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Analysis of Changes in Tram Service and Maintenance Process by Depot Infrastructure System Automation

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Abstract

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This thesis was carried out for Skoda Group Ltd during spring of 2023 as a part of Skoda Group's Smart Rail project. The target of this study was to find out what are the potential changes in existing Jokeri Light Rail tram depot infrastructure systems, and the possible new additional systems to enable autonomous tram movement inside the depot area, or to change manual tasks into automated activities. The results show how the autonomous tram movement or additional systems change the use of time in the service and maintenance process.

This study is based on observations at the depot and learning about the service and maintenance processes and the systems used. This study draws on the existing documentation and interviews with various experts from design, build, operation, and owner organizations. Observing the activities on the floor level provided a lot of valuable insight how the depot operates 24/7, what is the tram service and maintenance cycle and measure the key activities with the Skoda Group's personnel at the depot.

This thesis provides information for the whole tram ecosystem for future development projects of trams, depots, and service and maintenance processes. The emphasis is on control-command and signalling system, as it is responsible for safety and provides most of the benefit as described in this thesis.

Keywords: Tram, Depot, Automation

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Tämä opinnäytetyö tehtiin Skoda Group Oy:lle keväällä 2023 osana Skoda Groupin Smart Rail -projektia. Tämän tutkimuksen tavoitteena oli selvittää potentiaalisia muutoksia Raide-Jokerin varikon nykyisiin infrastruktuurijärjestelmiin. Lisäksi tarkasteltiin mahdollisia uusia järjestelmiä, jotka mahdollistavat autonomisen raitiovaunuliikenteen varikkoalueen sisällä tai manuaalisten tehtävien muuttamisen automatisoiduiksi toiminnoiksi. Tulosten perusteella voidaan arvioida, kuinka autonominen raitiovaunuliikenne tai lisäjärjestelmät muuttavat ajankäyttöä huolto- ja kunnossapitoprosessissa.

Opinnäytetyö perustuu havaintoihin varikolla, tutustumiseen huolto- ja kunnossapitoprosesseihin sekä käytössä oleviin järjestelmiin. Lisäksi perehdyttiin olemassa olevaan dokumentaatioon ja haastateltiin suunnittelu-, rakentamis-, käyttö- ja omistajaorganisaatioiden asiantuntijoita. Erinomaisena mahdollisuutena oli tarkastella toimintaa lattiatasolla. Tutkimuksen aikana saatiin paljon arvokasta näkemystä siitä, miten varikko toimii 24/7, ja mikä on raitiovaunujen huolto- ja kunnossapitosykli. Lisäksi päästiin mittaamaan keskeisiä toimintoja Skoda-konsernin henkilöstön kanssa varikolla.

Tämä opinnäytetyö tarjoaa tietoa koko raitiovaunuekosysteemille tulevia raitiovaunujen, varikoiden sekä huolto- ja kunnossapitoprosessien kehitysprojekteja varten. Analysointi painottuu varikonohjausjärjestelmään, joka vastaa turvallisesta vaunujen liikkumisesta ja tuo merkittävimmät hyödyt, jonka tämä opinnäytetyö osoittaa.

Avainsanat: Raitiovaunu, varikko, automatisointi

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1 Introduction

Urban mobility trends are changing because of the rising urbanization and suburbanization of the world. This includes an increase in public transportation due to it being practical and more environmentally friendly than owning a car running fossil fuels. Urban people are relying on public transportation, as driving a car will get more expensive and time-consuming when more people are moving to urban areas.

Globally, the number of people living in urban areas is expected to rise from 55 percent in 2018 to 66 percent in 2050. [1, p. 9] The Helsinki metropolitan area is expected to have an increase of 32 percent in the population between 2021 and 2060. [2, p. 29] The Helsinki metropolitan area MAL agreement has a target of 50% decrease in greenhouse gas emissions in 2030 compared to the 2005 level and expecting 16,500 new apartments annually. The cities and municipalities belonging to the MAL agreement intend to make major investments in rail transport. [3, p. 4.]

Having CO₂-friendly rail transport does not only need rail lines and rolling stock, but modern depots to store, service, maintain and repair the fleet. Metropolitan Area Transport has constructed a 25-km long new Jokeri Light Rail line in 2023 and a new depot for 29 new trams in Eastern Helsinki in 2022. [4.] Metropolitan Area Transport will start the construction of five new light rail lines by the year 2030. [3, p. 38] Three new depots will be built in Ruskeasuo, Koskela and Vaarala. Ruskeasuo depot will be completed in 2024 and Koskela in 2027. Vaarala depot schedule will be defined during 2023.

A modern tram depot needs modern processes and high efficiency. The key question in this thesis is “How much more service and maintenance time is gained by autonomous tram movement?” The question will be answered by analyzing the new depot rail infrastructure, service and maintenance time consumption used for moving the trams in the depot area, and the needed

changes in the existing depot infrastructure systems to enable autonomous movement.

This thesis is completed in theory for a time span of five years, as the trams being serviced and maintained at the depot are new and their service and maintenance program will start in the autumn of 2023.

This thesis is a part of Skoda Group's SmartRail project and acts as a preliminary study for further development of the infrastructure and infrastructure systems at Jokeri Light Rail depot and future depot projects of Metropolitan Area Transport.

1.1 Methodology

This thesis uses action research methodology, which targets to develop the organization by changing the actions or processes within the organization. In this thesis, the first step is to get introduced to the tram service and maintenance processes and the depot infrastructure systems by working at the depot for 4½ months. During the stay at the depot, relevant available documentation of Jokeri Light Rail depot's infrastructure and systems and relevant studies are reviewed. The observations at the depot and documentation review are supplemented by interviewing the key persons from Skoda Transtech, Metropolitan Area Transport, and the experts of the depot infrastructure systems.

Based on the study, data is gathered and modeled to give a thorough understanding of the situation using current service and maintenance model to gain insight and create a base model. Later, new data models are created based on the potential changes in the depot infrastructure systems and compared to the base model.

1.2 Scope and Limitation

The scope of this thesis is to analyze only Jokeri Light Rail depot, its infrastructure systems, and selected tram movements at the depot. The tram used in the analysis is Skoda Transtech's ForCity Smart Artic X54 only. The service and maintenance of ForCity Smart Artic X54 trams is analyzed in theory over a 5-year period. Details of the infrastructure and trams are excluded, as they play no role in the analysis nor the results.

1.3 Target of the Thesis

The target of this thesis is to identify potential areas of improvement in Jokeri Light Rail depot infrastructure systems to minimize non-productive time and increase efficiency and throughput in tram service and maintenance.

1.4 Theory and Hypothesis

In the study, qualitative research method was used with the hypothesis "It is possible to modify the depot infrastructure systems to enable autonomous tram movements to increase the efficiency of tram service and maintenance".

During the study, observations were made during two months at Jokeri Light Rail depot, and discussing with the experts working at the depot to find out the expectations of the personnel who is planning and executing the services. These two months helped to understand the service and maintenance concept, process, roles and responsibilities, and tram movements.

2 Jokeri Light Rail Depot

Jokeri Light Rail depot is located at the eastern end of the Jokeri Light Rail line in Roihupelto, Helsinki. The depot is designed to provide service, maintenance and inside storage for 30 trams of 35 meters in length. There are three main halls at the depot: 1) daily service, 2) heavy-duty maintenance, and 3) storage.

In the daily service hall, there are two drive-through tracks, one of which is extended by a tram washer. There are four tracks in the heavy-duty maintenance hall, one of which has tram lifts for removing the bogies for service and maintenance and one track with tram lifts and a lathe for turning the wheels. The storage hall has six tracks with a capacity of five trams each. The construction works were finished in the summer of 2022.



Picture 1. Jokeri Light Rail depot aerial view, 2022.

The service and maintenance is done on the ground level, office and meeting room facilities are located on the second floor. There are locker rooms with showers for both service and maintenance personnel and the drivers of Jokeri Light Rail trams.

3 Current State of Tram Service and Maintenance

This thesis covers Jokeri Light Rail depot only. As both the depot and trams are new and commercial traffic will begin in autumn 2023, some of the background information and basic data is based on expert opinions and the values stated by the manufacturers and suppliers in question. In addition, some of the information is based on the author's observations at the depot during Nov 14th, 2022, to March 31st, 2023. The results of this thesis may be used in other

depots either as aftermarket modifications or during the planning phase of a new depot.

3.1 Tram Depots in Finland

Currently, there are tram networks in Helsinki and Tampere. Helsinki has depots for downtown Helsinki trams in Koskela, Töölö and Vallila, and a depot for Jokeri Light Rail line in Roihupelto. [5.] The tram networks are not connected, and therefore downtown Helsinki trams may not be serviced or maintained at Roihupelto and Jokeri Light Rail trams may not be serviced in Helsinki tram's depots.

Tampere tram depot is in the southern part of Hervanta, near Rusko industrial area. It has a capacity of 26 trams of 37 meters in length and is designed to also serve 47-meter-long trams. The current depot has the capacity for the existing tram line and the trams of the upcoming line from Tampere city center to Lentävänniemi. [6.]

3.2 Tram Service and Maintenance

A daily service routine is done for every tram. After the daily service and cleaning is completed, the service and maintenance personnel drive the tram to heavy-duty maintenance, and the daily cleaning personnel drive the tram to storage. Of the 29 trams, Jokeri Light Rail uses 27 trams in operation, having two as a reserve in case of being in service, or an accident, breakdown, or any unexpected incident. [7.] The service and maintenance time of a tram is presented in Table 1.

Table 1. Annual service and maintenance time per tram.

	Daily (min)	1.5-month (h)	3-month (h)	Annual (h)	Total (h)
Times per annum	365	4	3	1	326

Every second 1.5-month service is replaced by a 3-month service.

3.3 Quality

Skoda Group has IRIS and ISO9001 quality standards certifications. [8] The IRIS certification has three components: 1) ISO/TS 22163:2017 standard, 2) IRIS certification conformity assessment: 2020, and 3) IRIS certification technology. The ISO/TS 22163 standard is largely based on ISO 9001, and it specifies a business management system requirement for rail organizations. The ISO/TS 22163 is tailored to fit for the companies within the railway sector for high quality business management. [9.]

To be able to obtain the IRIS certificate, a company needs to follow the rules and procedures set in the IRIS Conformity assessment. [9]

3.4 Depot Infrastructure Systems

Depot infrastructure systems are used to run the service and maintenance activities 24/7 described in chapter 3.2. The systems at Jokeri Light Rail depot are described in detail in chapters 3.4.1 – 3.4.5. In addition to the existing systems, there are various systems in the market to support the service and maintenance activities by automatically completing tasks that otherwise would require time-consuming manual work. One such system is the tram wheel

geometry monitoring system that is used to measure tram wheel flange for deviations. [10]

3.4.1 Control-Command and Signalling

European Union directive (EU) 2016/797 is a guideline for designing, implementing, and using a railway system in the European Union. The directive includes eleven TSIs, one of which is the Control Command and Signalling TSI. The CCS TSI does not cover urban rail infrastructure, and currently there are no common technical or operational guidelines within the EU. [11.]

The European Union has issued a directive (EU) 2016/798 for Common Safety Methods that describe how the targeted safety levels and systems' compliance are achieved and requirements fulfilled. The directive is applied in railway systems in the European Union, excluding urban railways. [12.]

Due to the lack of European Union wide, common directives for urban rail networks, each member state has its own set of rules and regulations.

Finnish Transport Infrastructure Agency has issued Finnish Interlocking Requirements that follow the directives and regulations set by the European Union Agency for Railways. The Finnish Interlocking Requirements refer to the CCS system and do not cover urban railway networks. [13.]

A CCS system is a set of rail infrastructure safety equipment that is used to ensure rail traffic operation and movement according to the safety rules. The system consists of four main elements: 1) a relay or microprocessor-based control unit, 2) turnouts, 3) visible signals, and 4) HMI to operate the system. [13.]

Finnish Transport and Communications Agency Traficom has issued a national regulation for urban railway systems, based on Act on Transport Services and Act on Railway Traffic. The regulation sets the targets for the operators' safety management system, obligations for storing and giving the safety-related

information to Traficom upon request, and requirements for reporting the safety deviations. [14.]

The CCS system at Jokeri Light Rail depot is designed and built according to Metropolitan Area Transport guidelines. The system provides information on the HMI for the user on occupied track section, not the actual physical position of the tram. [15.] ForCity Smart Artic X54 trams have accurate position data based on GPS and tachometer. There is no data communication between the CCS system and the trams. [16]

The production planner, and service and maintenance personnel have an HMI PC and an industrial tablet to control the CCS system at the depot to create routes for the tram. If the route conditions are met, the system sets the turnouts into the correct position and the signals to 'proceed' aspect. It is possible for the driver to drive the tram on a track without a set route, on an occupied track, pass a signal set to 'stop' aspect or exceed the 10km/h speed limit set at the depot. Eventually, safety is based on the driver's observations and actions, not the CCS system. [16.]

3.4.2 Door Control

The study at the depot shows that the door control opens the depot doors automatically when a tram approaches the door either from the outside or the inside. The doors will close automatically after the tram has passed the release point and the sensors do not detect any obstacles. The doors in the heavy-duty maintenance hall need to be opened manually when driving out from the depot. The heavy-duty maintenance hall doors have a timeout of 15 seconds, which is inadequate for track 8. Track 8 does not have a platform, so the person driving the tram needs to walk to the door, open it, turn off the main switch, walk back to the other end of the tram to enter it, and back to the cockpit to drive. When the tram is out, the driver needs to return to the door, turn on the main switch and close the door.

3.4.3 Tram Washer

The study at the depot shows that, the tram washer is operated manually from the control panel at the end of track 5B which is an extension of 5A, one of the two daily service tracks.

A tram arrives on 5A for daily service only when it will be washed. The trams are washed after 5,000 kilometers, which means once in every three weeks. If the tram requires underbody service, a special underbody wash cycle is done prior to the service. The service personnel drives the tram to the washer and checks that all the doors and latches are closed, walks to the control panel in the opposite end of the hall from the tram cockpit, selects the wash cycle given by the production planner and returns to the cockpit. He or she then waits approximately 13 minutes for the wash cycle to finish and drives the tram to the storage hall. If the tram should go to the heavy-duty maintenance hall, the driver drives the tram to the outside of heavy-duty maintenance hall doors. [7.]

3.4.4 Depot Safety System

The depot safety system is designed and built to ensure the tram catenary electrical safety, and occupational health and safety for the personnel working at the depot. The system has logical functions that do not allow the users to open the upper platform maintenance gates at the daily service and heavy-duty maintenance halls when the catenary power is on. Secondly, the depot safety system is connected with the heavy-duty maintenance hall crane so that the users may not move the crane to an area where the catenary power is on. Thirdly, the system is connected to the CCS to prevent a tram route on a non-electrified track. The users must perform certain observations when operating the system, such as ensuring the positions of the power breakers, service platform gates and tram pantographs. The users operate the system from control panels placed in areas where the observations are easily made. [17.]

3.4.5 Central Vacuum Cleaner

According to the study, the central vacuum cleaner has 94 inlets in the daily service and heavy-duty maintenance halls. The control unit is in the daily service hall. The system may be operated either in manual or scheduled mode. The scheduling of the system is done in an electrified control box, and would be considered as hard-coded, as it is not possible to change the scheduling remotely, or by the user. The recommendation of the supplier is that the vacuum cleaner is not on all the time, which means the users must walk to the control panel to turn it on and off.

3.5 Conclusion of Service and Maintenance

The study also shows that the service and maintenance process has clear roles. The production planner is one of the key persons whose responsibility it is to organize not only what should be done for the trams but also in what order the trams should be, where and what time. The production planner designs the tram routes in advance as a stack where the routes will be used as the process flows. It seems there is a need to optimize the number of tram movements within the depot and that Jokeri Light Rail depot would be an easy environment to move towards autonomous tram movements. [7.]

4 Base Data for the Study and Analysis

4.1 Tram movements

During the stay at the depot, it was noticed the tram movements are the biggest single time-consuming non-productive factor of the service and maintenance personnel. The depot has 1.7 kilometers of track inside the depot building and 2.3 kilometers outside. There are 24 turnouts, all of which are remotely operated with the CCS HMI. In the study phase data was collected about the selected six tram movements within the depot's three main halls: 1) D = daily

service and tram washer, 2) H = heavy-duty maintenance hall, and 3) S = storage. The tracks used for the movements are presented in Figure 1.

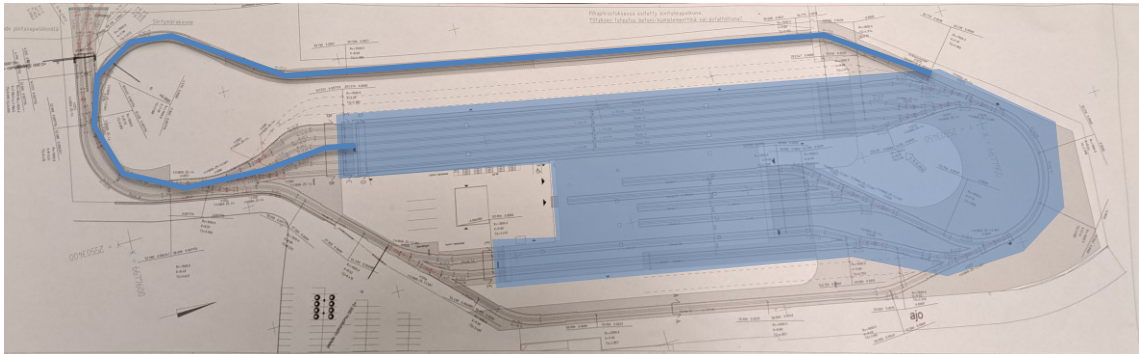


Figure 1. Track layout of Jokeri Light Rail depot.

One movement between each hall, both directions was studied. The route table for selected tram movements without a wash is presented in Table 2. Tram washing movements are excluded from the study as they are similar to any movement to and from track 4.

Table 2. Selected routes excluding tram washing.

Running ID	Start of the route (hall, track)	End of the route (hall, track)
1	D – 4	H – 8
2	D – 4	S – 12
3	H – 8	D – 4
4	H – 8	S – 12
5	S – 12	D – 4
6	S – 12	H – 8

The data is divided into two sets: 1) the time of driving the tram, and 2), the time used for other activities, such as walking, opening and closing doors, and assume the service and maintenance person returns to the same location in any of the three main halls. The ratio presents the value of driving time divided

by the total time. The timing was done on March 15th, 2023, together with Skoda Group's Aaro Tolmunen as driver and Mikko Gröndahl as the instructor of this Thesis.

The number of annual and 5-year period movements are theoretical and marked with (*), as there is not yet data or production planning available. The data is presented in Table 3.

Table 3. Time consumption and ratio.

Running ID	Driving time (s)	Time for other activities (s)	Ratio (%)	Number per a	Number per 5a
1			63.4	10*	50*
2			83.2	365	1,825
3			39.4	10*	50*
4			32.1	365*	1,825*
5			83.2	10*	50*
6			80.0	10*	50*

The data shows that running IDs 2, 3 and 4 play a significant role in the time consumption. The route with the running ID 2 will be driven daily for each tram. It is very unlikely that a tram will be moved from the heavy-duty hall to daily service, therefore it may be assumed the route with the running ID 4 will be driven daily from some of the three tracks.

4.2 Other systems

Besides the tram washer, it appears operating the other depot infrastructure systems do not play a significant role in non-productive time. The door control system is only used when moving a tram out of the heavy-duty maintenance hall and is included in table 3's other activities. The depot safety system is for

electrical and occupational safety, and operating it is and will be a part of the process as is.

4.2.1 Tram washer

The tram washer causes the 13-minute non-productive time per tram. The non-productive time for the 29 trams is estimated in total $29 \times 52/3 \times 13 = 6,534$ minutes = 109 hours, totaling 545 hours during a 5-year study period used in this thesis. The underbody wash cycles are excluded from the time estimation.

4.2.2 Central vacuum cleaner

If the central vacuum cleaner is in manual mode and the service personnel needs vacuum in the furthestmost inlet, the walking time to set the system on and off is 90 seconds. The need for the vacuum system is both periodical and ad hoc, with possible simultaneous users, it is not possible to reliably estimate the total non-productive walking time for a selected period.

4.3 Conclusion of Collected Data

The timing and analysis of the collected data show that there are non-productive tasks that may be automated without affecting the occupational health and safety, or the movement of trams. The key values are presented in table 4. Productive values are marked with '+' and non-productive with '-'. The ratio presents the estimated efficiency of service and maintenance; (daily service time + periodical maintenance time) / total time.

Table 4. Estimated annual time consumption per tram.

Daily service (h)	Periodical maintenance (h)	Moving of trams (h)	Washing of trams (h)	Ratio (%)
+	+	-	-3.8	88.9%

In conclusion, the analysis proves the moving and washing of trams by service and maintenance personnel accounts for 11% from the total estimated time consumption per tram.

5 System Development Potential and Interoperability

5.1 Control, Command and Signaling

An RBC is a wireless communication system that could be connected to the CCS, providing a safe two-way communication link between the CCS and the trams. Besides the RBC, the CCS system software would need a third operational mode, 'autonomous', in addition to manual and centralized control. The autonomous operational mode should be designed according to the existing safety rules and regulations with an appropriate SIL level. Most likely the system should be equipped with additional sensors to avoid a situation that would not happen when a human is driving the tram. One such situation is passing a signal with 'Stop' aspect, where the CCS system would then send a stop command to the tram via the RBC. [16.]

5.2 Door Control

During the study of the selected routes, it appears only the heavy-duty maintenance hall doors automatic operation when driving from inside to outside should be added to the automatic operation of the existing system.

5.3 Tram Washer

Technologically, automating the tram washer would be possible, but due to washing liquids, mist, and spills, the environment needs more research. As an environment from the occupational health and safety point of view, the tram washer is different from the other halls at the depot. The access to the tram washer hall is limited for authorized personnel only, and no personnel may be in the hall outside of the tram when the wash cycle is active. [7.] The 109 hours of

non-productive time would require further research and production planning to continue the development of the tram washer automation.

5.4 Depot Safety System

The depot safety system is automated to the highest possible level and does not provide potential for time-saving without endangering the safety targets set for the system. [17]

5.5 Central vacuum cleaner

The central vacuum cleaner system has the potential to be expanded with a wireless control box to operate the system from remote locations at the depot. The system would require e.g., a third-party mobile software which may be downloaded to service personnel's mobile phones' numbers only. Operating the system would be a part of the depot mobility application to provide ease of use and save electricity, as the system would only run when needed, with pre-programmed timeouts. Also, compared to the existing hard-coded schedule could be replaced with mobile software to provide more flexibility in the scheduling of the system.

6 Analysis of Changes in Service and Maintenance

The first step towards autonomous tram movement is to have all doors operating similarly. Modifying the door control gives a marginal time saving during the five years but will result in higher job satisfaction and personnel health and safety, as the driver does not need to walk back and forth using staircases and pits, nor jump in and out of the tram. Also, the working conditions will be more stable during the cold times and power consumption lower, when the doors will only be open for the time when a tram goes out.

Table 5. Analysis of time saving per system change.

System	Description of change	Estimated time saving in 5 years (h)
CCS	Adding an RBC to the system.	12,700
Door control	Door automation in heavy-duty maintenance hall, all tracks.	1,800
Tram washer	Software modifications to the tram washer.	545
Depot safety system	N/A	N/A
Central vacuum cleaner	Wireless control box for remote operation.	N/A

Theoretically, changing the CCS and door control systems would give fully autonomous tram movements and reduce the driving time by 12,700 hours, other activities by 1,800 hours, tram washer 545 hours, accounting to a total of 15,045 hours over a 5-year period. Figure 2 displays the time consumptions.

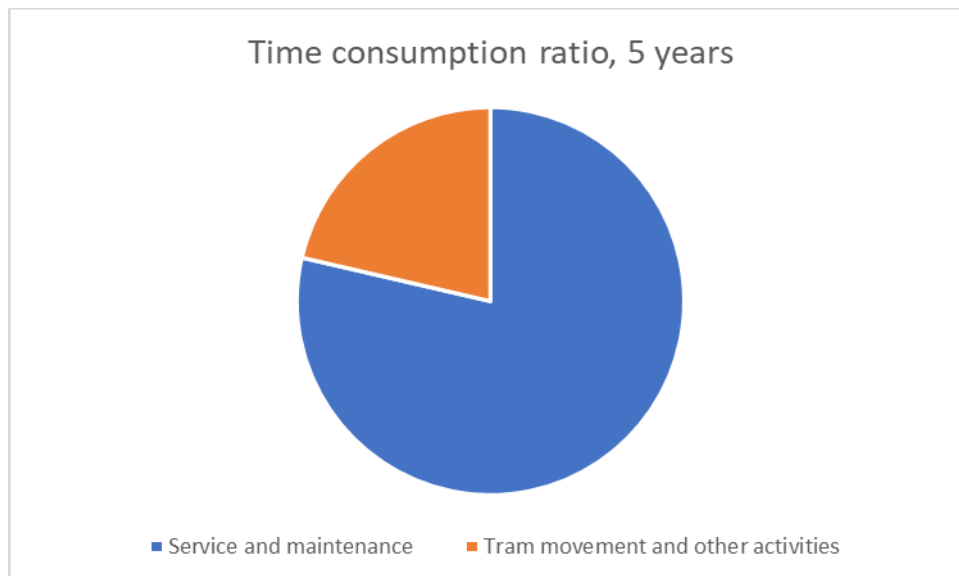


Figure 2. Time consumption of tram service and maintenance, and movements and other activities

If all the driving time with other driving-related activities could be converted to autonomous tram movements, it would increase the estimated service and maintenance efficiency from 88.9% to 99.1% as shown in table 5.

Table 6. Estimated annual time consumption per tram with automation.

Daily service (h)	Periodical maintenance (h)	Moving of trams (h)	Washing of trams (h)	Ratio (%)
+	+	-	-3.8	99.1%

The analysis proves that moving from human-driven trams to autonomous tram movements will increase efficiency by 10%.

6.1 Discussion

The autonomous tram movement would provide new tools for the production planning process. Developing the most effective combination of autonomous and human-driven tram movement with all the safety and risk aspects will take a long time. The approach is most likely Lean-like, first done with a simulator by a group of service and maintenance production planning experts.

It seems quite likely that in the future the service and maintenance will have a depot application in their mobile phones with which they can automate all the formerly manual tasks, to be able to e.g., call a tram to arrive at a certain time on a designated track in the heavy-duty maintenance hall and later send it back to the storage hall to be ready for commercial traffic. The apps will be connected to a centralized server with artificial intelligence capabilities which optimizes the depot tram routes, and proactive maintenance when future trams collect a vast amount of data and send the data in real time to the server. Additional systems could be used to move from manual and visual inspections by the service and maintenance personnel to collect the data that trams may not be able to collect. For example, high-speed cameras and radars could

inspect the tram's outside for damages or wheel flange geometry for deviations when the tram is moving. These kinds of systems will increase the throughput and accuracy in the tram service and maintenance.

A future depot will be an effective ecosystem where everything is based on accurate data and data analysis rather than driven distance, a calendar or because something has been done like that for years.

7 Summary and Conclusions

It is essential to perform a cost-benefit analysis for each potential change, and a combination of changes. Furthermore, a thorough risk assessment should be completed on a depot level according to the existing rules and regulations, considering the possible more detailed national or European Union regulations. Since the regulations do not cover urban rail networks, the focus should be on occupational health and safety, and the safety of the trams not colliding and causing significant financial damage and trams off the commercial traffic, and thus indirect costs.

VTT Technical Research Centre of Finland has published a pre-study regarding SmartRail Ecosystem. The technology roadmap states that during phases 2 and 3 depot conditional automation should be developed, whereas the legislation development takes place during the whole period of 2019 – 2028. [18, p. 3]

VTT's pre-study's proposed actions should act as a base when planning and designing new tram depots. The actions may be divided into three categories: 1) Tram technology, 2) Depot technology and 3) Users. Since there are already various types of trams, and some of the trams may not be technically modified to the needs of automated tram movements, there are many open challenges to be solved. The more modern trams the depot has, the more opportunities there are to move towards autonomous movements. In an environment where there are various tram types served in a depot, it is essential to acknowledge the tram

by its unique identification. When a tram is not able to perform autonomous movements, none of the systems will allow any autonomous-related commands.

As the global trend is to move towards zero emission public transportation, more tram networks will be constructed, safety will play a significant role along with high efficiency and throughput in service and maintenance.

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Appendices

List of Abbreviations

- CCS: *Control-Command and Signalling*. The system which is used to set routes for the tram according to the rules.
- GPS: *Global Positioning System*. A satellite-based system to provide position with accuracy of 30...500cm.
- HMI: *Human Machine Interface*. A control system for a user to give commands and receive indications from an underlying system.
- IRIS: *International Railway Industry Standard*. A global system for the evaluation of rail sector companies.
- MAL: *Land use, housing and transport agreements*. Used between municipalities in urban regions and the State to coordinate the use of land, housing, and transport.
- RBC: *Radio Block Centre*. A communication device to safely transmit the information between a control system and a moving unit.
- SIL: *Safety Integrity Level*. A system safety level based on IEC 61508 standard used in railway systems.
- TSI: *Technical Specification for Interoperability*. A set of technical and operational standards for railway subsystems to ensure the European Union's railway system interoperability.