operation.

The Living Lab ICT consist of on-board devices and cloud services. In the core of the on-board devices is the on-board computer that:

- controls the on-board devices in the living lab environment
- provides environment for software related to the living lab experiments
- provides an edge computing environment
- act as a communications network hub for devices in the on-board environment
- provides the connection to the selected tram subsystems (like CAN bus)

- collects data and pre-processes it for the real-time use or the accumulation of the history data
- send data to the cloud for further usage
- provides local interfaces for real-time data

One of the most visible on-board part of the living lab consists of the displays through which the experiments are often made visible to the customers. In the operative tram environment, there are three kinds of systems for their own purposes (*Figure 10*):

1. *Tram line information* showing progress on the tram route and transfer connections.
2. *Next stop information* showing the name of the next stop (and indication of stopping).
3. *Advertisements* dedicated to local advertisement company.

The only displays from the above that can be dedicated for the living lab purposes are those dedicated for tram line information. However, it is not clear how the use of replacement of the (partly restricted) background system for the display operation should be done. Furthermore, by adopting the line information displays fully to living lab use would restrict important travel information from the passengers. As a conclusion, the most optimal solution would be to install own extra living lab displays that are controlled by the living lab environment. In this way, experiments could fully utilize the power of advanced living lab environment without undermining the passenger experience of the operative information system.

Figure 10. Displays and their purposes in the tram (Photo: Tampereen Raitiotie Oy).

Above the on-board computer and displays, the on-board equipment may contain, for example, a (changing) set of sensors and interaction devices.

In addition to the on-board environment, the Living Lab ICT include a cloud environment that collects the data coming from the Living Lab ICT as well as from number of other sources. In this way, living lab experiments and research may combine and utilize the available data. For more detailed information about the technical solutions planned to support living lab can be found in Chapter 5.

3.4.3 Living Lab Co-creation Tools

Living Lab Co-creation Tools offer the means to execute the methods used to realize open innovation, user participation and co-creation activities in the living lab experiments. Studies on methods and tools used in the living labs are scarcely available, although the living labs themselves are discussed intensively in the academic fora (Leminen et al. 2017). Leminen (2017) categorizes living lab tools by the innovation process (Linear/Iterative) and usage of tools (Standardized/Customized) to distinguish archetypes of living labs. They argue that living labs based on standardized tools or linear innovation process (starting from an ideation or early development phase and ending with initial market activities such as a market launch) leads to predefined incremental innovation results. Iterative process and customized tools, in turn, increases the possibility to achieve undefined and novel innovations. The first type of innovation has the advantage of the simpler process with well-known activities on the development path, and this approach suits for certain cases when the desired outcome is relatively well-understood in advance. The latter approach leads to more complex and unpredictable process where iterations and activities must be added on the fly in order to crystallize the outcome.

In SmartRail, the living lab concept aims at supporting both iterative and linear innovation processes (see Section 3.4.4). Moreover, in many cases living lab support is needed only in some part of the process, and in SmartRail also this should be possible. While the next section addresses the methodological approaches in more detail, this section takes a closer look on required living lab functionalities to be supported by the tools.

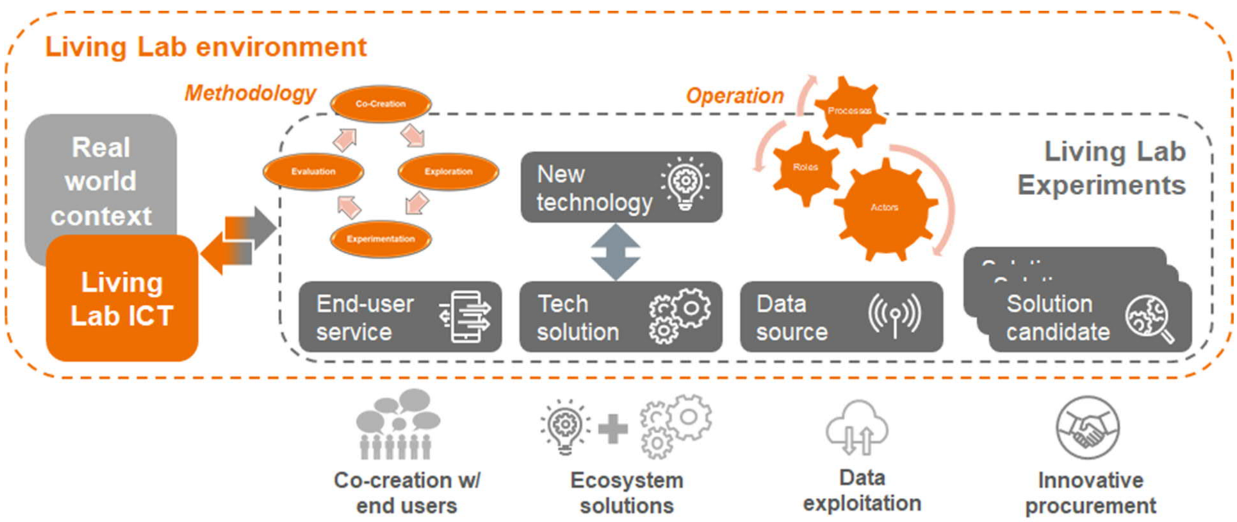

Figure 11. Co-creation examples in the SmartRail Living Lab.

The living lab is a tool for co-creation and integration of different stakeholders and end-users into the innovation process. Mengual et al. (2018) distinguishes three different categories for the tools needed to this:

1. *Tools for passive integration* enabling non-invasive way of obtaining information through observations on the (test) subjects using the solution under some phase of the development (for example, direct observation, observation from video, tracking and video analysis)
2. *Tools for reactive integration*, in turn, is based on explicit activation of the users of the experimented solution to provide information by asking it in different ways (for example, questionnaires, voting and interviews).
3. *Tools for co-creation* enables channels for the users to proactively participate by giving ideas and feedback or discussing the solution related topics (for example, feedback channels, discussion groups).

In the SmartRail Living Lab, co-creation with end users is only one mode of working and it can take place between other stakeholders and contexts too (*Figure 11*). For example, the co-creation support aims to reach also developers tapping the resources (e.g., data, living lab environment) available from the living lab. For that, the concept should include a developer portal and open APIs for experimenting with the SmartRail resources. The experiences of the developer portal in the Living Lab Bus (Kostiainen et al. 2019) will be taken into account in the realization of the SmartRail Living Lab portal. Such a portal should provide all the needed assets for developers to ideate, plan, implement and deploy their services for the test use (*Figure 12*).

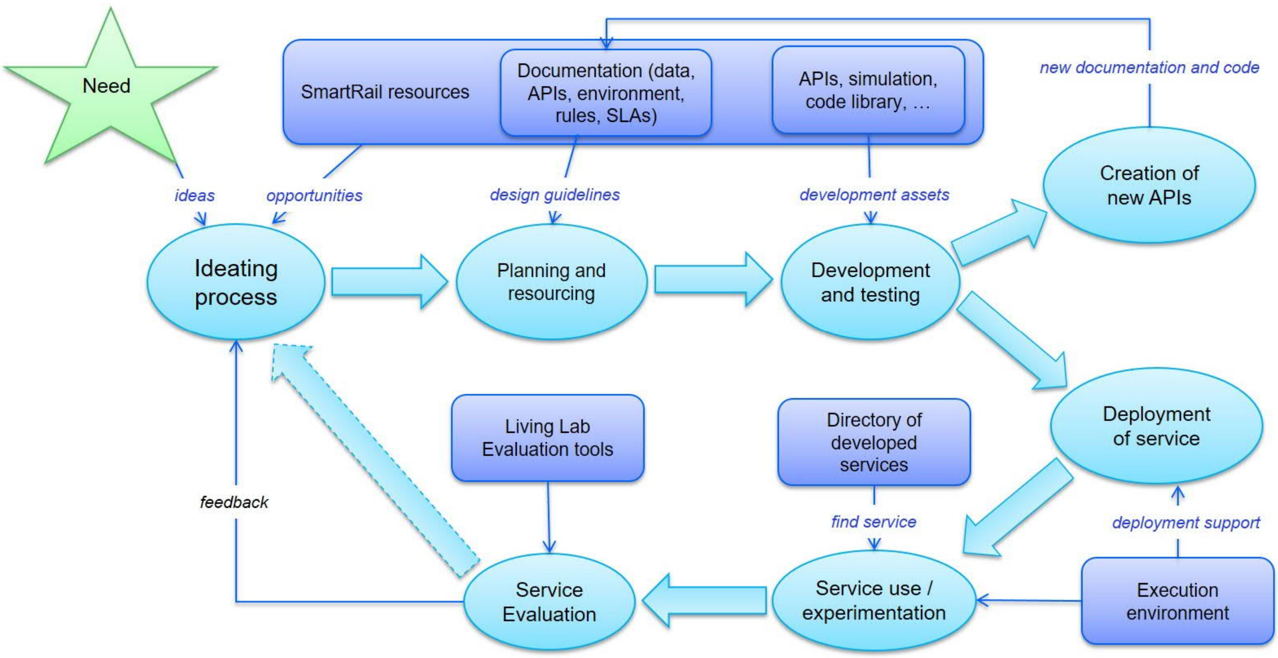

Figure 12. Developer process in the SmartRail Living Lab. Adapted from Heino (2016)

Yet another kind of co-creation processes takes place between ecosystem members where companies utilize solutions from each other and where public stakeholders make innovative procurements. The tools and resources are partially the same as needed in co-creation with end-users and developers utilizing SmartRail resources. Communicating needs and ideas to the ecosystem stakeholders, sharing knowledge, knowhow and resources, providing solutions to the ecosystem members (or openly to larger groups), getting feedback, usage data and observations from the experiments are all needs to be supported. Ecosystem workshops, like Ecosystem Days held in SmartRail, have proved to be one good way for sharing knowledge between ecosystem members. Furthermore, there are needs for preparing projects, making deals and contracts and facilitate co-creation activities among the ecosystem members.

One particular functionality that is usually not mentioned in the living lab literature but is proposed to be included in the SmartRail Living Lab is an Experiment Registry that stores information of all the experiments done in the living lab, and in addition to that, the realized benefits acquired from the experiments. With this tool, it is possible to market the SmartRail Living Lab further. In addition, the collected information about the experiments allows building a match-making tool, that enables different parties to find useful connections to companies and fostering further co-creation activities as well as attracting new members to the ecosystem.

3.4.4 Living Lab Methodology

The Living Lab Methodology defines how to achieve the results that address the SmartRail ecosystem goals and objectives. In the individual innovation experimentation, it means: how the living lab environment as well as its tools and methods are utilized in order to progress towards anticipated results. What kind of innovation, development, testing etc. processes are supported?

As brought up in Section 3.4.3, the living lab process can be linear or iterative, both processes having their strengths and weaknesses as well as fitting purposes. The starting point of the SmartRail methodology is iterative and is loosely based on the widely referenced living lab process (*Figure 13*) defined originally by Pallot, M. (2009) and later introduced, for example, by Vicini et al. (2012).

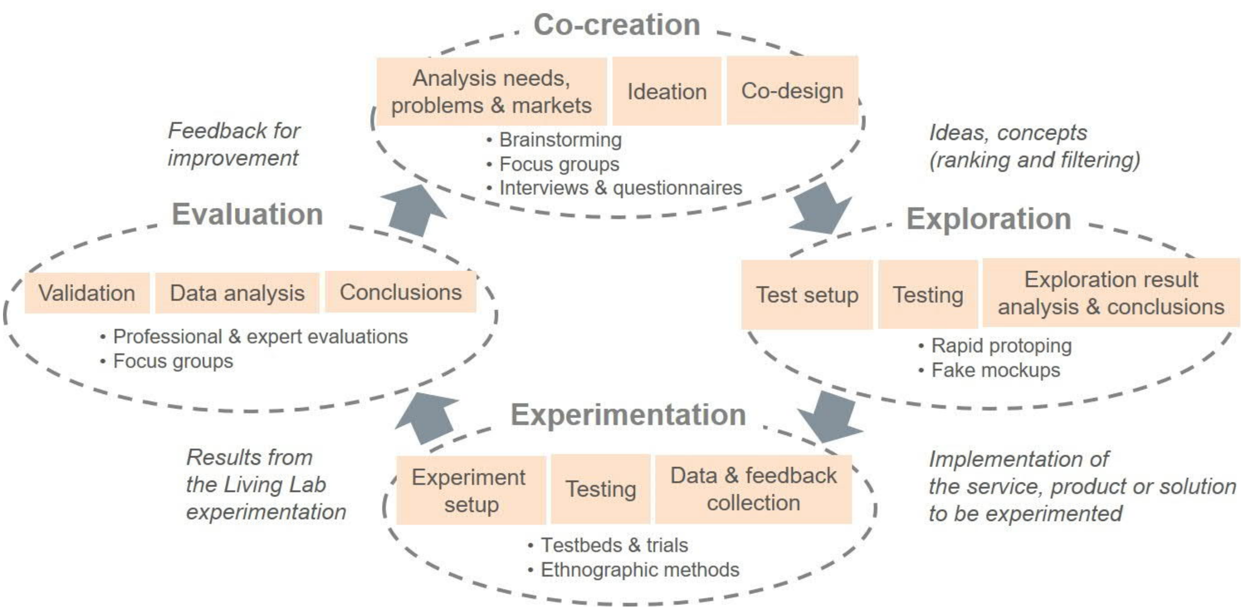

Figure 13. Iterative Living Lab process. Aadapted from Vicini et al. (2012).

The iterative living lab process introduced above can start from any point as the whole innovation process from idea to product is not always needed. Therefore, for example, it is possible to utilize the living lab just for testing ideas by using Co-creation phase for idea generation and elaboration and

Exploration phase for evaluating rough prototype or mockup. After that the development process can progress in various ways (that do not necessarily utilize living lab) or it can be abandoned if the idea proved to be less viable. Similarly, nearly final product can be brought into the Experimentation phase of the process introducing it, for example, in the SmartRail test tram just to get feedback from the end-users for the finalization of the product utilizing the Evaluation of the received feedback.

Hagy et al. (2017) propose that the linear innovation process (Chesbrough 2003) could be combined with the iterative living lab process with tailoring the approach case by case. In the SmartRail Living Lab methodology, the aim is the same added with the novel idea of *the Living Lab Path* (*Figure 14*). It adopts the idea of multi-cycle spiral process introduced by Ståhlbröst & Holst (2012) and puts it into the unique SmartRail Living Lab setting consisting of several possible living lab environments offering different levels of real-life context (see Section 3.4.1).

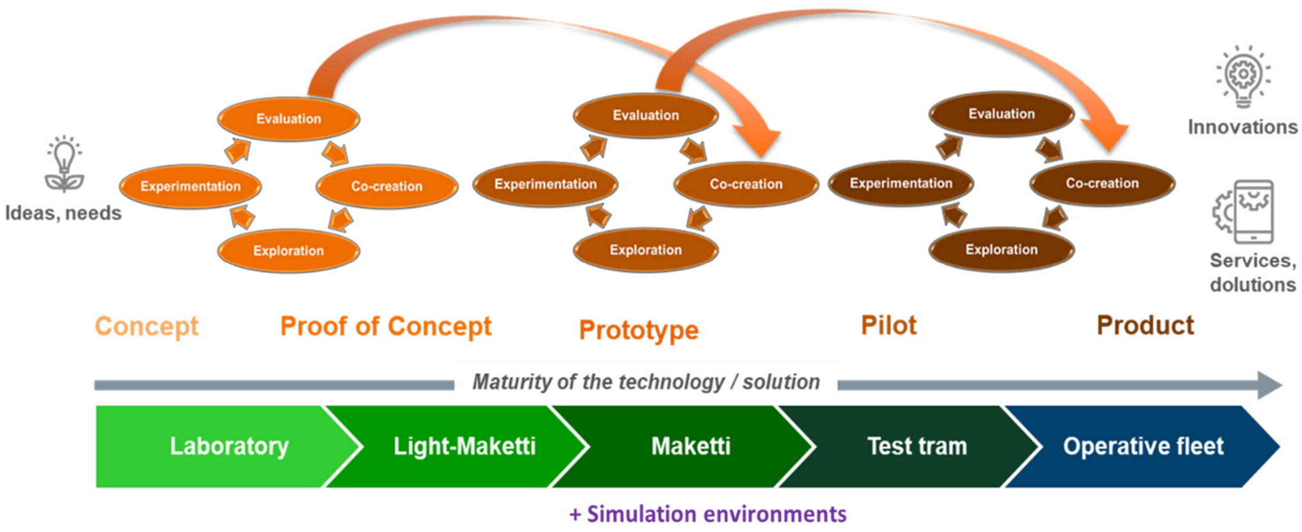

Figure 14. SmartRail Living Lab Path provides innovation process and Living Lab context for every stage of development.

The idea is that all kinds of living lab experiments are supported. The Living Lab Path allows multiple cycles of iterative development through the whole innovation process or only part of it depending on the needs. In practise, most experiments go through only partial living lab process, for example:

- Utilizing living lab (and its physical environment) stimulating ideation
- Testing an idea with mockups or prototypes
- Taking users into the development in the prototype phase
- Testing almost ready product in the real-life environment
- Providing β-version of software module for developers and other companies to experiment
- Testing in-house product in the real-life environment
- Providing data APIs for own on-board application for feedback
- Promoting existing product in real-life context for public procurement

The examples above are not giving an exhaustive list of use cases but reveals the potential of the Living Lab as multi-purpose tools for the ecosystem and its enlargement. It is also online with the categorization of the living lab projects provided by Schuurman et al. (2016b) and presented in *Figure 15*.

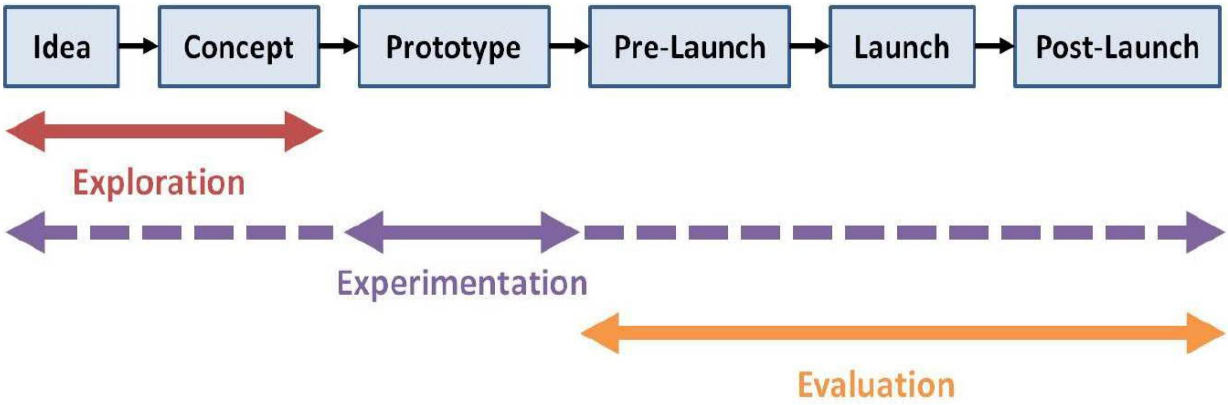

Figure 15. Different types of Living Lab projects in new product development by Schuurman et al. (2016b).

3.4.5 Living Lab Operation

Purpose of Living Lab

The purpose of building up the SmartRail Living Lab is to provide a concrete co-creation environment that maximize the benefits from the public and private investments directed to the Tampere tramway, the test tram and the related development activities.

On the course of the SmartRail Living Lab concept development, the work evolved to more concrete direction as it involved planning the operation of *Tampere Urban Rail Mobility Services (TURMS)* to be realized around the living lab in a test tram. Therefore, in the context of the living lab operation we refer to TURMS as the concrete planned instance of the SmartRail Living Lab concept. TURMS aims to bring together the excellence from all sectors to build a world class R&D&I environment that combines sustainable and inclusive public transportation and smart city services, enhanced and new solutions for rail transport manufacturing and operation as well as multi-sectoral innovation activities.

Actor roles

The SmartRail ecosystem that is in the centre of the tramway innovation activities forms quadruple helix innovation group, in which the leading stakeholders are:

- Public sector: City of Tampere, Business Tampere and Tampere Tramway Ltd. (TRO), Business Finland
- Business: number of companies led by Škoda Transtech
- Academy: VTT as a leader of the research group consisting of several research organizations
- Citizens: End-users and 3rd sector actors involved in the co-creation activities.

According to Leminen et al. (2012), these actors in the Living Lab context can be categorized to four different main roles:

- *Utilizers* that aim to develop their business within the living lab ecosystem through living lab experiments. Focus is in the development of their own products, services and solutions by collaborating with other stakeholders and setting up usually short-term co-creation experiments with the living lab.
- *Enablers* provide financial and policy support for the startup and maintenance of the Living Lab operations.
- *Providers* that build and maintain the Living Lab infrastructure and provide the products, services and expertise used in the Living Lab. They collaborate with other stakeholders and utilizers of the Living Lab co-developing new products, services and solutions advancing their long-term goals.
- *Users* consists of end-users involved in the living lab experiments.

In addition, Schuurman et al. (2016a) distinguishes *Researchers* to its own role rather than belonging to providers as the innovation helix concepts separate Academy from the other actors. They bring in the research expertise both in the user research, innovation and ecosystem theories as well as deep knowledge in the topics related to the work done in experiments in the living lab. The more detailed list of roles has been described, for example by Nyström et al. (2014).

Table 1. Roles and examples of actors in Tampere Urban Mobility Services (TURMS)

Role	Examples of SmartRail stakeholders
Utilizers	SmartRail ecosystem companies
Enablers	City of Tampere, Business Tampere, Tampere Tramway ltd. (TRO), Business Finland
Providers	Transtech, Tampere Tramway ltd. (TRO)
Researchers	VTT, TUNI, KAMK, LUT
Users	Citizens and visitors of Tampere

Financing

Enablers' role has a paramount importance in TURMS as financial investors. The test tram, dedicated to the Living Lab use and financed by TRO, form the biggest individual investment forming the core of the TURMS Living Lab environment. At the start, enablers provide also the greatest portion of the financial support and resources for the start-up and maintenance of the operation. In this, the responsibilities may continue years, but the goal is to get the living lab operations finally self-financed. This requires a business model, including the description of the revenue streams. For that, the planning of the TURMS operations have produced a model in which the costs and revenues of the living lab operations have been planned for the next 6 years, during which the goal is self-financed operations.

Enablers are not the only source of financing though. The TURMS environment has been seen beneficial also for utilizers, providers and researchers. From this basis, the SmartRail ecosystem members, independent of their role, are ready invest this joint venture. For the maintenance of the living lab operations, the financing model is based on customer fees for the usage rights to the TURMS Living Lab and its resources and in the first years complementing funding from Business Finland. In addition, separate service fees are charged from the special work to enable the living lab experiments. Above that, a separate shared benefit project financed by TRO, Škoda Transtech, VTT and TUNI, is planned to build the concrete initial living lab setup.

Management

Management of the living lab consists of its establishment and maintenance. Eschenbacher et al. (2010) divides management into four stages that are illustrated in Figure 16 by Wellsandt et al. (2012).

The first stage, *Connect* in *Figure 16*, refers to start-up of the living lab. In the TURMS context start-up is already an ongoing process. The core stakeholders have been bound to the process and given their initial roles (see sub-section 0). The separate shared benefit project to build the initial concrete version of the TURMS Living Lab environment is in preparation. Furthermore, major investment decisions, for example, for the test tram has already been done. Objectives and goals are clear in the general level but still require elaboration and binding to practical responsibilities and activities.

The second stage, *Set boundaries and engage*, has also been started. Rules for the TURMS activities and process for applying to the living lab experiments have been drafted. The business model, especially the revenue streams of it, has also been drafted and presented earlier in this section (see sub-section 0).

The third stage, Support and govern, refers to the operation of the Living Lab activities. The planned tools and methods have been introduced in Sections 3.4.3 and 3.4.4. The important role of animation

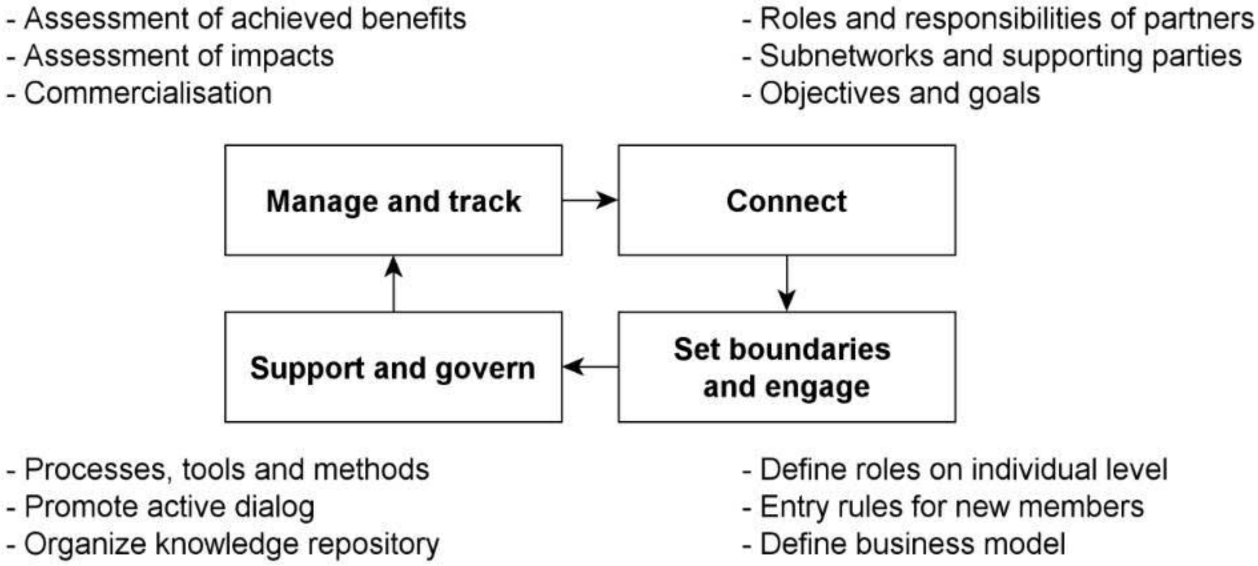

Figure 16. Living lab management stages (Wellsandt et al. 2012)

to keep the living lab alive and flourishing has been addressed in the subsection 0. The initial version of the process through which the utilization of the TURMS Living Lab is done is presented in Appendix 1.

The fourth stage, *Manage and Track*, includes the commercialisation of the living lab and the ongoing financial planning has this aspect as a primary goal. The plan is to get TURMS self-financed. For the assessment of the impact, it is proposed that TURMS would include register of the experiments done and the perceived impacts by the stakeholders involved in the experiments. This register is planned to have also tools to find out connecting factors from the experiments by different stakeholders and, in this way, to mine up new opportunities.

The Appendices include draft versions of concrete results from the operational planning:

- the TURMS rules - Appendix 1: TURMS Open Access Principles (Finnish draft),
- the TURMS partnership application form - Appendix 2: TURMS Partnership application (Finnish draft), and
- the Turms Living Lab utilization process - Appendix 3: The process for the TURMS Living Lab utilization (Finnish draft)

Animation

Another crucial task to enable the success of the TURMS Living Lab is the animation of the living lab, i.e.:

- marketing the TURMS Living Lab and motivating stakeholders to utilize it,
- bring in utilizers and their cases (experiments) through their networks,
- making the city policies and needs visible for living lab utilizers,
- arranging campaigns for the TURMS Living Lab utilization (e.g., competitions or using the living lab as a means for public procurement),
- connecting the TURMS Living Lab to city development and major events, and
- being an active partner in arranging joint national and international projects utilizing the TURMS Living Lab.

Leminen (2012), divides living labs to four categories depending on the actor driving their activities: utilizer-driven, enabler-driven, provider-driven and user-driven living labs. In the TURMS case drivers potentially come from all different roles. Enablers are probably the most important drivers as they aim at societal changes, better city life and flourishing business in the region. This means that City of Tampere and the companies owned by it are in the key role. For that reason, it is of paramount importance that, in addition to the funding, City of Tampere will dedicate personnel resources taking the TURMS Living Lab and its animation one of the flagships they drive in Tampere region. Tampere Tramway ltd. (TRO) owned by City of Tampere has a special role here with respect to the test tram that is meant to be the most visible part of the living lab for the public. The living lab activities and new technology solutions should be clearly visible and offering of the new experiments continuously evolving.

Škoda Transtech has also an important role as a provider driving its long-term development goals. TURMS gives them an opportunity together with TRO to maximize the potential of the development. In this, animation of the technology providers and development of the ecosystem-based co-creation with the help of TURMS is probably the most fruitful way.

In addition, utilizers have their own business goals and now in the SmartRail ecosystem a unique opportunity develop their offering. TURMS offers also for them an opportunity to drive their own business development by utilizing the Living Lab for their purposes.

Finally, 3rd sector as well as individual citizens have opportunity to ideate and co-create solutions to be tested in the TURMS context. Especially, in the software development, the developer portal and open data allows anyone to contribute.

In all the aforementioned lines of animation, researchers can give great help. For example, they can utilise TURMS in the courses and theses of their students and may, for example, arrange hacathons. These kinds of activities serve the overall goals the best if organized together with enablers and providers who give their needs and ideas about the topics.

Researchers have also another role in the animation. They can provide experimental services and solutions to the TURMS environment in order to trigger users' and other stakeholders' minds. The idea in these experiments is not always to test some product in development but only make visible what is possible and available in the environment. For, example visualization of the events and phenomena in the operating test tram context could raise positive interest. In addition, for developers these experiments can provide excellent know-how for their work when, for example code is released as public examples.

The animation part is easily overlooked and belief that investments to the building and basic maintenance is enough might conquer the minds. However, without continuous animation and dedicated resources to the responsibilities in that, TURMS has much slimmer chances to redeem the expectations.

Managing the experiments in the Living Lab

The experiments where the living lab is utilized have their own life cycle (*Figure 17*). The detailed tasks belonging to the different phases of the experiment depend on the nature of the experiment. The experiments can be divided roughly to two main categories:

1. End-user experiments that make themselves somehow visible to the end-users and may include end-user interaction, and
2. Technology experiments that are not actively involving end-users.

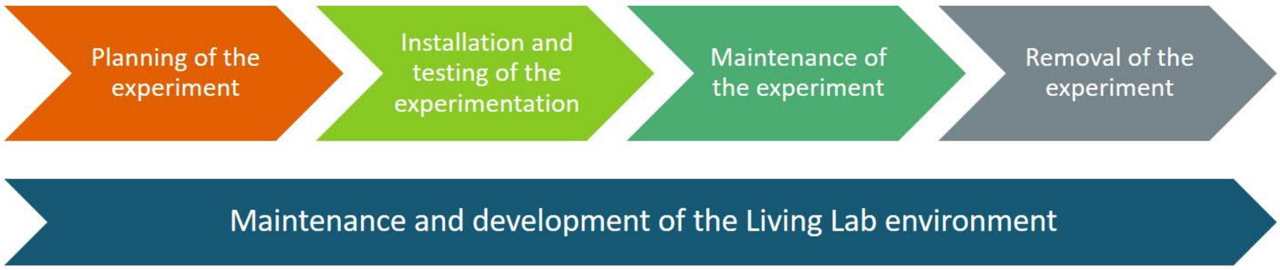

Figure 17. Life-cycle of an Living Lab experiment in TURMS.

Both kinds of experiments mentioned above have numerous possible considerations to be taken into account in the planning, e.g.:

- Placement, protection and mounting of the visible hardware
- Technical and safety requirements of the hardware and its connections to tram and Living Lab ICT
- Software requirements, additions and modifications for the Living Lab ICT
- Requirements from possible rules and regulations (GDPR, company policy, etc.)
- Rules for content experimented in the Living Lab
- Need for manufacturer, tram subsystem provider or depot worker assistance

The non-exhaustive list above gives examples of the practical considerations in the planning and realization of an experiment. While for some cases, it is possible to give detailed process how to proceed, it is impossible to provide any predefined set of processes for all the different kinds of the experimentation. In the end, all the experiments are unique and need support from the Living Lab workers in their realizations. Appendix 3 elaborates the generic process for the Living Lab utilization further.

3.5 Evolving SmartRail Living Lab

The SmartRail Living Lab concept is based on the idea of continuously evolving environment. The living lab planned to be realized in TURMS is a long-term endeavour. Since the technology and needs are changing rapidly, the living lab must be able to respond to these changes in order to serve the involved stakeholders well.

The first initial built of the living lab, *Living Lab Core* in *Figure 18*, is planned to be realized during the last half of the year 2021 and expanded during the year 2022 in the shared benefit project funded by the core SmartRail partners. After that, it is important to distinguish mere technical maintenance tasks (like operating system upgrades and installation of safety patches) and further development that extend the Living Lab environment, functionalities and services. The latter ones may need additional financing above the operation costs. Upgrading, extending and enriching the Living Lab Core may also include additional methods and practises in to support the Living Lab Methodology.

The second way to complement the SmartRail / TURMS Living Lab with new features and capabilities is to utilize the ecosystem involved into the utilization of the Living Lab. The idea of 'utilizing utilizers' is that suitable experiments that could be useful for other stakeholders could remain as a part of the living lab for longer time or even permanently. Good example on this is an experiment on some novel sensor that provides useful data from the tram environment. If the sensor experiment proves to be successful, there is no reason to remove it from the living lab environment but leave it as a permanent part of the living lab adding new feature and data source for it. In this way utilizers' experiments may end up to *Ecosystem extension* in the living lab (see Figure 18) and, in this way, gaining more attention and opportunities to its provider than mere short term experiment.

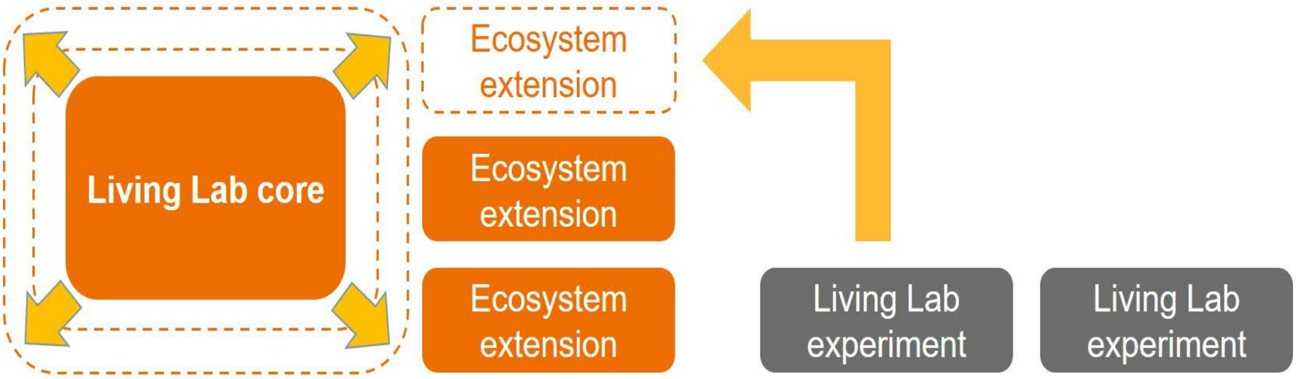

Figure 18. Evolving living lab concept.

3.6 Extending Living Lab from the test tram

The SmartRail Living Lab concept, and its realization as TURMS, is not restricted to mere test tram or even to the environments in the SmartRail Living Lab Path introduced in Sections 3.4.1 and 3.4.4. The new Tampere tramway is tightly bound to other people transportation in the region. It is also connected to the reasons of mobility: the places, infrastructure, events and services in the city. The living lab experiments may well be combining these city elements to the experiments and utilize also other physical city spaces than tram. Especially, the digital services do not recognize boundaries of the physical environments and mashups of different services including public transportation may give a birth to new fruitful innovations. In that, open data, data from the TURMS environment as well as, in some cases, combined with closed company data are in central position. *Figure 19* gives examples of potential connections to the SmartRail / TURMS Living Lab extending the environment to whole city.

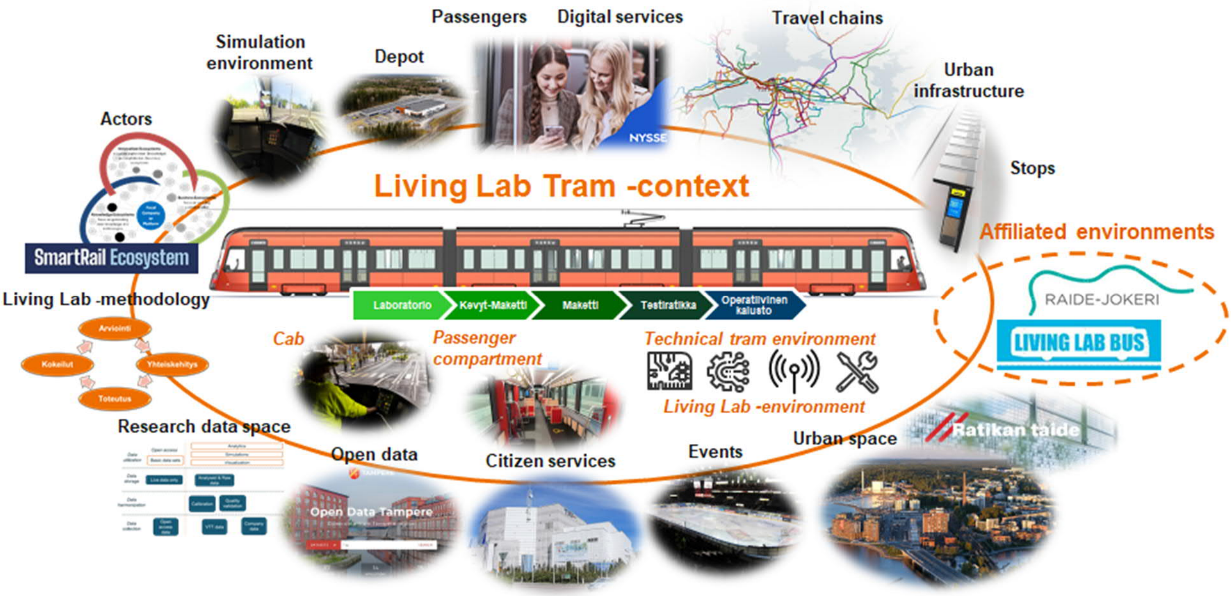

Figure 198. SmartRail Living Lab concept includes the city around the tram.

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4 SmartRail Living Lab Use Cases and Requirements

The aim of the SmartRail1 technical work was to define a system architecture that best serves research & development and living lab functions in SmartTram environment. A normal requirement analysis, also known as requirement engineering, is the process of defining user expectations for a new software being built. Since we were not able to analyse all possible users' needs and sort out their expectations, we tried to extract more generic requirements by studying user groups and their operational functions needs.

To collect these requirements, we concentrated especially on those functional areas what were expected to be crucial in R&D field the next five years on tram living lab environment. Based on this approach, following specific interest areas were recognized:

- SmartTrail "data ecosystem" support
- SmartTrail operational support
- Service development support for passengers

One of the main goal for technical needs analysis in all of these target areas is to identity what kind of data will be produced (data variety) and how fast it should be processed (velocity) and how much data (volume) will be accumulated into the system so that we could select the suitable architecture to respond these overall requirements.

Data ecosystems are composed of complex networks of organizations and individuals that exchange and use data as main resource. The ecosystems metaphor has been used to describe multiple and varying interrelationships between many actors and infrastructure that contribute to a resource (business, service or software) creation. The SmartTrail ecosystem here extends it to include to this network parties like companies, public authorities, universities, research organizations and developer groups (or even individual software developers).

In a data ecosystem, the products are data and their related technologies that can be used to support business, to deliver innovation, to promote transparency for governments and to validate research (Oliveira 2018). The aim of the Smart Trail data platform is to allow different actors to contribute to this data ecosystem and produce a set of tram related products and services. The chapter ecosystem data sharing use case examine some basic requirements enabling the SmartTrail data ecosystem.

The data platform should also support R&D functions in trams daily operations. To get a practical view to daily operational functions we studied the work organization of Helsinki City Transport (HKL, Helsingin Kaupungin Liikennelaitos, HKL) which has a long tradition in tram operation since 1891. Based on HKL's tram operations and earlier discussion with application areas experts following use cases were selected to be studied in more details:

- Automatic operations (automatic driving) especially at depots
- Passenger counting and related services
- Infrastructure maintenance (rail system, vehicle condition management)

Automatic driverless rail operations are intensively studied due to a need to control operating costs, growth in passenger volumes and needs more frequent service and an increased safety needs. Metro and shuttle systems with fully unattended train operation (UTO) are already used in airport transit lines. These systems are closed, whereas tram systems are open and should co-operate with other traffic and thus being considerably more demanding operational environment. According to Siemens "Depot automation is to be made commercially viable over the medium term as the first stage of autonomous tram driving”[6]. The SmartTram living lab data environment is intended to support test data collection, analyses and algorithm development for these autonomous tram operations first in depots, later in other test contexts.

Helsinki Regional Transport (Helsingin Seudun Liikenne, HSL), the organization that purchase services from HKL and other regional transport operators, is seeking for a cost-effective solution for robust passenger counting that will cover all transportation means. The system should include trains, metro, trams and busses. According to VTT’s study in 2019, camera-based counting is the most likely technical solution to provide cost efficient passenger counting and related additional services. As a real-world operating environment, SmartRail living lab platform is an ideal place to make passenger camera based counting technology experiments.

Advances of statistics measurement methods and cost-efficient sensor technologies have made preventive and condition-based maintenance (CBM) as a mainstream for infrastructure uphold like preservation of the existing transport network. Various kind of methods can be applied on CBM and recently machine learning techniques have been studied intensively also on the area of railway tracks maintenance. Development of new machine learning methods for maintenance require good quality and huge sample datasets that the data platform should enable to collect and handle efficiently.

Several factors like bus frequency, efficient ticketing system and trip planners (including real time information services) are some of the basic building blocks for increasing public transportation popularity. In a living lab environment, new schemes of ticketing systems and real time information services that might also be user originated (software solutions from developer communities etc.) can be tested in practise. For enabling data collection from the different experiments in tram environment, the co-innovation support and feedback systems – use case will cover some essential needs related to support handling of results.

4.1 Ecosystem data sharing use case

Data has become a tradable and valuable good. Clive Humby, a British mathematician who developed the world’s first supermarket loyalty card scheme, has said: “Data is the new oil. It’s valuable, but if unrefined, it cannot really be used. It has to be changed into gas, plastic, chemicals, etc. to create a valuable entity that drives profitable activity; so must data be broken down, analyzed for it to have value”. So, data, as it turns out, has no intrinsic value. Data may well be meaningless unless placed in some context. Value is created when data is applied to solve a specific problem e.g., when turning crude resource into useful end product. The value of data depends almost entirely on its uses, which may not even be fully known beforehand (Tayi & Ballou1998).

When organizations gather together to share and manage data, they can create value far beyond what would be available to the individual partners such as the creation of new business opportunities by using data and data services, as well as enabling innovation and value creation. Especially public organizations are eager to share data as open data (e.g., freely available) as basis to increase transparency, foster innovations and improve public services (Kucera & Chlapek 2014). Despite of expected benefits also for private sector, companies still appear to be quite reluctant to share their data (Richter & Slowinski 2019). A Finnish questionnaire (CTO Survey 2019) among company leaders (N=70) indicated that:

- 90% of companies are participating to some sort ecosystem or co-operation networks

[6] https://www.railtech.com/rolling-stock/2019/10/09/germany-will-test-first-autonomous-tram-in-automated-depot/

- 50 % are not eager to share their data (very low or low willingness)
- SME companies are more willing to share data
- 60 % thinks sharing data is difficult (quite to very difficult)
- All big companies insist that data sharing is very difficult
- The main reason for difficulties are IPR related (patenting questions etc.)

Three main typologies of data sharing barriers have been identified (Govindan 2020). First there are cultural/organizational challenges e.g., lack of awareness of potential benefits, lack of trust and fear of competition. Companies collect data to ample their core businesses, so the questions arise how to share data that doesn't hamper company competitiveness. There might be fear of unintentionally giving away valuable or sensitive data about the business, fear of losing negotiation power or a competitive advantage and lack of visibility into data usage and analysis once shared. Legal/regulatory problems also exist e.g. restrictions of data location and of the free-flow of data, uncertainty about data ownership and data access, data privacy.

Another set of obstacles are ttechnical/operational barriers e.g. due to the lack of interoperability between different datasets, accessibility issues that arise from combining data (e.g., lack of standards), high costs of data curation to adapt it for sharing. Interoperability and technical issues are perceived by stakeholders as an additional cost. Some other concerns are related to risk of data breaches and losses. Also fear of technological lock-ins (switching cost) exist.

So, observing the value of data ecosystems can be a challenge for companies. Many organizations get stuck in the initial stages, particularly in deciding legal issues and questions of value-add. For example, according to Accenture the issues of trust and security are two biggest obstacles that impact organizations' willingness to sell and buy IoT data[7]. D'agostino & al (2019) have studied mobility data sharing and observed following challenges related to it:

- Cost of data collection and storage; acquiring and managing data can be complicated and expensive.
- Lack of data standardization; companies collect data using different units of analysis measurement, scales, timescales etc. Inconsistency and data non interoperability across companies makes it difficult to aggregate data from multiple sources for further use.
- Difficulty of anonymizing mobility data; data is often personally identifiable since humans repeat certain moving patterns (Eagle 2009), even when time and identity information is removed (Gambs 2014). By using only a couple of position samples and additional information, individuals are distinguishable (De Montjoye 2013).
- High levels of expertise needed for data analysis and visualization. Managing large datasets can be time consuming, computationally intensive and thus expensive. Public organizations and SME companies may lack in-house data-science and data analytics experts or lack of resources to engage required experts.

The goal of SmartRail data environment should be lower these hurdles described above. The data platform should be able to:

- Enable building trust between data ecosystem participants. A data governance program is needed, which clearly defines the ownership of datasets and effectively promotes dataset

[7] https://www.accenture.com/_acnmedia/Thought-Leadership-Assets/PDF/Accenture-Securing-the-Digital-Economy-Reinventing-the-Internet-for-Trust.pdf

sharing rules. Platform should efficiently manage data access and keep tracking on data usage. Industrial (or International) Data Spaces (IDS, Jarke 2017), an open multi-sided platform (MSP) for secure and trusted data exchange (Otto 2019) can pave the way how to approach these topics.

- Ensure data quality. As previously mentioned, data has no intrinsic value and is only precious when it could be applied in certain context (e.g., data should have relevancy). Other data quality properties needed are accuracy, timeliness (data is up to date), completeness (no missing values) and consistency (data should be in the format expected). Incoming data should be controlled and profiled and when deviations from data quality parameters occur alerts should be announced. (Note: the system could be distributed, and data sources could be distributed among several different organizations).
- Ensure data security and privacy. Mobility related data is highly sensitive and hard to anonymize when needed for data analysis purposes (Heino 2016). The platform should be able to ensure data security e.g., protect data from unauthorized access and corruption throughout its lifecycle. Data handling should comply with existing regulations (notably European GDPR) and when privacy sensitive datasets are handled, privacy protection tools (like obfuscation, k-anonymity or cloaking anonymizer etc. if needed) should be provided.
- Provide easy to use toolset and services lowering the difficulties of data analysis for non-expert users. These tools include accessing the datasets, data analysis and visualization tools. The approach could be like data pipelines or data flow architectures (e.g., pipe and filters), where tools can be combined one after another to get the intended processing results.

4.2 Use case automatic driving

Development of ICT technologies during the last several decades has made automatic train operation (ATO) a viable solution to replace traditional manual driving in many urban rail systems. ATO is recognized to be a very promising approach by optimized train control decisions (train accelerating, coasting and braking commands), to reduce the energy consumption and carbon emissions while delivering an improved quality of services (Yin 2017).

IEC standard 62290-1 sets a clear classification of the grade of automation (GoA) for urban rail transit systems (Figure 19.):

- GoA 1: Non-automated train operation (NTO). There is a driver in the cabin, who is responsible for driving trains based on wayside or cabin signal, opening and closing door, observing the guideway, and stopping trains in case of emergency.
- GoA 2: Semi-automated train operation (STO). Automatic train operation (ATO) system controls the train movement by the acceleration and deceleration commands. The movement of the train is supervised by the ATP (Automatic Train Protection) system.
- GoA 3: Driverless train operation (DTO). Compared with GoA 2, there is no driver in the cabin to observe the guideway and stop the train in case of a hazardous situation. There is an operation staff on board. Safe departure of the train from a station, including door closing, could be the responsibility of the operation staff or may be done automatically.
- GoA 4: Unattended train operation (UTO). Compared with GoA 3, there is no operation staff on board. So the safe departure of the train from a station, including door closing, has to be done automatically.

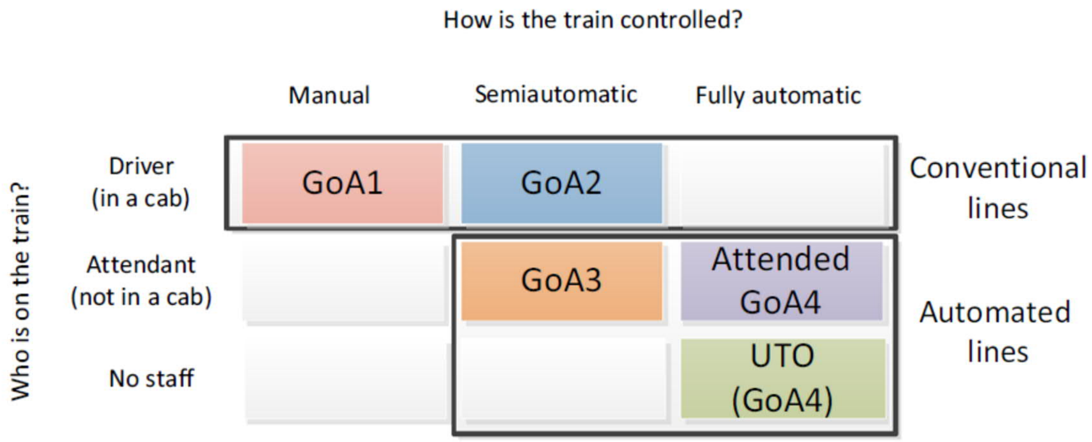

Figure 19. Level of automation in urban rail systems (Wang 2016)

Automated trams' infrastructure is more complex than for example autonomous underground (metro) trains. In the case of metro, driving is mainly controlled remotely, and the route is a closed system. Trams have to handle street traffic and therefore they have to interact safely with pedestrians, bicycles and cars, which is considered as a significant challenge comparable to autonomous car's driving requirements. Automatic depot operations on the other hand resembles more autonomous metro conditions being a more closed system.

Several experiments with autonomous tram systems have been carried out in Europe and Asia. For example, in 2018 Siemens Mobility, along with the transport operator Verkehrsbetrieb Potsdam (ViP), the Karlsruhe Institute of Technology (KIT), the Institute for Climate Protection, Energy and Mobility (IKEM), Codewerk and Mapillary experimented automating time-consuming shunting operations in the depot. Siemens have also demonstrated autonomous driving by using Siemens Tram Assistant. Passenger-free carriages have puttered through Potsdam more than 450 times on a 4-mile stretch of the existing tram network.

January in 2020, a tram performed the first unmanned journey on 3.4 kilometers in the city of Kraków, Poland. Similar kind of experiments have also been arranged in 2020 several regions in Russia. Some press releases have announced that Moscow's fully autonomous tram is expected to enter service in 2021 - 2022. Russian – Chinese venture is also developing self-driving trams in Shanghai area.

The main functional elements of autonomous driving are:

- Perception of the external environment/context in which the vehicle operates
- Decisions and control of the vehicle motion, with respect the external environment/context that is perceived
- Vehicle platform manipulation with the intention of achieving desired motion

In figure 20. these functional elements are depicted in more details.

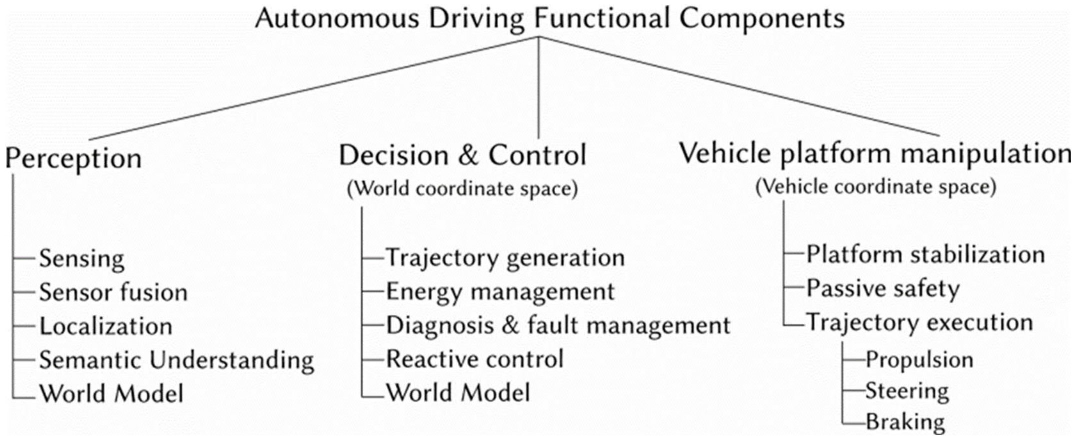

Figure 20. Functional architecture view of autonomous driving (Behere 2015)

Figure 21 depicts another view to the autonomous driving functions from environmental perception to vehicle control. The V2V refers to Vehicle-to-Vehicle communications and V2I to Vehicle-to-Infrastructure interaction. V2V communication enables to wirelessly exchange information about their speed, location, and heading of surrounding vehicles whereas V2I is the wireless exchange of data between vehicles and road infrastructure.

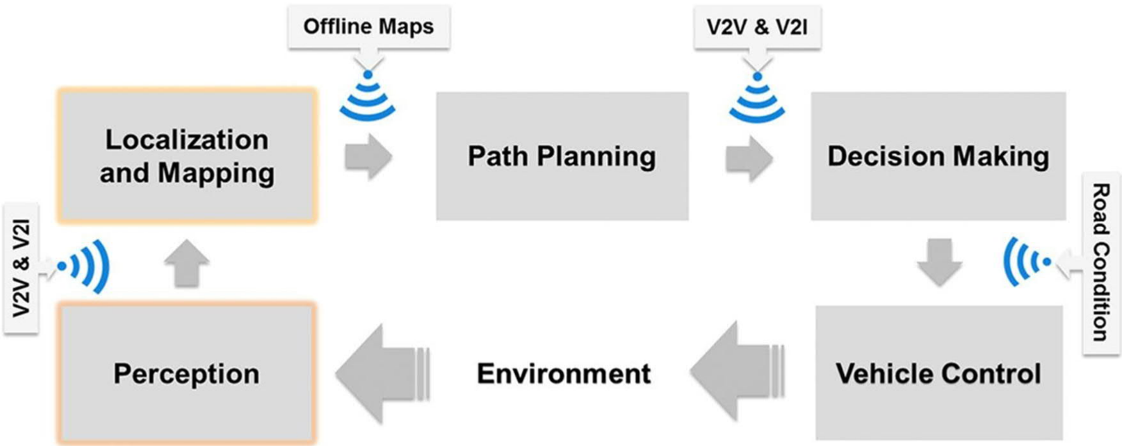

Figure 21. Autonomous navigation process (Brummelen & al. 2018)

Autonomous tram like any other autonomous vehicle (AV) driving system needs to:

- Locate where the vehicle is (e.g. localization) and follow up (pre-defined) routes (navigation) with extremely detailed mapping system that gives the vehicle information on its location and the trails surrounding.
- Requires generally ability to sense surroundings with on board ranging sensor systems for “obstacle detection” and make intelligent decisions in real-time.
- Requires intelligence how to “merge in chaotic traffic” and understanding of traffic rules and situations which is very difficult since our motions signal to the other road users our intention - and some of them are very complicated.

Basically, autonomous trams are getting all the technology from the self-driving car industry. To recognize objects on environment automated driving system needs two primary components:

- a perception module that provides detection and tracking information about surroundings such as vehicles, pedestrians, and traffic signs based on inputs collected from various types of sensors such as radar, light detection and ranging (LIDAR) measurements, or cameras
- localization and mapping module that refers to the relative states of AVs to others, for example, the distance of an AV to other vehicles, its position in the map, and relative speed.

A combination of sensor data (radar, video cameras, and lidar combined) with deep learning procedures (AI, Artificial Intelligence) is the most likely solution for a vast majority of autonomous driving cases. Short and long-range radar and lidar, combined with ultrasound and vision cameras are generally accepted as parts of the potential final solution. Cameras have been the predominant technology today in Advanced Driving Assistant Systems (ADAS) systems along with radars.

Multiple sensor technologies have to be used in a redundant and diverse way. This comes with the requirement to perform the non-trivial task to fuse the data of multiple inhomogeneous sensors (e.g sensor fusion). In order to perform sensor fusion, the data from the different sensors have to be aligned both temporally and spatially. The temporal alignment of sensor data relies on accurate timestamps added to each measurement of single sensors. Synchronization time is available from GPS clocks that are very accurate.

One of the key challenges for the development of fully autonomous vehicles is localizing the vehicle in known, unknown, or uncertain environments. Needed localizations functions can be divided to subcategories like global, relative and Simultaneous localization and mapping (SLAM).

The vehicle needs to locate itself with respect to a map in global localization. Without knowing its location, the vehicle cannot reach its destination nor be aware of where it is heading to. Absolute localization techniques are usually based on GNSS, maps and landmarks. GPS and digital maps are the most often used. LIDAR and vision sensors are two common methods to identify the landmark features. LIDAR is accurate providing distance to an object and can provide geometric features of the landmarks. However, it is difficult to use for differentiating landmarks with the same geometric shape. Using vision sensors to recognize the landmark is a potential approach to improve the drawbacks of LIDAR.

Autonomous vehicle needs to perceive its immediate environment and localize itself relative to static and dynamic obstacles. Relative localization techniques include dead reckoning (including inertial navigation) and visual odometry. Dead reckoning is done by fusing onboard sensor information about current direction of motion, such as first and second derivative of attitude and heading, with its previous (known) position information (a fix). Sensors include linear and rotary (angular) encoders and inertial sensors, including accelerometers and gyroscopes etc. Dead reckoning is subject to cumulative errors, cannot perceive the dynamic environment and requires accurate initial position information.

VO is similar to dead reckoning with the advancement of computational power and computer vision. The goal of VO is to compute relative transformation from one image to the next and to find the full trajectory of the camera. VO is a much cheaper solution compared to LIDAR-based localization, which can perform similar tasks but with higher computational power. Simultaneous localization and mapping (SLAM). SLAM incrementally constructs a map with information from sensors while simultaneously localizing itself to the map.

Sensor technologies utilized in autonomous driving can be classified to exteroceptive sensors perceiving environments and calculating distance to objects and proprioceptive sensors measuring values from the vehicle’s internal systems. Exteroceptive sensors includes LIDARs, RADARs, Cameras (passive) and Ultrasonic sensors whereas proprioceptive sensors are related to from Electric Control Units (ECUs or OBUs) like GNSS (GPS, Galileo, GLONASS etc.) receivers, inertial measurement Units (IMUs), encoders (odometers etc.) and CAN- bus information. In the Table 3. some advantages and disadvantages of different sensor types are listed.

Table 3. Some properties of autonomous driving related sensing technologies

Sensor technology	Advantages	Disadvantages
Radars Automotive radars working on licensed bandwidths 24 GHz, 77 GHz and 79 GHz. samples at an effective rate of 20 MS/sec over a 10 msec measurement time with a 50-msec cycle time	Less data intense than most sensors Does not need a direct line of sight – works well in dense fog, rain, and snow Effective for measuring relative speeds	Narrow field of view (stationary) requires multiple units for 360-degree coverage Lower resolution No color, contrast, or optical character recognition
Lidars Range > 200 m, range repeatability of < 5cm Angular Resolution 0.1 degrees Scan rate (frame rate) of >20 Hz as a target, at 20 Hz x 480,000 data points 400 points vertically by 1,200 points horizontally	Creates an accurate 3D map of a vehicle's surroundings Operates well in low light	Issues operating in dense fog, rain, and snow Most expensive of the sensor array No color, contrast, or optical character recognition Data intensive Needs direct line of sight
ToF Cameras TOF camera's CMOS sensors have resolution around 200 × 200 pixels. The typical operation range is 10 m - 20 m. The field of view of TOF cameras is around 40∘. Ranging accuracy is around 1 cm. Compared to laser scanners, TOF cameras have higher frame update rates ranging from 20 fps to 200 fps	Have higher frame update rates ranging from 20 fps to 200 fps (real-time applications) Small processing requirements No mechanical parts	Like LIDARs (environmental conditions) Sensitivity to background lights, Interference, reflections
Video Cameras Even cheap ($100, 10 – 30 fps) cameras produce high quality images (HD or full HD level	Provides color, contrast, and optical character recognition Affordable	Limited field of view Issues with changing light and shadows, dense fog, rain, sun glare, low light conditions

images, 4K cameras also available)		Processing intensive
Ultrasonic Range Sensors Ultrasonic sensor's triggering for sending a pulse is in microsecond range (40 kHz – 250 kHz => 25 ums to 4 ums)) transmitting power ~ 110 dB	Very accurate in short distances Works well in dense fog, rain, and all light conditions Small and inexpensive	Limited range No color, contrast, or optical character recognition Not useful for gauging speed Reflection of signal wave is dependent on material or orientation of obstacle surface Suffer from interference if multiple sensors are used Low angular resolution and scan rate
Global Navigation Satellite System (GNSS)	Worldwide coverage All weather operation Provides positioning between vehicles that cannot see each other Provides positioning when no road markings or signage are visible	Accuracy dependent on number of satellites in field of view Overall accuracy is lower than other sensors (+/- 1m in public use)
Inertial Measuring Unit (IMU) Usually, several sensors combined to a single chip like U-blox ZED-F9K module	Current IMU's are compact and inexpensive (MEMS) Provides feedback of the actual motion of the vehicle Works in all conditions (installed near the CG of the vehicle in the interior)	Higher precision needed; Fiber Optic Gyros (FOGs) are expensive Signals have drift due to the mathematical integration of acceleration to determine speed and position (double integration)

Autonomous driving systems requires to handle both map and sensor data. The processing should be done locally in vehicle (in an edge node) since the data related to sensors needs to be handled in near real-time due to the requirements for millisecond reaction times in traffic. For analysis and algorithm development purposes raw sensor data could be collected and data platform should be able to handle (transfer and store) raw data flows described in Table 4.

Table 4. Raw Data Flows

Sensortype	Data feed	Format
RADAR	Example: 24 MB/sec data rate for four receive channels	Proprietary, CAN or FlexRay

LIDAR and Flash LIDAR	At 20 Hz x 480,000 data points = 9.6 million points per second (400 points vertically by 1,200 points horizontally)	LAS (LASer or LiDAR Aerial Survey) 1.4
Vision (Camera)	10- 30 fps x (1920 x 1080 / Full HD, 3840 x 2160/ 4K) 4K = ~ 3 MB (JPEG) – 30 MB (TIFF) => max. 90 – 900 MB/s (cameras usually run at 60 Hz and, when several combined, generate around 1.8 Gbytes of raw data per second)	RAW, JPEG, TIFF, PNG, EXIF, HEIF etc.
Ultrasound	~ 100 KB/s – 250 KB/s	Proprietary byte stream
GNSS + Inertial (IMUs)	For example 30 Hz update speed ~ 30 x NMEA183 message max size (82 bytes) /s => 2,46 KB/s	NMEA 183, binary streams, RTCM 3.3. NMEA183 byte stream, BINEX, GPX

4.3 Passenger Counting Use Case

Passenger counting purpose is to determinate the number of public transport users as well as the number of people who get on or off at different stops or pass-through traffic hubs (e.g., a stations). The information produced by counting and its quality are important to public transportation authorities due to the operational needs related to the planning, quality assurance and reporting of services:

- Passenger counting enables demand analyzes by tracking people's mobility needs as a basis for route and schedule planning.
- The counting can also be used to verify the effects of changes made on routes and schedules and to measure and evaluate the efficiency of operations. This operational analysis combines vehicle journey times with passenger data for service quality assessment.

Demand analyzes are used to determine the get on and departures of passengers by routes and to create an Origin Destination (OD) matrix and load profiles. The load profile shows time and stop distribution of the number of passengers per routes, maximum load, maximum load intervals, etc. The number of passengers getting on and off from a stop is used to optimize the vehicle fleets and timetables required for the routes and to guarantee the quality of service (Eboli 2012).

Passenger counting information can be performed either by manual (manpower) or automated methods. Automatic Passenger Counting (APC) systems offer the following advantages over manual counting (Boyle 1998):

- Cost-effectiveness and accuracy compared to manual calculation. As the accuracy of computer-based technologies improves, features increase, and prices continue to fall, manual counting begins to be expensive compared to the total cost of automated systems.
- Information already in digital form is easier to process and combine with other data sources, such as automatically generated vehicle location information.

- Modern counting systems can also be used to track the movement of passengers, for example in trams, trains and terminals. This information can be used to understand passenger behavior and thereby, for example, to design facilities and services. Camera based counting systems can also be used to develop detect other interesting objects like baby carriages, wheelchairs etc.
- Real-time counting information is possible for value adding passenger real-time information services.

Passenger counting systems are also closely linked to support for operational analysis, which in turn requires Automatic Vehicle Location Systems (AVLS).

The basic requirements for APC systems are counting accuracy and reliability, scalability of a solution, low latency of result reporting and privacy preservation of passenger related information. Other important factors to consider are hardware, installation and maintenance costs related to chosen technology.

In academic literature current APC system are classified either image or non-image-based and latter is also divided further device based or non-device based solutions (Kouyoumdjieva 2019). Device based passenger counting is already widely deployed on RFID travel cards, but the problem related to this technology is that origin destination matrix is difficult to construct since only getting in is registered and stepping out from a vehicle is not usually detected. Another device-based approach is to use mobile phones as a device for passenger counting, but this method is not accurate enough since even though penetration of these devices is high, motivation to keep on bluetooth service required on counting cannot be guaranteed. According to our previous experiments (Lahti 2016) even when using several bluetooth beacons and measuring signal attenuation (RSSI) from those by using a mobile phone, accuracy is not enough and additional sensor fusion solutions (based on GPS and accelometers) are needed to increase counting reliability for BiBO (Be in Be Out) cases that enables origin-destination information.

Other non-device-based solutions include pressure sensors, LED and IR based counters and more experimental approaches like measuring exhalation Co_2 concentration in vehicles, different types of RF-signal attenuation (RSSI, CSI, UWB) and utilizing axle weight CAN-bus data or Weight in Motion (WIM) measurements (Kouyoumdjieva 2019). Counting accuracy of these latter (e.g., non-LED or IR solutions) technology alternatives are not high enough, but information can be used for example to give a rough real-time occupancy estimation of vehicles.

Previously mentioned counting technologies are gradually losing ground for visual based solutions. The information content of a picture is superior compared to simple sensors data and gives much more flexible possibilities for further interpretation of contents for security and different object detection (wheelchairs, baby carriage etc.) needs. According to manufacturers, counting accuracy (95-98%) is comparable to best nonvisual ones and camera sensor costs are continuously decreasing when picture quality is increasing all the time. Also, versatility and flexibility of camera bases solutions are unbeatable, detection and matching algorithms can be updated immediately when new algorithms are developed.

Camera based systems can be classified as mono cameras or 3D cameras. As the name implies, mono cameras produce a standard video image of the environment, and 3D cameras can also be used to measure the three-dimensional shape of objects (point cloud). The 3D camera can be implemented in three different ways, which are a stereo camera, ToF (time of flight) and SL (structured light). Another camera-based solution is to use thermal imaging.

Mono cameras are very affordable but reliable pattern recognition requires a lot of computing power. The systems may be sensitive to ambient lighting conditions, but active lighting (near-infrared LEDs) can be used to normalize system operation. Stereo cameras resemble mono cameras, but a pair of images can be used to estimate the shape of the object. Shape estimation takes advantage of texture information, so changes in lighting may not be detrimental to results. The imminent drawbacks with these camera-based solutions are sensitivity to poor visual or lightning conditions and user privacy issues.

Structured light (SL) cameras project a pattern on the environment with an IR projector that is detected by the camera. The figure can be used to calculate a distance map and a point cloud. The technology is more expensive compared to standard cameras (mono and stereo), but on the other hand, 3D data is typically of high quality, and computation requires less processing power (straightforward analysis of shapes). In the absence of texture information, the camera provides good privacy protection.

Radar technologies like LIDARs and millimeter range radars are also getting more attention since there is no imminent privacy issues. LIDARs and millimeter radars form a 3D point cloud of an area according to distances using scattering. Different surface materials scatter the signal differently, so LIDARs, along with pattern recognition algorithms, can recognize people and different objects in a bit like image recognition.

The possibilities of thermal imaging in passenger computing have been considered for a long time (Pavlidis 1999) and with the development of measurement sensors and analysis methods (e.g., neural networks, Amin 2008) passenger computing systems can be implemented with an accuracy of 95-98% (especially indoors). The advantage of visible light cameras is the preservation of privacy and operation even in (lighting) conditions where other camera systems have operational challenges.

As a summary of passenger counting use case data feeds of different prominent sensing technologies are collected to Table 5.

Table 5. Summary of counting technology properties

Counting technology	Data requirements	Data formats
Camera based system	10- 30 fps x (1920 x 1080 / Full HD, 3840 x 2160/ 4K) 4K = ~ 3 MB (JPEG) – 30 MB (TIFF) => max. 90 – 900 MB/s (cameras usually run at 60 Hz and, when several combined, generate around 1.8 Gbytes of raw data per second)	RAW, JPEG, TIFF, PNG, EXIF, HEIF etc.
LIDARs and radars	At 20 Hz x 480,000 data points = 9.6 million points per second (400 points vertically by 1,200 points horizontally) ~ 1.2 MB/s	LAS (LASer or LiDAR Aerial Survey) 1.4

Thermal imaging	240 x 320 pixels to 640 x 512 pixels from 9 - 60 fps (for example 640 x 480 professional cameras are very expensive ~15k€) 640 x 512 px x 30 fps = ~ 10 Mbit/s = 1.2 MB/s	Bitmap (.bmp), GIF, JPEG, PNG, TIFF

4.4 Condition Based Maintenance

Condition-Based Maintenance (CBM) approach makes a diagnosis of the asset status based on wire or wireless monitored data, predicts the assets abnormality, and executes suitable maintenance actions such as repair and replacement before serious problems happen (Shin 2015). Condition based maintenance (CBM) has proven to be an effective strategy for getting more profit form an asset. The asset's parts are not replaced on basis of calendar schedule or operation time or failure, but when the monitored part reaches predetermined condition indicating it has to be replaced. Condition based maintenance needs real-time component diagnostics e.g., sensors for collecting data and tools for analysis and predict potential faults.

In tram operating environment condition monitoring detects and identifies deterioration in structures and infrastructure before the deterioration causes a failure or prevents rail operations. Monitoring can be performed continuously or periodically. Continuous monitoring detects a problem straight away but it is often expensive and energy demanding. Real time sensor data is often noisy, which requires careful preprocessing to ensure accurate diagnostics. Real-time measurement during normal operations allows for rapid response, such as emergency inspection and maintenance. Periodic monitoring on the other hand is cheaper, uses less energy, and allows time for data cleaning and filtering. The drawback is that a problem will only be diagnosed at the next inspection and processing run.

Condition monitoring can apply either model-based techniques or signal based techniques. Model based techniques are used when there is no direct measurements of parameters but access to the relationships between input and output signals (Figure 22). Observer based fault detection filter (Kalman. Monte Carlo Particle Filters, Bayesian approach etc.) can be applied when there are unknown disturbances and model uncertainness. Mathematical system models for condition monitoring are hard to develop for the whole system since the systems are usually nonlinear.

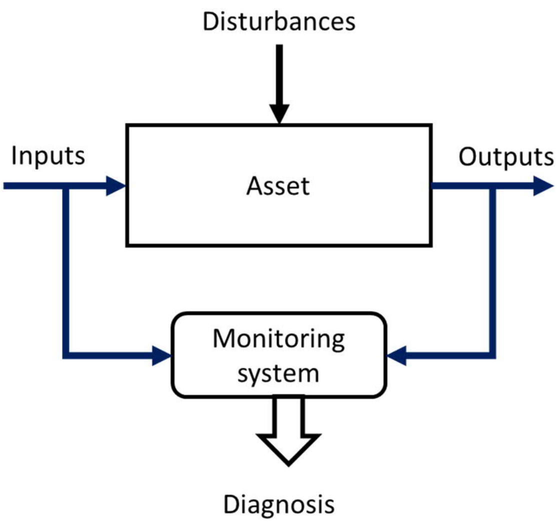

Figure 22. Generic model for condition monitoring

Signal base techniques are used when only output signals are available. Extraction of fault relevant signals are usually associated to amplitudes or amplitude densities within a certain bandwidth. For signal processing statistical, spectral, wavelet analysis and band pass filters are utilized. Sensor data are often noisy and sensors themselves can become defective wherever they are installed. They also generate large amounts of data at very rapid rates and often on an ad hoc basis and data may be produced from multi sources that have to be fused. Condition monitoring systems must therefore store large quantities of data to build models for analysis. The systems and structures monitored using sensors often exhibit complex behavior, which is difficult to understand and interpret.

Signal based analysis contains several phases:

- Triggering - Searching for threshold limit deviations
- Classification - Identifying know problem signatures
- Short term analysis using outliers – identifying unknown events
- Long term outliers detection – identifying drifts over long period of time

In basic form condition monitoring data enables distinguish normal and subnormal conditions (e.g. fault vs. no fault). For more sophisticated analysis a 5 level system is developed (Lopez-Higuera).

When considering the suitable system first the type of sensor used needs to be carefully considered to ensure the maximum value and the best quality data. Sensors are also often located away from energy supplies, minimize energy usage yet communication needs to be maximally efficient, and communication requires energy. Energy harvesting solutions might be needed if reliable energy source is hard to obtain. In general, the results obtained with wireless systems do not present the same level of accuracy when compared to those provided by wired techniques.

Measurement system could be on-board (vehicle based) or track based, but from economic reasons most of the systems are track based since one system enables monitoring several assets instead of one system per one asset. Installation and maintenance of a single detection system is also easier. Typically moving measurement equipment are used to monitor static assets (like in tram case rails & switches) while static systems are often used to measure moving assets (wheel profiles, axles, bearings).

In tram operating environment two main areas are constantly monitored: tracks and vehicles (especially bogeys). About 5–10% of all failures of tracks are weather related, being mostly caused by high temperature, icing, and storms. Wired sensor systems have been widely used for a long time in tracks' Structural health Monitoring (SHM). Drawbacks of the traditional wired measuring techniques like high cost and complex, often inconvenient installation processes and vulnerability to damages (e.g., corrosion), vandalism (e.g., wire cut), dirt and nature elements have led to the adoption of wireless sensor networks (WSNs) as an alternative approach.

Railway track monitoring is typically based on impact loading, which is a high magnitude force of short duration. Impact forces are significantly dependent on speed and type of irregularity, either in the wheel or the rail. Strain gauges are installed on the rails, and axle or wheel forces can be quickly estimated from their response as the rolling stock passes over the installation site. An accelerometer can measure the rate of change of velocity in the instrumented body. To identify crack growth, remaining life, and fatigue life of the track components, an acoustic emission (AE) is often used. The fluid pressure in the ground, ballast, sub-ballast, and sub-grade can be measured using water pressure sensors (Figure 23). The table 6. presents a summary of different track measurement methods.

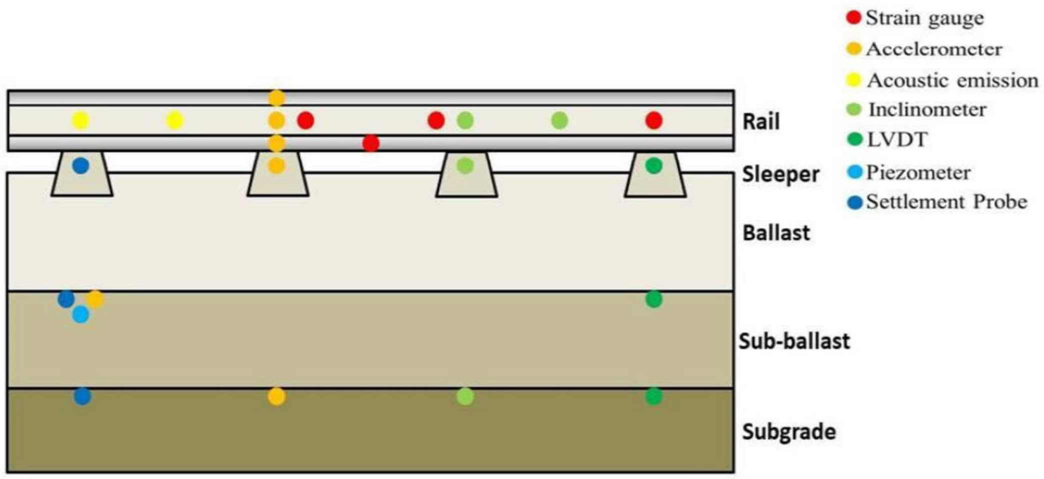

Figure23. Measuring track conditions (Ngamkhanong & al. 2018)

Table 6. Summary of different sensing technologies for track CBM

Target	Measurement	Sensor
Track	Crack/Fatique	Acoustic emission
	Wheel flats	Acoustic emission, accelometers
	Stresses	Strain gauge, piezoelectric strain gauges, Fiber Bragg strain gauges
	Vibrations (dynamic load)	Accelometers, Fiber Brag

	Settlement and twist	Inclinometers
	Incline	Inclinometers
Rail Bed	Dynamic acceleration (track)	Accelometers
	Ground water pore pressure	Piezometers, tensiomaters, wire potentiometers
	Track long term settlement	Settlement probes
	Temperature	Thermistors
	Vertical motion	Extensometers
	Water content	Reflectometer
	Movement and shape	Accelometers

Vehicle condition monitoring in railway and tram environments are concentrated on bogeys (axles) and wheels (Figure 24.).

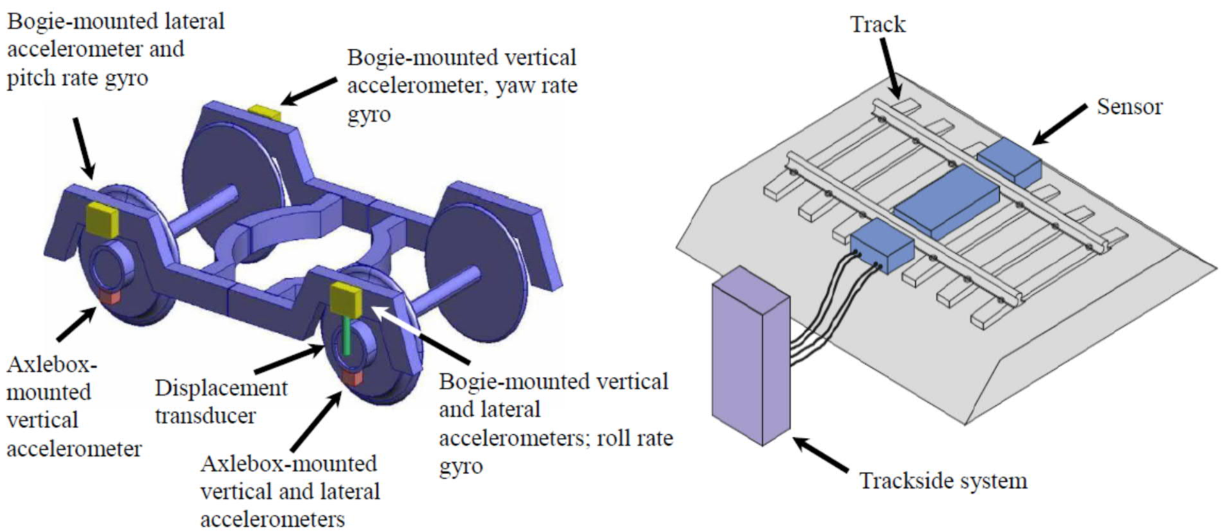

Figure 24. Bogey and wheel monitoring with on board and way side units (Ngigi & al. 2012).

Wheel fault are in general more frequently related accidents than other vehicle components. Wheel degeneration is complex phenomenon depending on wear and fatigue, which depend on route, axle load, speed profile, wheel position. Wheel flats (eccentric wheels) are caused due to braking locks, eccentricities, corrugation, roughness etc. On board analysis methods are still not very reliable, instead health assessment is performed by using wayside detectors that can use several measuring principles like lasers, cameras, vibration measurements, acoustics sensing. Wheel Impact Load detectors (WILD) contains an instrumented track section with strain gauges or accelerometers for force quantification.

Wheel rail contact monitoring is measuring derailment coefficient e.g., ratio between lateral and vertical wheel trail contact forces. It permits derailment probability estimations for specific tracks and running conditions. Standard wheel (and axles) can be instrumented with stain gauges on inner face of wheels applying processor units in axles. Some systems like Lavalin uses over 20 Hz sampling rate whereas other (CETEST) use 1000 Hz sampling rate. Sensor system can be powered by using inductive transmission but cannot be used with brakes since temperature will destroy strain gauges.

In addition to WILD systems, some experimental on-board systems have been tested. Ultrasonic on-board measurement by using 500 MHz sampling rate fixed on wheel (laboratory experiment) has been used and correlation with ultrasonic pulse and vertical and lateral forces were found. Another method used a hollow shaft on an axle and acoustic sensor to monitor health (300 kHz upper limit), enables detect artificial cracks on wheel (speed 0 – 240 km/h). Wheel flats detection based on axle box vertical acceleration with1kHz sampling rate enable detection up to 90 km/h

As a summary for infrastructure CBM in railway and tram environment several different measuring techniques may apply and data requirements from vary considerable depending on techniques. Data accumulation varies from quite low sampling rates to very high and voluminous high speed camera pictures but since cars are passing the measurement points occasionally, the data accumulation is non-continuously and the dataset are not extremely huge. For statistical method development thus the telemetry type IoT data set might be quite big. This preliminary requirement analysis for CBM use case only indicated variability of different measuring methods and needs some further work to give some more reliable conclusions of the actual accumulation velocity and volume of data.

4.5 Passenger co-creation and feedback use case

As described in previous sections Living Lab typically refers a physical environment in which companies, public sector and people cooperate and test new services, products and technologies (Niitamo et al., 2006). Living Labs enable an open innovation environment as they provide access to current developments as well as obtain feedback and new insights using knowledge from customers, suppliers, partners, universities, and competitors. Testing and generation of ideas happening in a “real life” context is supposed to lead better conception regarding the practical suitability of the tested products and services (Leminen et al., 2012). Products and services are not only tested in living labs but the aim is also to co-develop those with potential living lab users.

Research on tools and methods used in Living Labs are still under development and only a limited number of studies have investigated of Living Labs facilitation and co-creation tools. Eriksson et al., (2005) states that the integration of users in Living Labs should proceed beyond traditional methods such as focus groups and surveys. Mengual & al. (2018) have tried to classify tools supporting living lab integration into following groups (Figure 25)

- Tools for passive observation that enable interact non-invasively with prototypes featured in living labs.
- Tools for reactive integration such as questionnaires, guided interviews, digital voting mechanisms etc.
- Tools for co-creation enable participants to express own thoughts, associations and ideas without a question or feedback stimulus

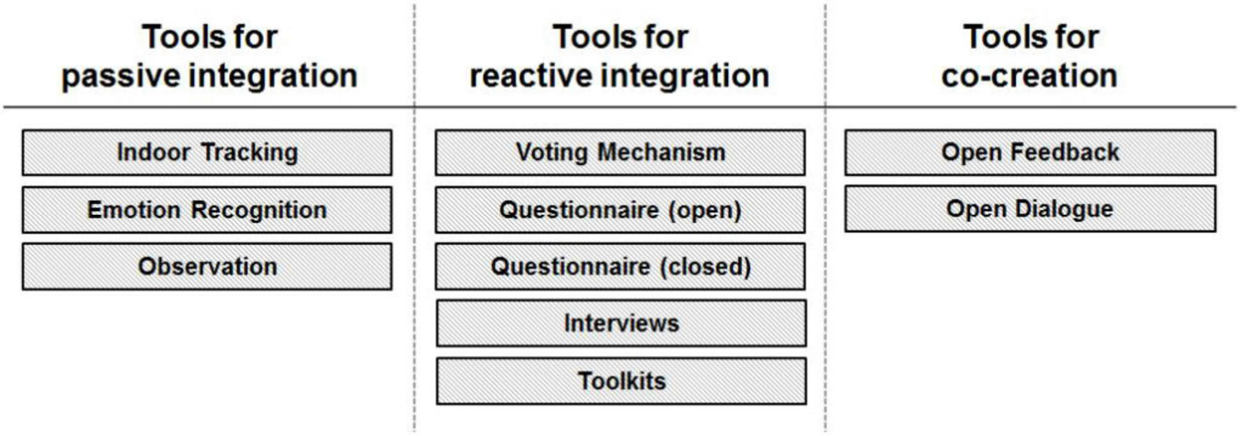

Figure 25. Classification of living lab tools (Mengual 2018)

Observational-based tools rely on trained staff on site shadowing a subject. Observers try not to disturb an observed so that the behavior of a subject remains as natural as possible. These kinds of passive methods don't provide opportunity for open feedback from the observed. Passive integration tools can be further included indoor tracking systems for recording people movement patterns and emotions recognition observation technologies.

"Indoor tracking" is a generic term for technologies used to monitor people location and movement within buildings. Common approaches for tracking use technologies such as radio-frequency-identification (RFID), wireless local area networks (WLAN) and Bluetooth to determine subjects' location through triangulation and proximity inference. These methods often require subject cooperation (as our previous use case with passenger counting indicated) and due to this camera based non- intrusive tracking has gained more popularity recently.

Detecting and tracking people by using affordable RGB camera tracking systems has been studied intensively during last decades. The problem of camera-based detection has encountered several serious challenges, such as occlusion, change of appearance, complex and dynamic background. Cheap depth cameras like Microsoft's Kinect and Asus's Xtion Pro Live Sensors opened new opportunities to activity recognition and Human Behaviour Analysis (HBA) for many application fields from retail to at home for elders in AAL (Ambient Assisted Living) environments [Liciotti 2017]. Some experiments using depth camera technologies in living lab contexts have already been performed [Sevrin 2015]

Emotion recognition can be based on human performed analysis utilizing either real time or recorded video capture observations. Since human has a great variability in their abilities to recognize emotion, technological aids to support emotion analysis have been developed. Use of technologies such computer vision, machine learning and speech processing to help people with emotion recognition is a relatively new and fast developing research area. Several different publicly available data sets already exist for research purposes.

Audiovisual facial expression analysis is based on motion and the deformations of facial features. Systems are able to classify emotion into categories like anger, fear, sadness, happiness, surprise and disgust to name some. Facial emotional recognition is essentially a pattern recognition problem and involves finding regularities in the set of data being analyzed. Other factors also contribute to the recognition of a person's emotional state like as body language, gestures, voice and the direction of the gaze. Emotion recognition utilize all these factors with contextual information to infer accurate results. [Mehta 2018]

Tools for reactive integration include such as questionnaires, guided interviews and digital voting systems. So called closed tools incorporate either manual or technology assisted voting mechanisms and questionnaires that use set of questions with fixed answering possibilities. Open tools use questionnaires with text-based answers or semi-structured interviews enabling participants to express own thoughts and ideas. Interviewers' observations during sessions can provide additional insights. Questionnaires and voting mechanisms are often used after the interaction with a prototype in living labs while interviews are also used during this interaction. Technically closed questionnaires and voting can be implemented by using web-based form and polling tools or by using so called "happy-or-not smiley" devices.

Toolkits enable participants to create own prototypes by using an interactive development environment. Usually these are software-based system enabling building user interfaces with a fixed set of widgets. Observation or interview during the prototype creation can be used to acquire additional insights. Tools for co-creation enable the visitor to express own thoughts, associations and ideas without questions or feedback stimulus.

Living labs can also utilize hackathons as a tool for co-creation. Hackathons are a specific focused sprint-like events for creating functioning software or hardware by the end of the event. Typically, these events last one or two days and can be extended to become an overnight competition. It is expected that these events "strengthen the ecosystem by bringing together the academic community, investors, and entrepreneurs" (Alba 2016, Kostiainen 2018)

Summary of data provision concerning living lab feedback collection is presented in Table 7.

Table 7. Summary of data provision concerning living lab feedback collection.

Data class (value)	Data types (Variability)	Volume	Velocity
Shadowing	Textual descriptions, images	low	Very low
Indoor tracking	Positional data	low	low
Video based tracking/HBA	HD/4K video	High (raw data)	Very High
Emotion recognition	Video captures, speech, sound HD/4k video (see calculations from)	High (depending on required data set)	Very high
Questionnaires, voting	Text, numeric data	Low to middle (depending on how large is the participant)	Low to middle
Toolkits, hackathons	Images, code (text)	Low	Very low

4.6 Summary of Technical Requirements

The following Table 8 presents a summarization of technical requirements and needs deducted both from the use cases presented in the Chapter 4.1 and from the general living lab specification presented in the Chapter 3. The requirements are divided according to technical functionality groups/layers.

Table 8: Technical Requirements

Phase	Requirements
Data collection	Push and pull data collection. Incremental updates and batch uploads Real-time stream ingestion Ability to integrate different type of data sources with various ingestion speeds (even batch type data imports) Elasticity needed Mostly time series data High parallelism, high scalability needed for data ingestion
Data pre-processing	Edge processing/analysis for massive and (audio)visual data Basic anomaly detection and cleansing methods Harmonisation for interoperability
Data storing	Relational database with spatio-temporal capabilities Massive high speed data ingestion and big data storage File format data storage and management Modular meta model for data utilizing unifying spatio-temporal core data model for interoperability between different data models and data sets Archival and versioning of accumulating data Data isolation, confidentiality and access control (to increase trust) Ability store huge amount of data (hundreds of gigabytes) Indexing and partitioning tuning essential (H3, geohash etc.)
Data access	Query APIs for data File data access Real-time feed mediation Open data (no strict contracts needed, lower security requirements) Ability to connect to and handle very voluminous and high velocity data sources Access control and identity management, (customer need: POT, Platform of trust) Openness, low barriers for SMEs user-friendliness

Data tools	Re-playing selected real-time data feeds Map-based visualization of real-time spatio-temporal data Constructing views by joining multiple data sets by spatio-temporal core model Support for analytical tools (mainly for batch processing) Powerful data processing capabilities for analysis purposes (even with 80 M samples the analytics response time is extremely slow)
Interoperability and data sharing with other data spaces	IPR and data sharing contracts are essential (handling confidential customer data). Ability to support IDS distribution mechanisms (interoperability needs) Enabling data exchange across different actors in the ecosystem Interoperability across domains and applications Trustworthiness and secure data exchange via a uniform, standardized and open identity management Ability to describe Gaia-X metadata (by using Self Descriptions) for federated catalogues IDS connector (interfacing) compatibility
Cross-cutting and general needs	Clear practices for IPR, licencing and contracts for data usage Robust data security & privacy (e.g., access, processes and IT solutions) Practises for sensitive data management and use (cf. e.g. GDPR) API management and platform usage monitoring High system security (from data sources to distribution) Identity management & access control Data metering mechanisms

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5 Technical Specification of the Urban Mobility Data Space

The technical specification of the Urban Mobility Data Space, presented in this section, is based on the high-level requirements from the living lab concept presented in the Section 3 and the technical use case requirements presented in the Section 4. The aim of the Urban Mobility Data Space is to offer an environment that allows the development, testing and demonstration of information and technology solutions in a real public transport context. The concept of the Urban Mobility Data Space and the transport environment context is discussed in the Section 5.1. The overall System Architecture of the Urban Mobility Data Space is presented in the Section 5.2 and the core parts are presented in more detail in the Sections 5.3 and 5.4.

5.1 Concept of Urban Mobility Data Space

The key asset for traffic intelligence is the use of high-quality mobility data available from various sources like public transportation vehicles, smart city sensing systems and other appropriate data origins. The Figure 26 below illustrates the different types of data that are available in the context of the smart tram environment.

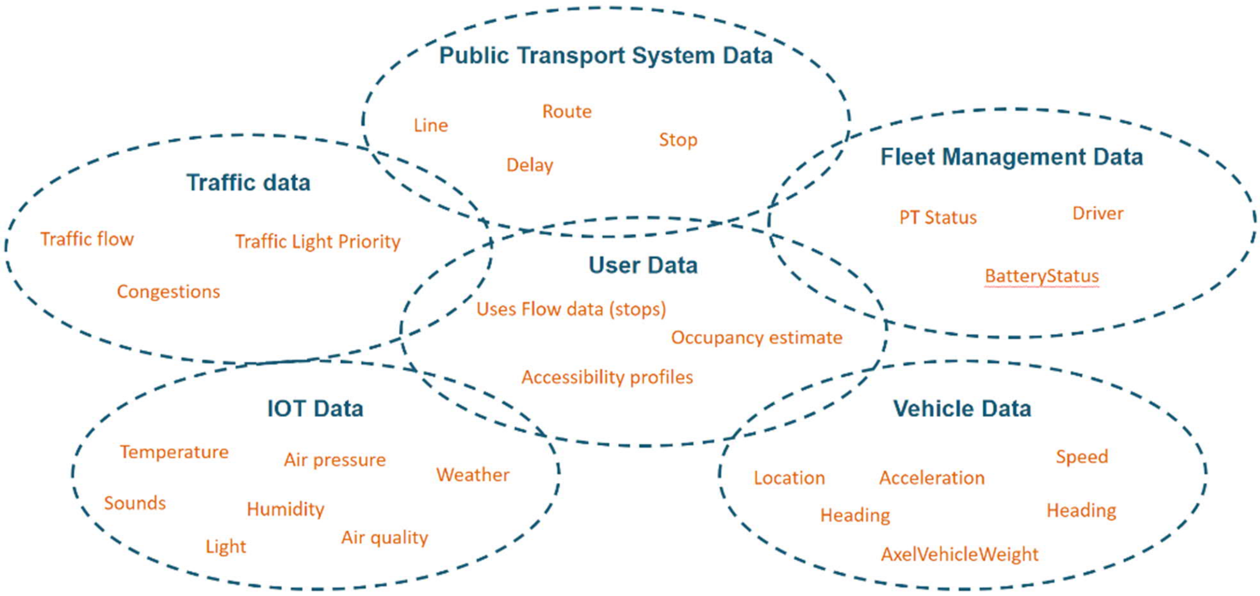

Figure 26. Types of Transport Data in Smart Tram Context

The nature of transport data is heterogeneous. There are high-volume real-time streams that accumulate large chunks of historic data (big data). On the other hand, there a complex data models describing the transport infrastructure parts, such as roads, stops, terminals, etc. There are also a lot of metadata and environment data that have impact on transport, such as weather and traffic flows. There are some typical denominators, such as spatio-temporal aspects, but, as can be seen from the Figure 27, the metadata model combining the data to the real world can be quite complex.

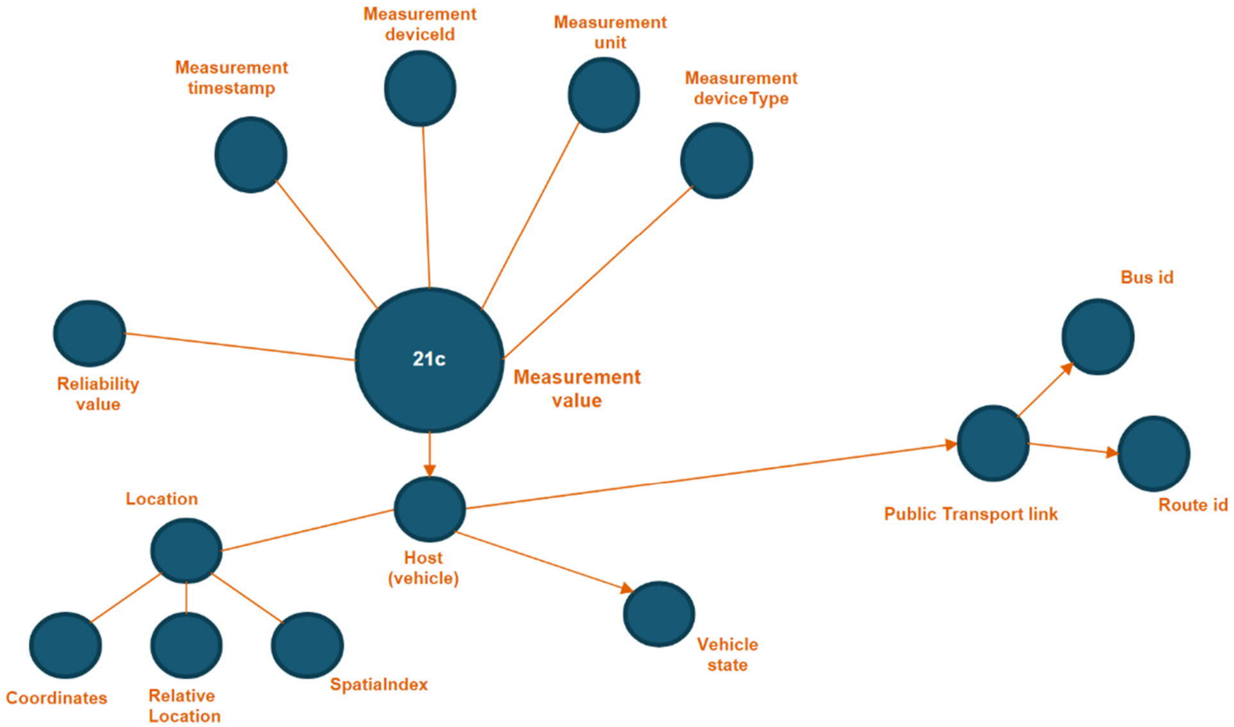

Figure 27. Data and Metadata (Time-series data)

In transportation domain we can observe a shift away from infrequent measurement to nearly continuous monitoring and recording of the events in the transport environment. Advances in diverse sensing technologies, ranging from IOT sensors to camera-based image analysis, are generating a rapid growth in the size and complexity of time series data archives. Transport domain time series data pose significant challenges to existing techniques (e.g., spatiotemporal structure).

The production, distribution and consumption of digital data are driving rapid advances in analytics, AI, and automation. New holistic mobility services usually require high-level of co-operation between several distributed transport information systems. The problem with current transport information systems is the lack of data interoperability and tools for creating and ensuring data quality. While the abundance of data sources is available, there is a serious lack of technological solutions that are able to extract ‘intelligent insights’ from these data silos.

The aim of this project was to create an *open living lab tram environment and ecosystem* for accelerating sustainable mobility and the development of user-centric mobility services. We created an *Urban Mobility Data Space* that combines an actual tram as physical platform and cloud-based research data platform as a digital platform, for creating an authentic and secure innovation, development, and testing environment for novel mobility solutions and services.

The Urban Mobility Data Space is built as an open data integration architecture that utilizes existing standards and solutions, as well as governance and business models, to facilitate secure and standardized data exchange and data linkage in a trusted business ecosystem. It provides a basis for creating smart-service scenarios and facilitating innovative cross-company business processes, while at the same time guaranteeing data sovereignty for data owners.

The aim of the Urban Mobility Data Space is to offer a co-creation environment for the SmartRail ecosystem providing a link and feedback loop between research, business and service design and technology development. The SmartRail ecosystem itself is built on shared practices on a network of distributed competence by bringing together public administrations, citizens, companies and researchers to advance smart rail solutions.

The Figure 28 below presents an illustration of the overall concept of the Urban Mobility Data Space. The core of the concept is the vehicle environment, in this case a tram, that provides the platform for the data collection and services. On top of the vehicle(s) is the research data platform that connects the tram context to the wider transport context and provides link between the vehicle environment, data and the services. At the outer rim are the various co-development tools and services that provide access to the resources at the vehicle and data platform and form a linkage between living lab ecosystem and technical environment.

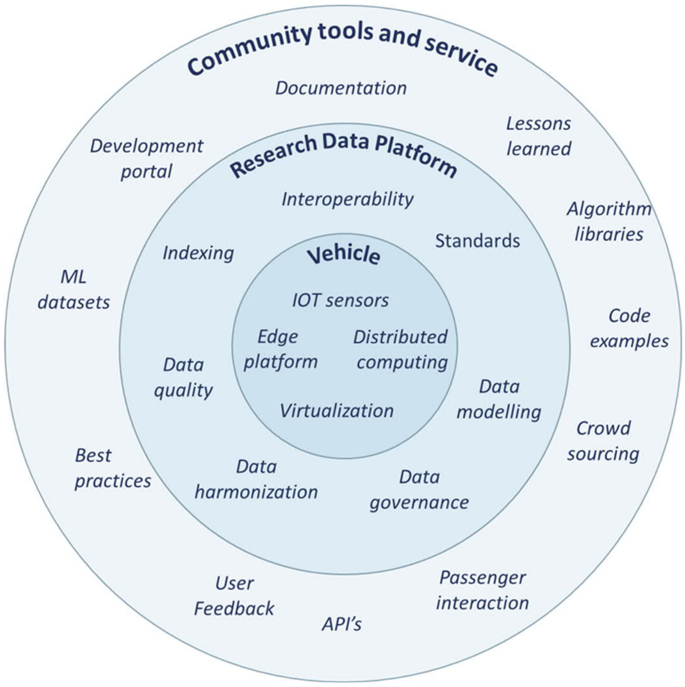

Figure 28. Overall Concept of the Urban Mobility Data Space

5.2 System Architecture

The overall system architecture of the *Urban Mobility Data Space*, presented in the Figure 29, consists of two parts, 1) *The Smart Tram* (i.e. the vehicle edge node*)*, and 2) *The Transport Research Data Platform* (i.e. the cloud environment. The system architecture is built around the requirements of the use cases (presented in the Section 4) and of the general needs and requirements of the living lab environment presented in the Section 3.

The vehicle (tram) acts as a kind of mobile sensor platform providing an extensive and real-time situational awareness of both the vehicle and its surroundings. It consists of a computing platform (with an onboard computer) for controlling the collection and propagation of data and enabling its pre-processing as well as hosting 3rd party software. The edge platform also allows means for provision of services and content to passengers utilizing onboard computing power, and public displays.

In addition to software development, the Smart Tram Environment can be used for testing hardware and complete third-party systems in a real public transport environment. The solutions to test can be standalone systems but they can also utilize the basic onboard setup, for example to get power and internet connectivity.

The platform architecture is based on a micro service model. In such a model, small and stand-alone micro services jointly constitute more extensive service bundles and combinations. This kind of architecture enables easy and flexible introduction of new functions and configurations. The open-source approach for architecture modules enables participation in the platform and service development for anyone interested and it is based on a concept on how to utilize existing and open resources, such as open data, open or shared API's and open-source software components for minimizing unnecessary replication of existing functionalities and focusing to truly value adding components.

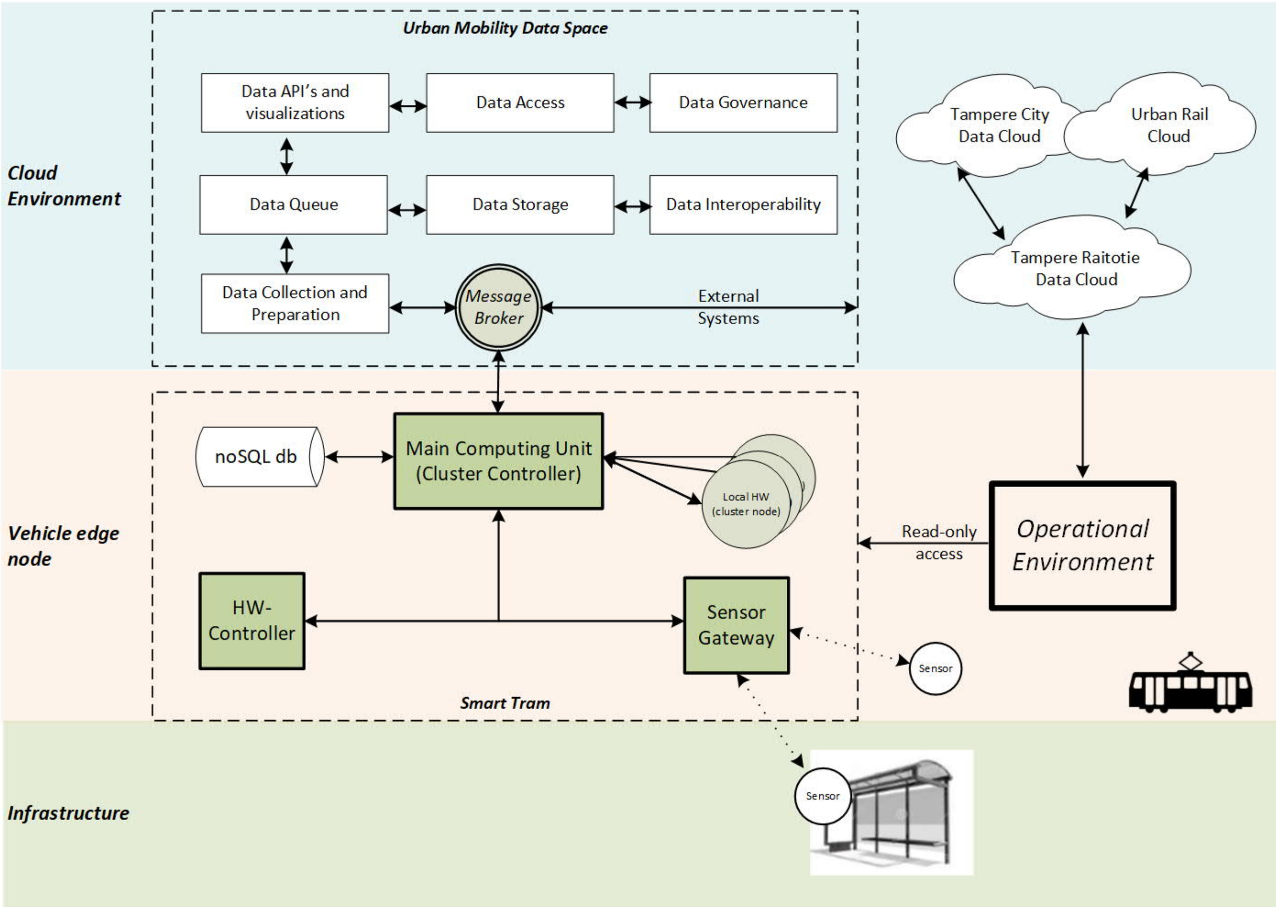

Figure 29. Overall System Architecture for the Urban Mobility Data Space

As the vehicle automation is increasing rapidly in current transport environment and it is promising safer, more convenient, and especially more efficient transportation systems, but it means also more requirements for the supporting ITS systems. There is a growing need for accurate, reliable, and real-time information from transport infrastructure.

For example, with the help of Edge computing, it would be possible for fleet operators and traffic controllers to get an accurate and real-time situational awareness of the transport network, and e.g. in case of traffic congestions start to "inform vehicles of the preferred new routes". Vehicles are ideally suited for environment surveillance and sensing, acting as a kind of mobile sensor platform that can offer wide geographical coverage (although time dependent) with limited number of cameras (compared to the number of cameras need in case of fixed camera installations). By looking at the sheer amount of generated data (e.g., with camera-based sensing it is order of a few several gigabytes per hour per vehicle) it is obvious that simply dumping all raw data to a cloud server, if desirable at all, is not a realistic option. Therefore dynamic, real-time and context-aware selection of which content to store onboard, and which send to a cloud server is an important research question to be addressed.

The overall system architecture of the *Urban Mobility Data Space* is based on edge computing model. This places the computing resources at the network edge, in this case inside the vehicle. enabling development of local services with quick response to the changes in the environment and for reducing the amount of data to be send to the cloud. In addition, in some cases, e.g. camera based passenger counting, privacy and GDPR-issues may also impact on the decision between edge and cloud processing locations. With the Edge computing approach, it is possible to pre-process part of the data inside the vehicle edge node and send only the calculated parameters or features to the application located in the cloud.

Although edge computing offers solutions for many ITS challenges, it is not complete solution. The typical vehicle edge computing platform is usually quite resource constrained (e.g. in regards to CPU, memory, disk space, energy consumption), so the decision of what is processed locally and what is send to the cloud, is essential. In addition, it seems that the decision process should be quite dynamic and dependent of the context. This would require mechanisms to deploy distributed data-analysis functionalities and algorithms to the vehicle nodes in a dynamic manner.

Another formidable challenge relates to security and privacy aspects. The connected Edge-computing node inside the vehicle is probable more vulnerable to potential security attacks compared to traditional cloud-server environment. On the other hand, it is possibility to keep the sensitive raw data (e.g. captured video or picture material) inside the vehicle, in other words, not to send the user sensitive material out of the device but process it locally and send only the calculated and anonymized features to the cloud.

5.3 Smart Tram

Smart Tram forms the “lower” half of the *Urban Mobility Data Space*. It is a vehicle edge node operating inside a (public transit) vehicle, in this case a tram. The system is parallel to the operational tram ICT system and sandboxed out of the critical systems, such as driving controls and driver interaction. The system architecture of the Smart Tram IT Environment is presented in the following Figure 30.

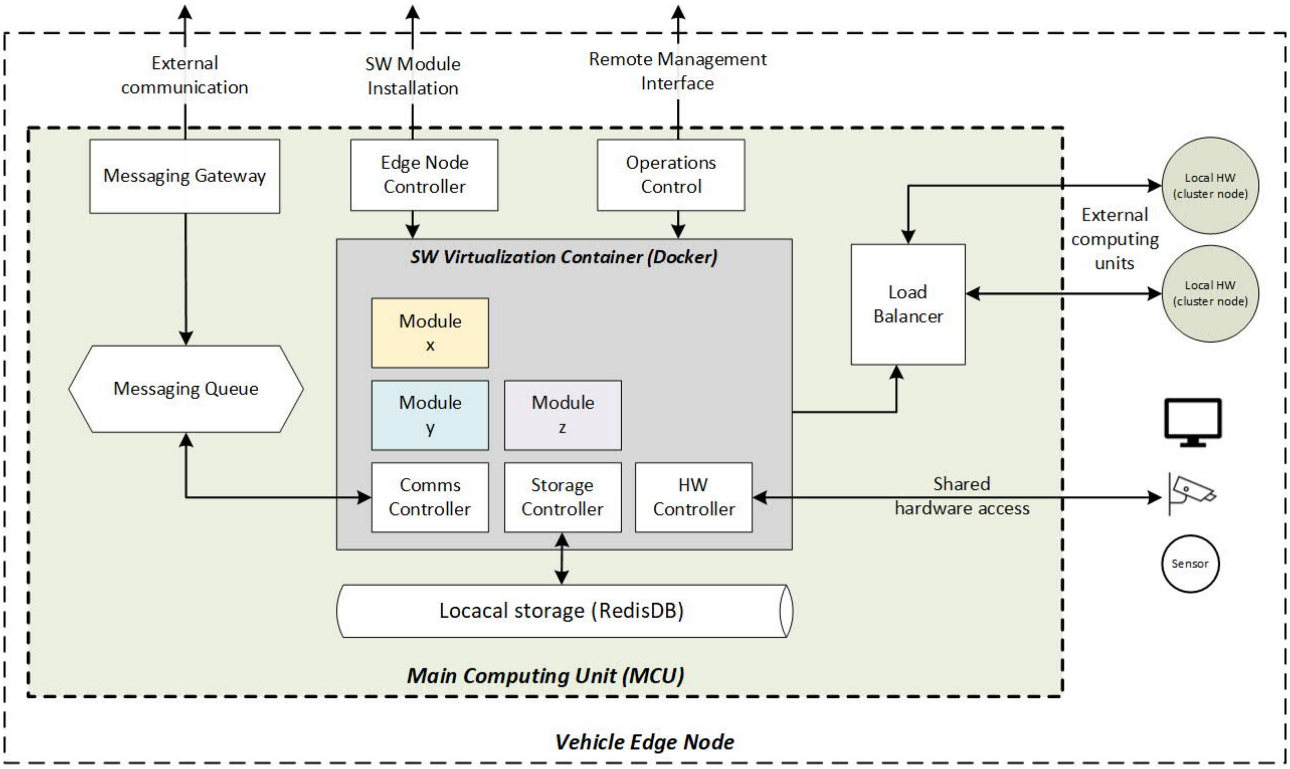

Figure 30. System Architecture for the Smart Tram Environment

Vehicle edge environments, such as the Smart Tram, are typically more resource constrained in terms of computation and communication (and recommended power usage) when compared to Cloud and Internet based computing-platform, on the other hand a modern tram can carry dozens of independent computing units (e.g., door/display computers) that are not used all the time or to the full potential, meaning that there might exists un-utilized computing power, at least intermittently. For example, AI-based image analysis from tram camera feed requires a lot of computational resources and may put a heavy load to single computer system (maybe making it un-responsive to the other services). In some cases, if there are no strict time limits, the computation tasks could be divided to available computing nodes inside a larger computation cluster where image processing task could be done in sync with the allocation of computing resources.

The Smart Tram software component architecture is based on a service virtualization model. The virtualization is done using Docker[8] to create and manage containers allowing multiple applications, worker tasks and other processes to run autonomously on a single physical machine. Compared to the traditional deployments, the virtualization introduces several benefits, such as easy deployment of new software modules, portability between different vehicles, monitoring and maintenance of resource usage. In addition, the virtualization can make it easier to create and operate task or workload queues. This allows the deployment of computing tasks in line with the resources availability, allowing a platform as a service (PaaS)-style of deployment and scaling.

By using virtualized containers, such as Docker, services running inside the vehicle can be isolated and restricted. It is also possible to sandbox the “testing” computing environment from the operational environment where processes have an almost completely private view of the operating system with

[8] Empowering App Development for Developers | Docker

their own process id space, file system structure, and network interfaces. Multiple containers share the same kernel, but each container can be constrained to only use a defined amount of resources such as CPU, memory and I/O.

Virtualization of edge computing resources is still an open research question, and the current state of edge computing (and IoT) is that there are no globally standardized edge computing environment available for application and service development, but each application and service is built as a heterogeneous mix of technologies relying only on available global horizontal digital infrastructures available for any type of applications - namely the Internet and public clouds

5.4 Transport Research Data Platform

Transport Research Data Platform is the "upper" half of the Urban Mobility Data Space, offering the cloud-based functionalities for the living lab environment. It is an innovation platform that enables testing and development of new product and services for transport domain. Transport Research Data Platform combines rich set of available transport data together from various data sets and acts as a centralized hub where it can be accessed for analysis and integration. It harmonizes data into usable and uniform structures and provides managed APIs and applications to access the data. The Figure 31 below, presents the component architecture for the Transport Research Data Platform.

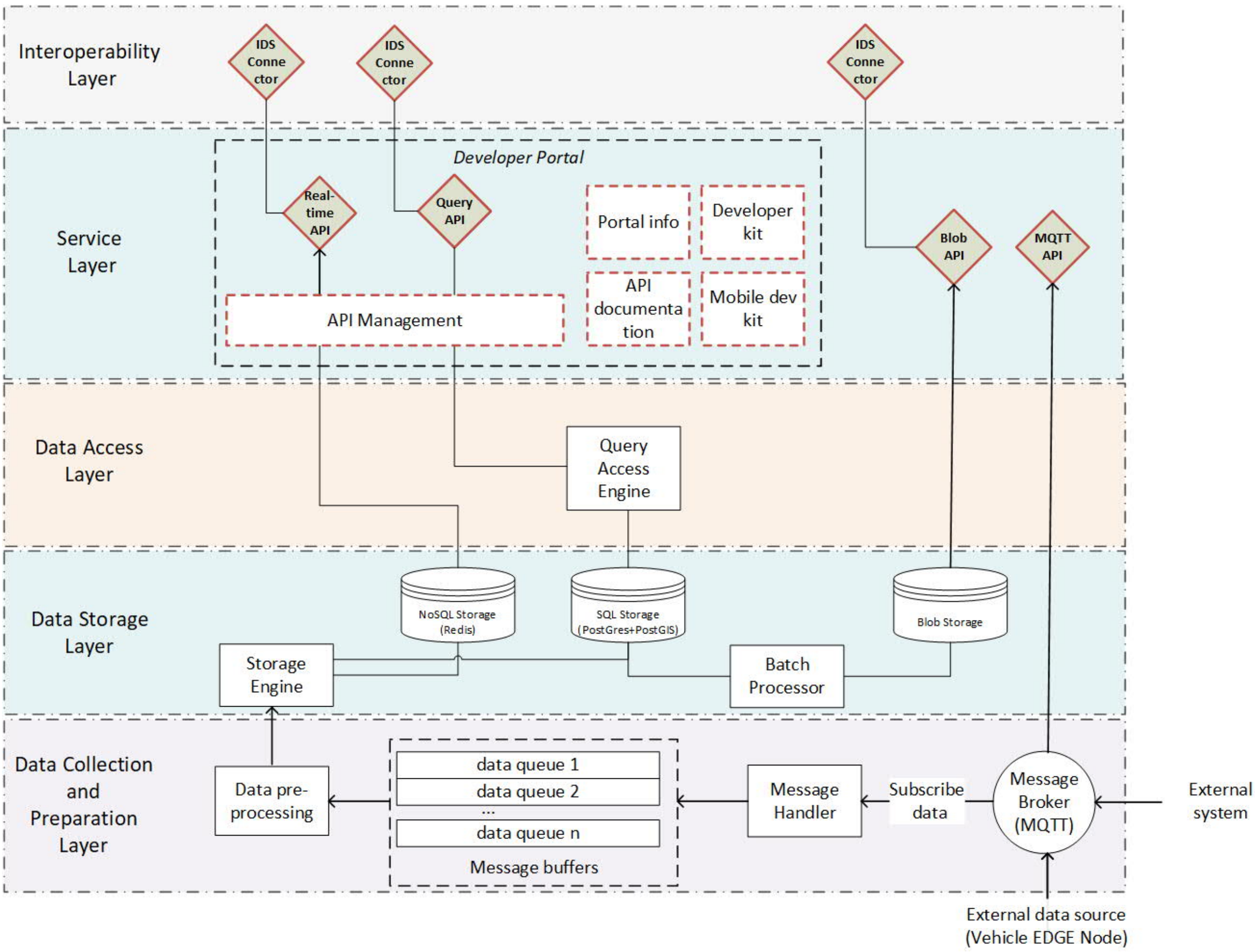

Figure 31. System Architecture for the Transport Research Data Platform

Transport Research Data Platform acts as a cloud-part of the Smart Tram Environment processing all the data created by the vehicle unit(s). In addition, it also collects data from the whole transport system and the surrounding smart city context.

The system architecture of the Transport Research Data Platform is divided into the following five layers, each handling specific part for the flow of data from tram to actual end users/services.

Data Collection and Preparation Layer.

This layer takes care of all the functionalities related to the data collection. It provides necessary interfaces for data injection both from tram fleet and external transport information systems. The main data injection interface is MQTT message broker where the MessageHandler component subscribe the needed message streams. Upon receiving a message carrying data, the MessageHandler injects the data object to a message buffer that provides a queueing mechanism for scalability. The Data Pre-processing module then reads the data from the buffers and depending on the data type performs set of quality control and harmonization tasks. After which the data is passed to the Data Storage Layer.

Data Storage Layer.

The StorageEngine module handles the storage functions for the data. Depending on the data type, e.g., if the dataset is intended to be shared through real-time API, data is stored to the noSQL storage (Redis) for minimum delay. Some data types are indexed and stored to the SQL-storage as time-series model and can accessed and queried through API layer. As the amount of data received every day is huge, the datasets are not permanently stored in the data base. Every day the Batch processor module converts previous day segment of collected data into a CSV clump and archives it in Azure Blob storage.

Data Access Layer

As in many cases analytics services may require making queries on structured data also for older data, the Query Access Engine provides the reverse fetching of archived data from azure blob storage to the SQL database.

Service Layer

The Service Layer provides all the functionalities related to the interaction with services and other external users. The developer portal combines tools and documentation necessary for 3rd party developers as well as overall API management.

Interoperability Layer

The Interoperability layer aims for providing functionalities that enable secure and trusted data exchange with external data platforms. The layer contains the data connectors needed to achieve integration with European data interoperability frameworks (Gaia-x, IDS and European mobility data spaces).

5.5 Proof-of-concept testing

5.5.1 Big data management systems

The key element of the Transport Research Data Platform is the data storage for big data. The data volumes has generally increased considerable lately due to the use of internet and emergence of social media. Also cheaper sensor technologies and decreasing cost of data processing, transfer and storage have enabled to increase intelligence of our physical environment as IoT applications. Intelligent Transportation Systems (ITS) is an important application area for big data and IoT technologies (Alam 2017).

During the last decade there was a debate wheatear or not the traditional relational data base management systems (RDBMS) are suitable for storing very big amount of data (petabytes). To response new application requirements Internet giants developed their own distributed non-relational systems to help with this new flood of data like MapReduce (Dean 2004) and Bigtable (Chang 2006) by Google, and Dynamo (DeCandia 2007) by Amazon. This research led to non-relational databases, including Hadoop (based on the MapReduce paper 2006), Cassandra (inspired the Bigtable and Dynamo papers 2008) and MongoDB (2009). These new systems were written from scratch and because those don't adhere relational model and thus didn't support SQL, those were called NoSQL databases.

Traditional relational databases were not designed to be highly scalable and distributed (relational databases scale vertically not horizontally), mainly because relational joins would be unacceptably slow if the data didn't all reside on the same machine (Jatana 2012). Also some other issues have been noticed like traditional RDBMS were not very good for storing semi-structured data, the rigid schema also makes those more expensive to set up, maintain and grow since setting up a RDBMS requires users to have specific use cases in advance; any changes to the schema are time-consuming (deployment problem). Due to the rigid ACID (Atomicity, Consistency, Isolation, and Durability) requirements, there are transaction speed limitations leading to flimsy response to high velocity and volume requirements. For social media and IoT applications thousands of transactions per a second is not very much.

Traditional database systems based relational SQL try to use very reliable hardware (fault tolerant) that is expensive. For handling immense amount of data (petabytes) NoSQL/Big data system start to use unreliable commodity hardware that can have frequently problems. Typical Google cluster had thousands of HD failures, 1000 single machine failures, 20 rack failures and several network partitions per a year (Dean 2011). Replication allows to maintain availability but fails inflict synchronization problems that leads to consistency problems. RDBMSs suffer from no horizontal scaling for high transaction loads (millions of read-writes), while NoSQL databases solve high transaction loads but at the cost of data integrity and joins (Ameri 2016).

5.5.2 IoT type traffic data management with RDBMS

As stated in the requirement use cases traffic data is a real big data. Traffic IoT system may contain many categories of sensors like GPS, RFID ticket readers, video cameras, traffic-flow analysis sensors, traffic loop sensors, track condition sensors to meteorological and other environmental sensors. CBM "telemetry" type sensor data accumulation can be very heavy depending on sampling rate, automatic driving or passenger counting raw data sets based on video stream or lidar information for algorithm development can be huge. Use of this data is also probably very asymmetric e.g., "write over reads" where huge amount of write request are caused by telemetry and visual data with occasional, but very big (gigabytes) read requests when analyzes are performed.

The traffic related data is inherently time based - a piece of data is a fact that is true at some moment of time. From this property of data follows immediately from that data is inherently immutable, the truthfulness of a piece of data never changes. This means that there are only two main operations related to data: reading existing data and adding more data. There are a very few cases where data will be permanently deleted, such as regulations requiring to purge data after a certain amount of time due to the privacy issues (e.g. European General Data Protection Regulation, GDPR). This "immutable perspective" at first seems to favor to use systems like Hadoop and MapReduce.

Spatial-temporal attribute is intrinsic for traffic data. Every sampling value corresponds to a location and a time stamp describing where and when the value is sampled. Location and a sampling time are crucial information for query processing and spatial support for NoSQL databases are often severely limited. MongoDB and some other NoSQL has support for GeoJSON and Hadoop Big data environment has a spatial extension[9], but only small amount of research paper handle spatial data and NoSQL integration. It seems that support for geospatial data handling in NoSQL databases is still immature. On the other hand, relational database management systems like Postgre has a very robust extension (PostGIS) to handle spatial queries.

There are limited amount of performance testing experiments related to geospatial information handing in different types of database management systems. Baralis & al. (2017) made some experiment with Azure DocumentDB (noSQL) and Azure SQL which indicated that on the average Azure DocumentDB is faster than Azure SQL Database due to sharding that allows parallelizing the execution of the user requests over several nodes. On the other hand Azure SQL Database scales better with respect to the number of concurrent users submitting simultaneous requests.

Based on our requirement analysis and experiences from Cern (Stefancova 2018), where they has used 90 InfluxDB NoSQL time series database instances and made a project for a testing PostgreSQL as an alternative for fixing performance problems with 65 K messages/s, ~3 TB data/day, we decided to make some experiments with Timescale Database Management System. TimeScale is an opensource time-series database developed on top of the PostgreSQL as an extension on PostgreSQL. For complex queries, TimescaleDB vastly outperforms InfluxDB, and supports a broader range of query types. The difference here is often in the range of seconds to tens of seconds.

Timescale, a spin off from research in Princeton University USA, has some attractive properties. It is based or relational model - each time-series measurements is recorded in own row and tables can be wide or narrow depending of data types. Row columns might be standard data types, JSON blobs, binary data or even more complex data. Rigid schema enables to validate input types or read-as-schema for JSON blobs. TimescaleDB supports the full range of SQL functionality (full SQL query language) including time-based aggregates, joins, subqueries, window functions, and secondary indexes.

Timescale has a very high data ingest rates (as high or better than NoSQL InFluxDB database), especially at larger database sizes and query performance ranging from equivalent to orders of magnitude greater. Timescale is implemented using B-trees top over PostgreSQL that allows to use the full range of PostgreSQL features and tools like geospatial queries via PostGIS, pg_dump and pg_restore, any connector that speaks PostgreSQL and use of visualization tools like Grafana and analysis tools like Promscale.

5.5.3 Transport Research Data Platform data handling experiments

The practical experimentations with TimescaleDB were performed with two different datasets: Helsinki Regional Traffic's traffic High Frequency Positions and Living Lab bus dataset. Both datasets were acquired by utilizing the SmartTram system architecture depicted in Figure 32. The aim of the study was to get some hands-on experiences TimeScale database time related queries with

[9] http://spatialhadoop.cs.umn.edu/

PostGIS geospatial queries by using different data types like public transportation time schedules and telemetry data.

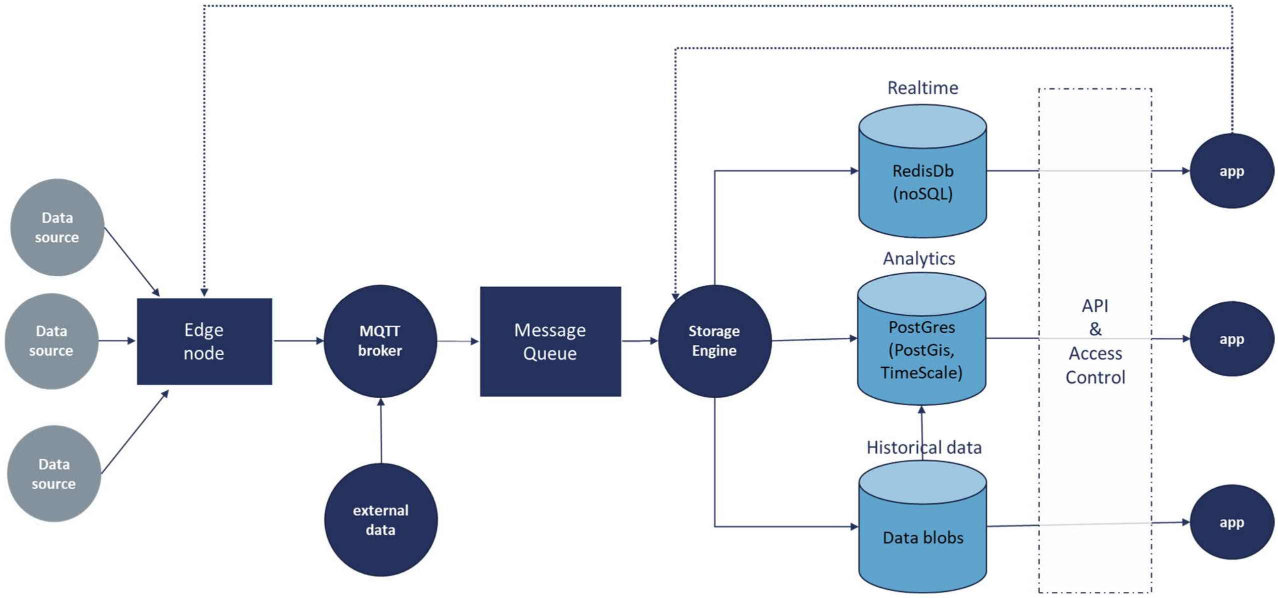

Figure 32. Transport Research Data Platform data architecture

The goal of the traffic emission demonstration was to provide energy consumption and $C0_2$ emission calculations from Helsinki Regional Traffic's (HRT/HSL) vehicle fleet in Etu-Töölö and Malmi district in City of Helsinki by using HRT's High Frequency Positions (HFP) service. Most of the vehicles (like busses and trams) in the HRT area can publish their status, including their position, once per second. This information with over 20 other attributes is provided as MQTT data streams and end users may subscribe to receive the relevant messages based on their interest, e.g. filtered on the mode of transport, the route ID etc. by using this HFP API.

HRT has totally 290 bus lines (routes), 11 tramlines and 2 metro lines, 14 rail lines and 2 ferry lines in greater Helsinki area. Route types that existed in our target region were buses, metro, trams and trains. The route count in the target area was 92, but some of vehicles operating in those lines are not equipped with real-time data collection abilities. Most notable examples are trains and subway trains (e.g., metro). When real-time information was available, all emission and energy calculations were based on driven kilometers (e.g., available odometer counts and vehicle's position information from the fleet). From each of observable routes driven kilometers were stored to the Traffic Data Platform's TimeScaleDB database and from this information; energy utilization and Co2 emissions were concluded by reconstructing driven routes. This reconstruction process requiring both time and geospatial searches is very time consuming (inefficient) since we couldn't find or easily develop any more time and space efficient algorithm than *O(n)*.

Emission and energy calculations were be based on LIPASTO[10] model developed by VTT. For more information see: http://lipasto.vtt.fi/yksikkopaastot/. For those lines/vehicles without real odometer information, we will estimate energy consumption and Co_2 emissions based on the length of the lines in areas and how many trips are scheduled daily- this feature will be added in the future.

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[10] http://lipasto.vtt.fi/yksikkopaastot/

The demonstration traffic service provided REST web APIs for making queries how much energy HRT's fleet is utilized and how much Co_2 is emitted in a certain bounding box area (e.g., geographical area that is defined by latitude and longitude coordinate points on opposite corners of a rectangle in WGS84 coordinate system) in a certain timeframe (e.g. from t_1 to t_2) within the town districts Etu-Töölö or Malmi.

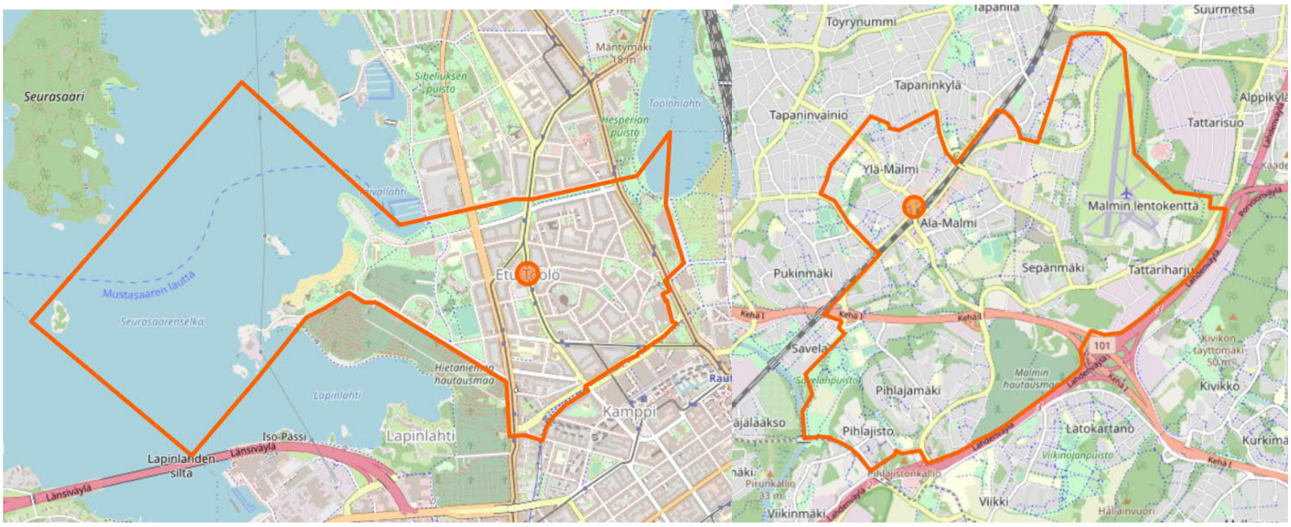

Figure 33. Etu- Töölö and Malmi districts geometries

Each row in the HRT sample set contained over 20 different attributes containing some information related to routes, current locations and driven kilometers (odometer counts). This real-time information available from HFP fleet was so voluminous that we decide to use a campaign-based data collection approach where the data is accumulated only a limited period of time once. For testing purposes two weeks period was considered to be big enough and didn't exceed to selected cloud based virtual server's disk quota (100 GB). This is roughly the same dataset size that HRT stores as on-line data on their big data system and after every two weeks accumulation of data, they compact it to non-searchable BLOBs for later use.

Collecting data from HRT fleet information from HRT's MQTT service by using dedicated Java clients was flawless and indicated that TimeScaleDB can easily handle insertion traffic generated by several hundred sources at once. Also, simple time based queries were very fast, but the sample dataset with only 80 GB data indicated that handing more complex spatiotemporal queries (utilizing convoluted WGS84 based geometry of Etu-Töölö and Malmi border lines shown in Figure 33.) are quite slow and geographic indexing schemes like use Uber H3 and Geohashes should be studied more closely in the future in addition to TimeScale table portioning and indexing to speed up searches.

Another similar kind of experiments with the Transport Research Data Platform was performed with Living Lab Bus data. LLB bus fleet contains seven electric busses operating in certain daily routes in Helsinki city area. Like HRT's fleet, every running LLB bus transmit once a second a telemetry data sample containing over 100 different attributes including route information, location and several measurements available from vehicles' CAN- bus via an MQTT broker. Also, some environmental information inside a bus could be obtained by using VTT's TinyNode sensor hubs that were wirelessly connected to vehicle's edge processing units (OBUs, On Board Units) via Bluetooth and transmitted as a part of the data packets to the MS Azure backend cloud where our TimeScaleDB resided.

The LLB test interface allows web-based access to LLB traffic data sets collected into the Transport Research Data Platform from the LLB fleets' data feeds (Figure 34). Web based access (read only) is much safer way to handle LLB data compared to direct manipulation enabled by PostgreSQL tools like psql. The web layer between the database and the user tools isolates the data from accidental changes and enables to add an additional security and access control layer into the system. This additional security layer enables fine grain access control methods in the future in addition to existing access control enable by TimeScale/Postgres DBMS, thus increasing the system security when handled confidential and personal mobility information that is under the General Data Protection Regulation, GDPR) legislation.

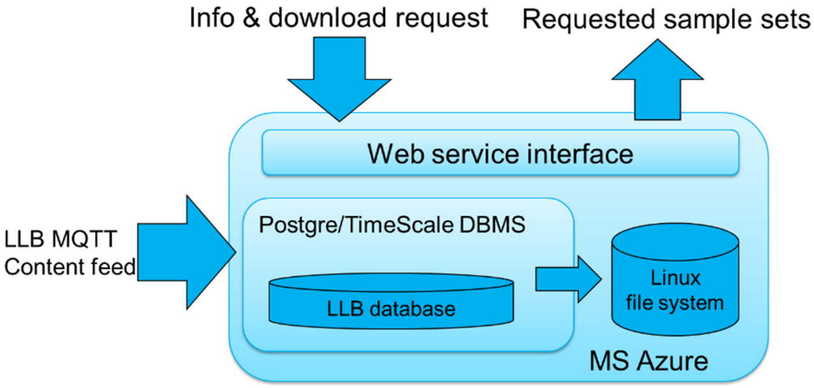

Figure 34. Basic principle of LLB data extraction

LLB data contains over 100 different attributes that are stored as a wide column rows in TimeScale database. This constantly accumulating information was available as downloadable dataset via LLB web API. Two types of experimental API data queries were offered for tests:

- Metadata queries, which enables to get some statistical data about the currently available LLB dataset
- Sample set download queries, allowing to access specific route or vehicle data within a specified timeframe.

Depending of the LLB database size, queries might take several seconds, especially metadata queries that collect information from the database by using several sequential SQL queries. Sample set download queries are much faster if the extracted dataset is smaller one, downloading the whole dataset might take a longer time and is not recommended due to the used limited intermediate storage (e.g., Linux server file system which capacity depends on virtual machine's settings as already mentioned in the case of HFP data).

Metadata queries provided were:

- Asking all available route data in the database and timeframe that it covers and how big is the sample set size.
- Getting a summary of vehicle data in the database including operator ids, vehicle ids, how much information is collected when the vehicle has driven on-route and how much non-route information id available and the timeframe of the collected data.

By using data requests, a user is able to download more specific information according to his/her interests. Both route and vehicle specific data queries within a certain timeframe could be expressed. For experiments we were not supporting downloading all available information from a specific route or vehicle at once, but if such an interest will emerge in the future, this functionality can be added later.

The LLB dataset available are provided by Comma Separed Value (CSV) format files with the header information. Files are zipped to preserve bandwidth since the compression can reduce the file size substantially. Downloading a vehicle information (concerning for example vehicle 1614) data set can be expressed as:

- xba-datastorage.northeurope.cloudapp.azure.com:4000/samples?vehicle=1614&start=2020-11-04T18:14:35&stop=2020-11-04T23:14:35

As a request result a new dialog box opens (note that this picture 35 is extracted from the development environment as the “from” field has an URL referring to a localhost). By using alternatives given in the dialog box, a user can either save zip file or open it by using WinZip decompression utility and store it as unzipped:

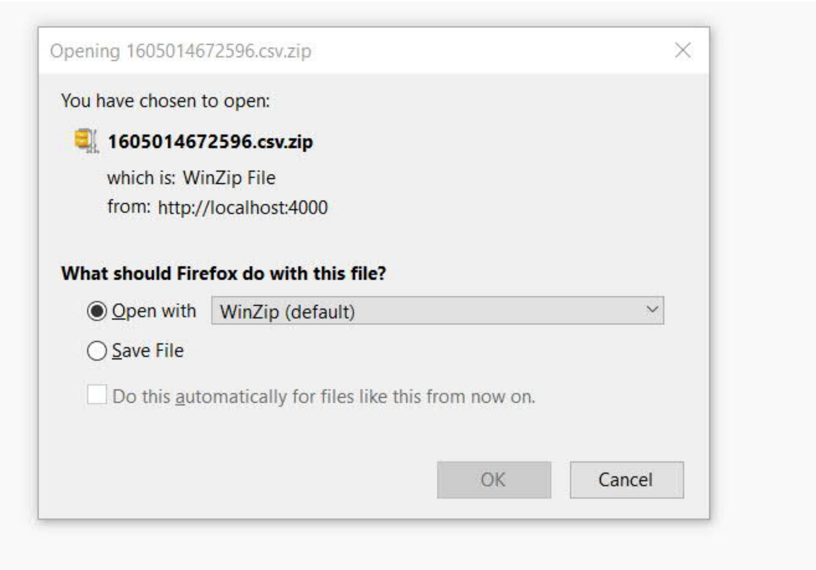

Figure 35. Downloading LLB sample set from the TimeScaleDB

This experiment also indicated the flexibility of TimeScaleDB based time series database solution. The implementation of this experimental web service was easy due to toolsets offered by underlying Postgre DBMS.

5.5.4 Experiment conclusions

As a conclusion from these practical tests with (both dockerized and plain installation) TimeScaleDB in MS Azure environment indicated it to be a very promising candidate for handling traffic related telemetry data when both time and space related queries are essential. Postgre also enables handling JSON and text data (with full text search) efficiently that might be needed to support other living lab functions. Our experiments didn’t cover content types related to CBM and automatic driving like camera or lidar information that are even far more voluminous than telemetry data, but for these some other solutions like Hadoop HDFS (Hadoop Distributed File System) is expected to be much more suitable (Liu 2015). Practical experiments are also needed to be performed in this area to get a more comprehensive view of video stream handling solutions.

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6 Conclusions

In Tampere, the activities related to the new tramway has given birth to the SmartRail ecosystem led by tram manufacturer *Škoda Transtech.* In this ecosystem City of Tampere and numerous companies and research groups, aims at enabling and boosting user centric mobility services, sustainable mobility, and new business opportunities. To support these aims the SmartRail project started building a living lab tram environment in the context of the new Tampere tramway, that enables and boosts the development of new types of services. This living lab tram environment is intended to act as an enabler for the tramway ecosystem development activities and to concretize the co-operation between the ecosystem partners.

As a first step towards these goals, this report presented a specification for the smart tram living lab concept and necessary supporting technical environment. The work presented in this paper is partly based on the work done in the Living Lab Bus project (2016-2019) where a living lab environment for electric busses operating at Helsinki area was created.

The living lab concept is adapted to support both the participative development of the city services related to the new tramway and the public transportation as a whole according to the ecosystem goals. In addition to the living lab concept, we defined also specification for the necessary technical environment required to support the R&D&I work in the ecosystem. The specified technical environment serves at the same time as a part of the SmartRail Living Lab (Living Lab ICT) and more generally as a mobility research data environment serving also other R&D&I activities.

The technical specification is based on the high-level requirements from the living lab concept and the technical use case requirements and comprises of a cloud environment, offering access to data and other living lab resources, and of a vehicle environment that offers an operational tram as a vehicle ICT platform. The aim of the vehicle ICT platform is to enable involvement of people in the innovation process and can also be used for studying user needs in an authentic everyday use environment.

The aforementioned living lab concept is the first step towards the operational smart tram living lab environment. The second step will be the implementation and deployment of the concept and the supporting technical environment to the operational Tampere tramway environment. The work for this next step will start in the coming TURMS (Tampere Urban Rail Mobility Services) project, where the aim is to create a world class inclusive R&D&I environment for rail based urban mobility services.

Appendix 1: TURMS Open Access Principles (Finnish draft)

Avoimen TURMS-kehitysympäristön pelisäännöt

Tampere Urban Rail Mobility Services (TURMS) on **globaalisti avoin Living Lab -kehitysympäristö** raitiovaunuliikennettä runkonaan hyödyntäville kaupungin liikenne- ja liikkumispalveluille sekä niihin kytkeytyville digitaalisille palveluille.

Ympäristön **isäntäorganisaatio on Tampereen Raitiotie Oy** (TRO) ja se on osa Testbed Finland -verkostoa.

TURMS on tarkoitettu vauhdittamaan käyttäjäkeskeisesti tuotteiden ja palveluiden syntymistä sekä kestävää kaupunkikehitystä todellisessa ympäristössä tapahtuvien ketterien kokeiluiden, todennusten ja referenssiratkaisujen kautta. TURMSin toimintaan kuuluu myös kaupungin liikennejärjestelmän kehittämiseen liittyvien tavoiteohjattujen haasteiden ratkaiseminen.

TURMSin päämääränä on palvella **innovaatioklusteria** (ja SmartRail ekosysteemiä), joka koostuu yritysten, julkisen sektorin, tutkimusorganisaatioiden ja palveluiden käyttäjien muodostamasta kokonaisuudesta. Klusterin yritykset ovat tyypillisesti **palveluiden ja teknologioiden kehittäjiä, palveluiden tarjoajia** sekä näihin liittyviä **startup-toimijoita**.

TURMS tarjoaa sovelluskehittäjille tiedonsiirtoyhteyden testiraitiovaunuympäristöön ja rajapinnat testiraitiovaunun sekä sinne asennettavien laitteiden/järjestelmien tarjoamiin datalähteisiin, jotka ovat yhdisteltävissä muuhun kaupunkiliikenneympäristöstä saatavaan dataan (web-osoite ml. kuvaus). Raitiovaunu- ja laitetoimittajien kanssa on mahdollista myös sopia järjestelmiin liittyvien erityisdatojen hyödyntämisestä. Lisäksi käytössä ovat **fyysiset ympäristöt** (web-osoite ml. kuvaukset) varikkoon, pysäkkeihin, latausasemiin, liityntäliikenteeseen sekä raitiovaunuun liittyvien kokeiluiden toteuttamiseen.

TRO, Tampereen kaupunki, Skoda Transtech, Tampereen yliopisto ja VTT tuovat TURMS-testbedin tueksi VTT:n koordinoimana rakennettavan **Living Lab ympäristön**, joka tarjoaa kokeilijoille TURMS-dataa hyödyntävän **tutkimusdata-alustan**, **sovelluskehitysympäristön työkaluineen, HelpDesk -toiminnot, kokeilurekisteri + itsearviontityökalu** sekä monipuolisen ja helppokäyttöisen **käyttäjäpalautejärjestelmän** (web-osoite ml. kuvaus).

Avoimen TURMS-kehitysympäristön käytön perusperiaatteet ovat seuraavat.

1. Avointa TURMS-kehitysympäristöä voivat hyödyntää yritykset, julkiset toimijat, tutkimus- ja koulutusorganisaatiot, kaupungit, säätiöt, toimialajärjestöt jne. Tämä koskee sekä kotimaisia että kansainvälisiä toimijoita.
2. TURMS-ympäristön rekisteröityneet ja vuotuisen kumppanuusmaksun maksaneet käyttäjät muodostavat TURMS-innovaatioklusterin. Rekisteröityminen tapahtuu täyttämällä verkosta löytyvä hakemuslomake (web-osoite tähän). Samassa yhteydessä kuvataan suunnitellun kokeilun sisältö ja aikataulutus. TRO käsittelee hakemuksen XX viikon sisällä ja palaute sisältää mm. hyväksytyn jäsenyyskategorian.
3. Raitiovaunuun sisäiseen rakenteeseen ja osajärjestelmien yksityiskohtiin kohdistuvat kokeilut ja muut toimenpiteet edellyttävät myös hyväksyntää raitiovaunu- ja/tai osajärjestelmätoimittajalta.
4. Kehitysympäristön käyttöön oikeuttavat jäsenyyskategoriat ovat: suuryritys, midcap yritys, pienyritys, mikroyritys, startup-yritys, yliopisto ja AMK, tutkimuslaitos, säätiö/ yhdistys/ toimialajärjestö, kaupunki tai kaupunkiyhtiö sekä julkisen sektorin toimija.
5. Kehitysympäristön koordinointi tapahtuu yhden luukun periaatteella isäntäorganisaation kautta. Isäntäorganisaatio järjestää kontaktihenkilön(t) sekä ajantasaisen web-sivuston tiedonvaihtoon.

Kehitysympäristön jäseniä tiedotetaan aktiivisesti tulevista TURMS-tapahtumista ja tarjotaan mahdollisuus vaikuttaa niiden sisältöön.

6. Kaikilla jäsenillä on yhtäläiset oikeudet varata ja käyttää kehitysympäristön palveluita isäntäorganisaation kokeilujen arviointi- ja hyväksymisprosessin mukaisesti (web-osoite tähän, prosessin kuvaus myöhemmin). Kokeilusta riippuen prosessiin voi sisältyä myös raitiovaunutoimittajan sekä laite- ja järjestelmätoimittajien toiminnallisuuteen ja turvallisuuteen liittyviä reunaehtoja.
7. Kokeilut edellyttävät tarkentavat keskustelut isäntäorganisaation kanssa, joissa selvitetään yksityiskohtaisemmin kokeilun valmistelut, tarvittavat asennukset ja käytännön juoksutus. Samassa yhteydessä käydään läpi kehitysympäristön turvallisuusperiaatteet ja muut pelisäännöt. VTT opastaa kokeilijat Living Lab -ympäristön ja sen tarjoamien työkalujen käyttöön. Nämä opastukset ovat kokeilun tekijälle ilmainen palvelu.
8. Jos kokeilut ja niihin liittyvät asennukset vaativat kokeiluympäristön turvallisuuteen tai toimivuuteen liittyviin osiin (esim. rakenteet, laitteet, tietojärjestelmät) puuttumista, edellytetään että kyseisen osajärjestelmän toimittajan edustaja hyväksyy ja tarvittaessa valvoo tehtävät toimenpiteet. Raitiovaunuun liittyvät toimenpiteet suoritetaan Tampereen raitiovaunuprojektin (TRO/Skoda-Transtech) muutoshallintaprosessin mukaisesti.
9. Kokeiluihin liittyvistä laitteista ja muista hankinnoista sekä asennus- ja purkukustannuksista velvoitteineen vastaa käyttäjä itse. Asennuksia käyttäjä voi tehdä TROn asettamissa rajoissa itse. Muut asennukset tehdään isäntäorganisaation osoittamien tahojen toimesta palveluna käyttäjän kustannuksella. Pääosin asennuspalvelu tarjotaan TROn toimesta, mutta tarvittaessa osajärjestelmien toimittajien kautta TROn koordinoimana. Liitteessä Y on esitetty kehitysympäristön tarjoamien palveluiden hinnoittelu kokonaisuutena. Hintalista päivitetään vuosittain.
10. Kehitysympäristön tarjoamien datalähteiden (liikennejärjestelmä + fyysiset ympäristöt) ja tietoliikenneyhteyksien käytöstä ei peritä maksuja. Mikäli datan hyödyntäminen edellyttää Living Lab -ympäristöön tehtäviä (vähäisestä poikkevia) muutoksia, niin tästä aiheutuvat kulut sovitaan erikseen.
11. Kokeiluihin liittyvä tiedonvaihto on lähtökohtaisesti luottamuksellista niin isäntäorganisaation kuin alihankkijoina toimivien tahojen osalta. Tarvittaessa tehdään erillinen NDA -sopimus.
12. Kokeilijoiden toivotaan kuitenkin luovuttavan TURMS-kokeilurekisteriin lyhyen kuvauksen tekemistään kokeiluista ja suorittamaan kokeilujen vaikuttavuutta kuvaavan itsearvioinnin. Kokeilurekisteri ja itsearviointityökalun tulokset tulevat ainoastaan isäntäorganisaation (TRO) sekä Living Lab toiminnasta vastaavien alihankkijoiden (VTT ja Tampereen yliopisto) käyttöön.
13. Lisäksi kokeilijoiden toivotaan luovuttavan omaa kokeiludataansa koko innovaatioklusterin käyttöön tarkemmin sovittavin ehdoin (esim. kokeiludatan omistusoikeus säilyy kokeilijalla). Luovutus tapahtuu joko tutkimusdata-alustan kautta tai kokeilijan omien rajapintojen kautta. Näin dataa voidaan luovuttaa aineistoksi erilaisiin T&K-hankkeisiin sekä innovaatioklusterin muiden kehittäjien käyttöön, mikä mahdollistaa myös luovuttajalle liiketoiminnallista hyötyä oman tarjoaman esiin tuomisen kautta.
14. Kumppanuusmaksu oikeuttaa käyttäjän tekemään useampia kokeiluja kumppanuusjakson aikana. Kokeilut ovat käyttäjälle ilmaisia, jos niiden toteuttamiseen ei tarvita erikseen hinnoiteltuja tukitoimenpiteitä isäntäorganisaatiolta tai osajärjestelmien toimittajilta. Yksittäisen kokeilun pituudesta sovitaan isäntäorganisaation kanssa, jolla on oikeus rajoittaa kokeilun pituutta perustelluista syistä.

15. Kokeilut tapahtuvat isäntäorganisaation määrittelemän aikataulun mukaisesti. Osa kokeiluista voidaan toteuttaa ilman matkustajia suoritettavien testien yhteydessä ja pääosa normaalissa operatiivisessa liikenteessä.
16. Omistus- ja käyttöoikeudet kehitysympäristössä tehtyihin tuloksiin (foreground) ja niiden tausta-aineistoihin (background) kuuluvat kokeilun tehneelle organisaatiolle.
17. TURMS on jatkuvasti kehittyvä ympäristö, ja BF:n Testbed Finland -rahoitusta voidaan myös käyttää testbedin kehittymistä tukeviin hankintoihin. Testbedillä tapahtuva kokeilutoiminta tarjoaa mahdollisuuden osoittaa ratkaisujen toimivuus ja TURMS voi testbedin tarpeista riippuen ostaa ratkaisuja osaksi TURMS-kokonaisuutta. TURMSin ulkopuolella TRO:lla on mahdollisuus myös keskustella hankinnoista koskien koko raitiovaunukantaa. Tällaisista hankinnoista sovitaan aina erikseen ratkaisun tarjoajan sekä TURMSin/TROn välillä.

Appendix 2: TURMS Partnership application (Finnish draft)

Organisaation tiedot

Organisaatio	Organisaation koko nimi (lyhyt nimi)					
Organisaation kuvaus	Pyydetään lisäämään lyhyt kuvaus (4-5 riviä) organisaation liiketoiminnasta ja sen alueista, tuotteista ja palveluista, pääasiallisista markkina-alueista, henkilöstöstä ja omistuspohjasta. Indikoi myös mahdollinen kytkeytyminen isompaan konserniin.					
Osoite	Osoite tähän					
Web	Internet-osite tähän					
Maa	Maa, johon organisaatio on rekisteröity					
VAT numero	VAT numero, jos sellainen on olemassa					
Yhteyshenkilö	Nimi, ammattinimike ja organisaation alaosasto, sähköposti- ja käyntiositteet, puhelin					
Luokittelu (katso liite 1) (rastita relevantti ruutu)	*Iso yritys* *Mid-cap yritys* *Keskisuuri yritys* *Muu organisaatio*		*Pienyritys* *Mikroyritys* *Startup-yritys* *Kaupunki/ kaupunkiyhtiö*		*Yliopisto tai AMK* *Säätiö, toimialajärjestö* *Tutkimuslaitos* *Julkisen sektorin org.*	

Kehitys-, testaus-, validointi- ja yhteistyömme painopisteet TURMS testbed:iin liittyen
Pyydetään kuvaamaan lyhyesti tuote-, palvelu- ja/tai digitalisaatiokehityksenne pääalueet, joissa aiotte hyödyntää TURMS testbed:iä.

Sitoutuminen TURMS testbed:in hyödyntämiseen

Tampere Urban Rail Mobility Services (TURMS) testbed on globaalisti avoin ja eri intressiryhmiä osallistava kehitys- ja validointiympäristö (Living Lab) raitiovaunuteknologialle sekä raitiovaunuympäristöön liittyville kaupungin liikenne-/liikkumispalveluille mukaan lukien digitaaliset palvelut. Testbed rakentuu Tampereen kaupungin raitiovaunujärjestelmän ympärille käsittäen mm. testiraitiovaunun, muut raitiovaunut soveltuvin osin, varikon, pysäkit ja niiden oheisjärjestelmät, kehittäjäportaalin, datan integroinnin alustan ja loppukäyttäjien palautejärjestelmän. TURMSin ennakoitu elinkaari on vähintään 6 vuotta (2022 - 2027).

TURMSin käynnistysvaiheeseen haetaan Business Finland:in (BF) testbed-rahoitusta. Kyseessä on ns. innovaatioklusterirahoitus, joka edellyttää testbed-toimintaan sitoutuneen organisaatioryhmän olemassa oloa (yritykset, yliopistot ja tutkimuslaitokset, julkinen sektori, säätiöt ja järjestöt jne.). Tämä sitoutuminen osoitetaan vuotuisten TURMS kumppanuusmaksujen kautta. BF-rahoitus ja kumppanuusmaksut käytetään testbed:in kehittämiseen ja markkinointiin. Operatiivinen kehitys-, testaus-, validointi- ja muu toiminta TURMSissa tapahtuu toimijoiden omalla työllä ja kustannuksella hyödyntäen tarvittaessa TURMS-organisaation maksullisia palveluita (asennusapu ja -valvonta, turvatarkastukset ja luvitukset jne.; ks. TURMS-sääntökirja).

Organisaatiomme näkee TURMSin ainutlaatuisena mahdollisuutena nopeuttaa ja parantaa tuotteidemme kehitysprosessia ja sitoudumme TURMS innovaatioklusterin partneriksi seuraavin ehdoin.

VTT

Sitoutumisjakso (rastita relevantit vuodet ja täydennä kokonaisaika vuosissa; min. 1 vuosi + 1 vuoden askeleet)							
2022	2023	2024	2025	2026	2027		
Sitoutumisaika						*N*	vuotta

Kumppanuusmaksu (katso voimassa olevat vuosimaksut liitteestä 1)	Yhteensä [€]
Kumppanuusmaksu koko sitoutumisajalta	*0*

Vuotuinen kumppanuusmaksu vaihtelee sitoutumisajan ja organisaation koon/tyypin mukaan. Pyydetään valitsemaan asianmukainen kumppanuusmaksukategoria ja kertomaan indikoitu vuosimaksu kokonaissitoutumisajalla.

Kumppanuusmaksu veloitetaan kumppanuusjakson alussa vuosittain. Kumppanuusjakso voi alkaa sovitun kuukauden alusta kesken kalenterivuoden.

Kumppanuusmaksun vastineeksi saa:

- Todellisten käyttöolosuhteiden kehitys- ja testausympäristön kaupunkiliikenteen tuotteille ja palveluille.
- Eri käyttäjäryhmiä osallistavan kehitysympäristön palautejärjestelmineen.
- Näkyvyys ja referenssien mahdollistaminen ainutlaatuisessa kaupunkitason Living Labissa .
- Verkottumisympäristön partnereiden kohtaamiseen ja uusille liiketoiminta-avauksille.
- Mahdollisuuden käyttää keskenään yhteensopivia kaupunkiliikenteen tietovarantoja (testiraitiovaunu, raitiovaunukanta, syöttöliikenne, rataverkko, pysäkit ja varikko, jne.) .
- TURMS kumppanuuspäivät vuosittain sekä aktiivisen tiedottamisen TURMS-tapahtumista ja mahdollisuuden vaikuttaa niiden sisältöön.
- TURMS vuosi- ja palvelumaksut ovat hyväksyttäviä kuluja Business Finland -rahoitteisissa projekteissa.

Haemme tällä hakemukselle kumppanuutta Tampereen Raitiotie Oy:n johtamassa TURMS innovaatioklusterissa.

Olemme tutustuneet TURMS sääntökirjaan ja sitoudumme noudattamaan siinä ilmaistuja sääntöjä ja periaatteita, mikäli hakemuksemme hyväksytään.

Olemme tietoisia, että kaikki testbed-aktiviteetit, jotka edellyttävät pääsyä testiraitiovaunun sisäiseen rakenteeseen ja/tai osajärjestelmien yksityiskohtiin edellyttävät lupaa testiraitiovaunun valmistajalta (Skoda-Transtech Oy; yhteyshenkilö Kai Hermonen).

TURMS-kumppanuuden tavoitteena on käynnistää kehitys-, testaus-, validointi- ja yhteistyöaktiviteetit testbed:illä. Mikäli aktiviteetit syystä tai toisesta eivät käynnisty, niin organisaatiollamme ei ole mitään vaatimuksia testbed:in isäntäorganisaatiota Tampereen Raitiotie Oy:tä kohtaan.

Hakemuksemme astuu voimaan alla olevalla päiväyksellä ja nimenkirjoitukseen valtuutetun henkilön allekirjoituksella ja on voimassa niin kauan, kunnes Tampereen Raitiotie Oy on hyväksynyt tai hylännyt hakemuksemme.

Parhain terveisin,

Paikka ja aika

Nimenkirjoitukseen valtuutetun nimen selvennös
Ammattinimike
Organisaatio

Appendix 3: The process for the TURMS Living Lab utilization (Finnish draft)