Efficient Maintenance for Sustainable Transport Solutions - EMATS

Public report

Project within: Efficient and Connected Transport systems - FFI
Author: Johan Andreasson, Klas Hedvall, Lauri Vänttinen, Abhishek Shetty
Date: 2020-02-11

Contents

1 Summary

Vehicle maintenance and the workshop are both a part of the transport solution. This means that the maintenance solution is a subset of the transport solution. New technologies create conditions for new business solutions and vice versa. With new types of vehicles with advanced powertrains and fuel systems, the need for advanced maintenance and maintenance planning of the vehicles has increased. In EMATS we wanted to adapt the workshop solutions to one vehicle fleet consisting of electric vehicles, vehicles with alternative fuels and autonomous vehicles. An efficient transport solution requires an efficient maintenance solution where all stakeholders are integrated. In this project, we have looked at a comprehensive solution for the workshop and how the workshop processes can be integrated into the transport solution. The overall objective of the project was to develop aftermarket concepts for sustainable transport solutions with a holistic approach, and how can we ensure vehicle maintenance in the transport chain, linked to everything from the haulage's planning to the technician's work environment.

Based on previous FFI and Vinnova projects (Vinnova, 2014, 2015, 2015, 2016), (Energimyndigheten, 2016) we have knowledge about workshop concepts that meet the various demands of the stakeholders for sustainable transport solutions. In the EMATS project, we have developed workshop solutions with tools and integrated information flow (including digitalization) that streamline the activities in the workshop and improve the working environment. The result have been demonstrated in a physical workshop lab that was built for the project. The workshop can be seen as an innovation lab for all involved parties where we developed and validated our solutions. Further, the project has delivered tools that facilitate the work for the haulage and the driver with daily inspection and reporting deviations.

The main applicant in the project was AB Volvo and co-applicants in this project were Chalmers University of Technology, ARHO and Post Nord. Chalmers was responsible for designing new aftermarket concepts for sustainable transport solutions, ARHO developed a workshop system solution, Post Nord demanded and validated the system solution. Volvo handled the integration of vehicles, workshop systems and system solutions in the workshop lab. In the project, we have developed a comprehensive study of future transport solutions and how business relationships between the various actors can work. All parts of the project have received a lot of attention and confirmation.

This project has contributed for Sweden to maintain a leading position around sustainable transport solutions and cross-border collaborations on innovation; development and system solutions of sustainable transport solutions. The project will contribute to the foundation for future EU and FFI project applications, partly within robotics but also around workshop efficiency and above all in sustainable transport solutions where the workshop is included. The project enables long-term development in an area where there are many new research issues and potential projects together with universities and other companies. Partly in pure engineering development though the solutions and methods can also be applied in other areas. The projects holistic approach included sustainable transport solutions that include workshop solutions for autonomous vehicles and vehicles with alternative powertrains (electric, hybrid, DME, etc.). This means that we get more efficient transport solutions and we reduce the risk of unplanned stops. Through the holistic approach to the entire transport chain, we can create conditions for efficient and sustainable transport solutions.

2 Sammanfattning på svenska

Fordonsunderhåll, och därigenom även verkstaden, är en del av transportlösningen. Det gör att underhållslösningen är en delmängd av transportlösningen. Nya teknologier skapar förutsättningar för nya affärslösningar och vice versa. Utmaningarna kring den effektiva transportlösningen (inkl. el och autonoma -fordon) kräver en effektiv underhållslösning där alla intressenter är integrerade. Genom att använda teknik för integrerat informationsflöde mellan fordon och verkstadsutrustning kan nya digitaliseringslösningar tas fram för att effektivisera underhållet när fordonet är i verkstaden. En effektiv verkstad måste också vara en bra arbetsplats med en bra arbetsmiljö. Genom att ta fram automatiserade lösningar kan såväl effektivitet (inkl. administration) och arbetsmiljö förbättras. För fordonsägarna och förarna medför en bättre serviceplanering bra uptime. I EMATS projektet har vi tagit fram verkstadslösningar med verktyg och integrerat informationsflöde (bland annat digitalisering) som effektiviserar aktiviteterna i verkstaden och förbättrar arbetsmiljön samtidigt som åkeriet och föraren har fått verktyg för att underlätta kontroll före körning och avvikelserapportering. I projektet har vi tagit fram en omfattande studie kring framtidens transportlösningar och hur affärsrelationerna mellan de olika aktörerna kan fungera. Alla delar av projektet har fått stor uppmärksamhet och bekräftelse.

Syftet med EMATS var att ta fram en underhållslösning utifrån ett holistiskt perspektiv för alla aktörer kring transportlösningen. I projektet har vi tagit fram ett integrerat informationsflöde för verkstaden (digitalisering), samt lösningar som förbättrar arbetsmiljön för både mekanikern i verkstaden och effektivitetshöjande lösningar för föraren och åkeriet. Samverkan mellan aktörer involverade i transporter och underhåll har studerats för att identifiering av möjligheter till förbättrade underhållslösningar, ökad transporteffektivitet och nya affärsmodeller.

Övergripande målet för projektet var eftermaknadskoncept för hållbara transportlösningar med ett holistiskt synsätt. För att nå dit har vi tagit fram en konceptverkstad där vi testat olika systemlösningar för det integrerade informationsflödet mellan fordon och verkstadsutrustning. Vi har även tagit fram en plattform som hjälper åkeriet och föraren. Lösningarna är beroende av nya förhållningssätt till affärslösningen. Genom samarbete med akademin har vi tagit fram uppmärksammade forskningsresultat.

I projektet har en större studie genomförts kring den framtida transportlösningen och underhållslösningen. Detta tillsammans med dagens systemlösningar och utmaningar har vi jobbat utifrån ett holistiskt synsätt kring hur den framtida underhållslösningen bör se ut, utifrån ett affärsmässigt och tekniskt perspektiv. En konceptverkstad har byggts upp och delresultat från verkstaden har testats separat i verkliga verkstäder. Vi har även tagit fram lösningar på kort sikt som stödjer både åkeriet och föraren med fordonsuppföljning.

I konceptverkstaden har även test och utveckling av det integrerade informationsflödet för verkstaden har. Bland annat har semiautomatiska lösningar utvecklats som förbättrar arbetsmiljön i verkstaden. Förbättrad administration och automatisk sammanställning av insamlad data medför förbättrade skattningar av komponenternas hälsostatus. Med nya typer av fordon såsom autonoma fordon kommer kraven på underhållslösningen öka, lösningar framtagna i projektet skapar förutsättningar för en effektiv underhållslösning med tillhörande affärslösningar.

3 Background

The entire society faces major challenges in developing sustainable transport solutions, which includes integrated maintenance processes in the transport system. According to Näringsdepartementet (2012) we know that by 2050, we should have changed the vehicle fleet to use fossil-free fuels. Freight transport is expected to increase by 50% between 2000 and 2020 (European Union, 2006). Another challenge that the automotive industry faces is autonomous vehicles (a vehicle may be autonomous in restricted areas such as on vehicle depots or in the workshop area).

A prerequisite for sustainable transport solutions is that vehicle maintenance also meets requirements around the work environment and in handling of environmental hazardous liquids /substances. New types of fuel and materials together with increased vehicle complexity place higher demands on the technician and the workshop design. A technician must be able to handle new vehicle systems and the vehicle systems place new demands on the workshops. For example, the workshops must be able to handle LNG (liquefied natural gas), DME (dimethyl ether) and hydrogen at the same time as the workshops will handle super capacitors, batteries and power electronics. This mix of different types of components means that the workshops must have efficient processes and functions for the handling of a large variety of vehicles. In addition to new processes and functions, the vehicles must also be adapted with improved diagnostics and serviceability. These new conditions for the workshop and staff mean that the technician's way of working in the workshop must be adapted. Several vehicle manufacturers have started manufacturing hybrid and electric trucks and buses. With such a rapid change in the fleet, it is important to update and modernize the workshop concepts.

The need to be able to predict the service needs of vehicles is an active area of research. Several projects have developed methods for estimating errors or indicators of possible errors, including FFI projects (Vinnova, 2014) and EU projects (Smart Vortex, 2014). The common statement in these projects is to extract information for maintenance planning based on data available both on and off the vehicle. The results from these projects are a prerequisite for producing good estimates on when the vehicles must come into the workshops for service. Other projects focus on developing a diagnosis of new driveline components on vehicles, such as electric motors (Energimyndigheten, 2016). For the maintenance planning to be effective, the business models must be adapted to the varying needs that exist (Palo & Tähtinen, 2013), (Kindström, 2010).

New types of vehicles, transport solutions and workshop solutions bring new types of concepts around vehicle maintenance and business solutions. We want to know as much as possible from the vehicles, as early as possible, to be able to do the vehicle maintenance as efficient as possible. Before the vehicle arrives to the workshop, we must know what needs to be done on the vehicle. We want to develop solutions that make vehicle maintenance more efficient, to create efficient and sustainable transport solutions.

With a deep and broad research experience not only from Chalmers but also from Volvo allows us to create a research environment where we benefit from each other's experiences and international contact networks to develop competitive aftermarket concepts for the global market. With Chalmers in the project, we can build on competence and experiences from different industries. The project includes Post Nord, which means we can secure that our research and development in the project is relevant and meets the haulage needs around how services and solutions should be designed from a user perspective. It also gives us the opportunity to get to the market faster with our services and products/solutions for vehicles with the greatest potential.

4 Purpose, research questions and method

This section presents the purpose, research questions and methodology of the EMATS project. The purpose is divided into three main categories to keep a clear structure in the report. Vehicle maintenance in sustainable transport solutions, Integrated information flow and Connected and integrated workshop equipment. The project and research design of EMATS will be presented in the method section.

4.1 Purpose and research questions

The purpose of EMATS is to investigate and develop new concepts for efficient maintenance of sustainable transport solutions.

The focus of the project is three research areas that together enable an effective vehicle maintenance process. The three interdependent research areas are:
(1) Vehicle maintenance in sustainable transport solutions.
(2) Integrated information flow.
(3) Connected and integrated workshop systems.

Vehicle maintenance in sustainable transport solutions
New and sustainable transport solutions also require maintenance solutions that match the demands posed by actors in the new types of transport systems that could be foreseen. Therefore, to better understand these demands, the EMATS project also involve studies regarding future transport solutions and the implications of new technology, new industry structures, and new business models. The work related to the overarching question related to future sustainable transport solutions was divided in two steps. The purpose of work package 2 of the EMATs project was thus two-fold and divided in two steps. The first step involved an analysis of the key change-drivers related to transport solutions with the objective of identifying a set of alternative future scenarios. The second step, at the other hand, aimed at analyzing the need for, and design of, maintenance solutions meeting the needs of each specific scenario.

Integrated information flow
The purpose of the integrated information flow part was to integrate various systems in the workshop with each other and with the vehicle. Further it was to link the workshop systems with the haulage companies transport efficiency system to create a comprehensive solution.

Connected and integrated workshop equipment
For a technician to do service, diagnose and monitor the status of the vehicle, the technician needs to be supported with workshop equipment solutions and information flow. The purpose with the connected and integrated workshop equipment part was to improve vehicle diagnosis, support the technician in the workshop and improve working environment for the technician.

4.2 Method

In the project a larger study has been conducted focusing on the future transport solution and maintenance solution. This together with today's system solutions and challenges we have worked with a holistic perspective on how the future maintenance solution will be like, both from a technical and business perspective. A concept workshop has been built and specific solutions from the workshop have been tested in regular workshops. We have also developed solution on short time horizon that supports the operator and the driver with vehicle follow up.

Vehicle maintenance in sustainable transport solutions

The work managed by the academical partner of the project, I.e. Chalmers University of Technology, could be divided in two connected parts, each applying a different methodological approach.

Future Transport Solutions

To collect information concerning the change drivers and their impact on transport solutions a Delphi study was designed and performed (Day and Bobeva, 2005). The study, "Future Transport in Sweden 2030 and 2050" was performed as an online enquiry involving representatives from the academy, the industry, and, the government. The year 2030 and 2050 were chosen because they are important for political environmental and emission goals for Swedish transport. The study was based on a set of 16 projections for which the respondents were asked about their feedback, including the probability, impact on industry and desirability of the change happening until 2030 and 2050, respectively. The development of projections for the Delphi survey began with identifying variables that influence the future of transport in Sweden. Variables were searched for in academic publications, such as literature reviews on transport and sustainability, government reports, papers from conferences and consultant and industry reports. News articles on the topic were also read. We searched in databases such as Web of Science and Scopus. We also searched in web sites of consultancies, governments and industrial firms within the transport sector. An overview of the projections is included below in Table 4.1. We identified over 100 experts in transport to participate in the Delphi study. In total, 57 experts agreed to participate in the Delphi study. The Delphi study built on experts from industry, university and government answered a questionnaire. A total of 40 respondents participated in the first Delphi round. Then, the answers were put together, and all experts were invited to re-answer their views on the projections based on the expert group as a whole, their answers. Of the experts, 27 completed the second.

Table 4.1: Projections of the Delphi Study

Consumer behaviour	
P1	A majority of consumers demand locally produced food.
P2	Consumers demand transport information regarding environmental sustainability for the products they buy.
P3	A majority of households use home delivery for all food and consumer products.
Transport industry	
P4	Business models for transport solutions have been subject to dramatic change.
P5	New transport actors (such as '"Uber goods") have taken on a significant share of all goods transports.
Automation and digitalization	
P6	All vehicles on the road are connected and communicate with each other and with infrastructure.
P7	All trucks are driverless.
Urban transport	
P8	The amount of passenger cars in urban areas has been radically reduced.
P9	No heavy trucks (3,5 tons) are allowed in urban areas.
P10	New transport solutions have replaced trucks in urban areas.
Energy solutions	
P11	Environmental legislation has resulted in zero CO_2 emissions from road transport.
P12	Fossil fuels have been replaced by other solutions in the road transport sector.
P13	Roads connecting Stockholm, Malmö, and Gothenburg have been electrified.
Policy and public investments	
P14	Fuelling and charging infrastructures has been determined by governmental regulations.
P15	There has been a major shift towards rail instead of long-haul road transport (of goods).
P16	The attention given to transport policy has been reduced due to other political priorities.

Maintenance Solutions in Business Networks

For the second part, related to the PhD project, the research has been designed as a qualitative case study (Yin, 2014) and through interviews with managers representing actors in the business network, rich data concerning the operations and business of firms, as well as the ideas and perceptions of managers, has been collected (Dubois and Araujo, 2007). Details on the method applied are available in, for example, Hedvall (2016) and Hedvall et al. (2016).

5 Objective

The overall objective of the project is to develop aftermarket concepts for sustainable transport solutions with a holistic approach. To get there, we have developed a concept workshop to test different system solutions, focused on the integrated information flow between vehicles and workshop equipment. The workshop can be seen as an innovation lab for all involved parties where we develop and validate our solutions. We will also develop a platform that facilitate the interaction between the haulage company and the driver. Those solutions will depend on new approaches to the business solution. The objectives are divided in three subcategories which follow the structure in section 4.1.

Vehicle maintenance in sustainable transport solutions
The key objective of the research performed in the work package managed by the Chalmers University of Technology, was to improve our understanding of how future maintenance solutions should be designed and deployed. Based on data regarding future transport industry networks and the actors therein, the research aims at developing knowledge and guidelines for firms involved the design, development, and deployment of maintenance solutions.

Integrated information flow
The objective of this part was to integrate various systems in the workshop, with each other and with the vehicle. By linking the workshop systems with the haulage companies transport efficiency system, a comprehensive solution could be designed. Vehicle health monitoring and service planning should benefit from this integrated information flow.

Connected and integrated workshop equipment
To support the technician in the workshop to do service, diagnose and monitor the status of the vehicle, the technician will be assisted by a system solution including robotics, workshop automation and associated sensors and tools. Digitalization will be an important part in order to connect the workshop equipment, the vehicle, and cognitive support for the technician and increase efficiency in the workshop. The work environment for the technician will be improved by the system solution in the workshop.

6 Result and deliverables

6.1 Vehicle maintenance in sustainable transport solutions

Introduction

The results related to the work performed by, or closely connected to, the department of Technology Management and Economics at Chalmers University of Technology can be divided in two key areas. 1), related to the overarching question concerning *Future Sustainable Transport Solutions* and their need of, and implications for, future maintenance solutions, and 2), the implications of seeing *Heavy Vehicle Maintenance Embedded in a Transport Industry Setting*. Below, these two areas will be further discussed together with examples of some of the key results and deliverables.

Future Sustainable Transport Solutions

The scope, process and results of the study is reported in detail in Melander et al. (2019) and Melander (2018), see the list of publications in Section 7.2 of this report. In this report, though, we would like to share a general view of the somewhat unexpected outcome. In opposite to what is normally expected in a Delphi study, there was no convergence of the views of the respondents after the loop2 in which the aggregated results of the first loop was shared among participants. Figure 6.1 below includes one way of visualizing the challenges faced as a result of the divergent results.

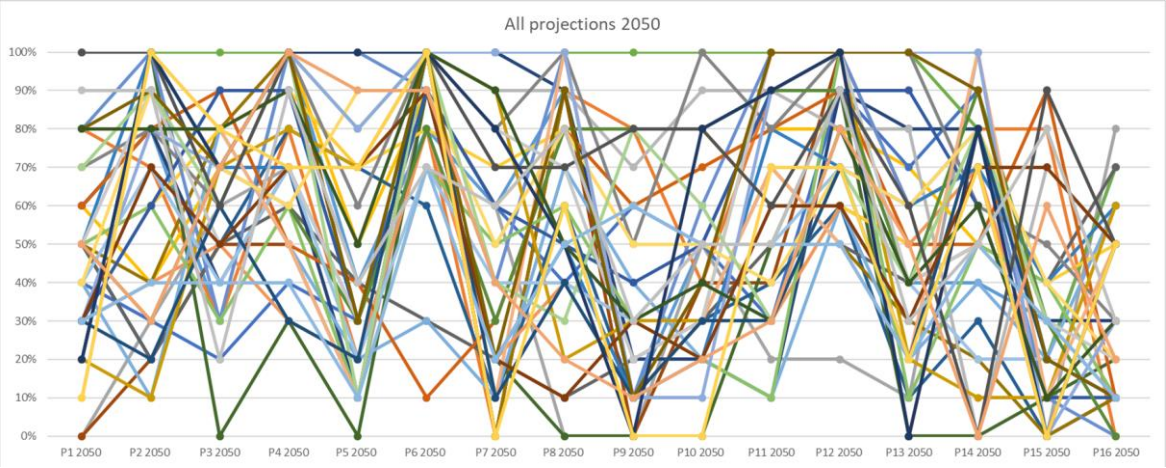

Figure 6.1: A visualization of the aggregated result of the projections for year 2050 (The different colours on the curves corresponds to the respondents.)

As could easily be understood, the outcome has a significant impact on the possibilities to design scenarios. Without a convergence and without clear indications on the timeline for, and order of, the changes foreseen it has been virtually impossible to create a set of clearly different scenarios. Instead, the project applied another approach in which we organized two “interpretation workshops” at which the participants (also here triple-helix) reviewed and analyzed selected results.

All-in-all, even though the outcome deviated from what was expected, the results of the Delphi study has proven very valuable for the project as well as participants in the study and the “interpretation scenarios”. Reflecting the outcome, it has been clear that the industry and society has to prepare for many different possible scenarios simultaneously. Moreover, it has been clear

that the industry, society and academy have to cooperate closely in order to mitigate problems and align the efforts for enabling the future sustainable solutions.

Heavy Vehicle Maintenance Embedded in a Transport Industry Setting

While the work related to the overarching question concerning Future Sustainable Transport Solutions aimed at improving the understanding on a macro, or societal, level, the research performed in relation to the second focus-area aimed at the meso- and micro-levels. In the context of this project, the meso-level relates to the business network involving firms involved in, or concerned by, road transport. The micro-level, at the other hand, relates to the activities and resources managed by the same firms.

The lion's share of this research has been performed as part of a doctoral student project. The research and its key outcome has been described in detail in the licentiate thesis Hedvall (2016), but also in several other journal and conference publications, see the list of publications. Below, in this section, selected parts of the project and its outcome are discussed.

Aiming at improving the understanding of maintenance offerings in the settings of current and future transport solutions, the research acknowledges the embeddedness and connectedness of firms, activities and resources. Hence, the research has been performed with a business network perspective, applying the ideas of the Industrial Network Approach (Håkansson et al., 2009). The research has been designed as a qualitative case study (Yin, 2014) and through interviews with managers representing actors in the business network, rich data concerning the operations and business of firms, as well as the ideas and perceptions of managers, has been collected (Dubois and Araujo, 2007). Below, in Figure 6.2, a simplified business network involving the key actor categories studied within the doctoral project is depicted.

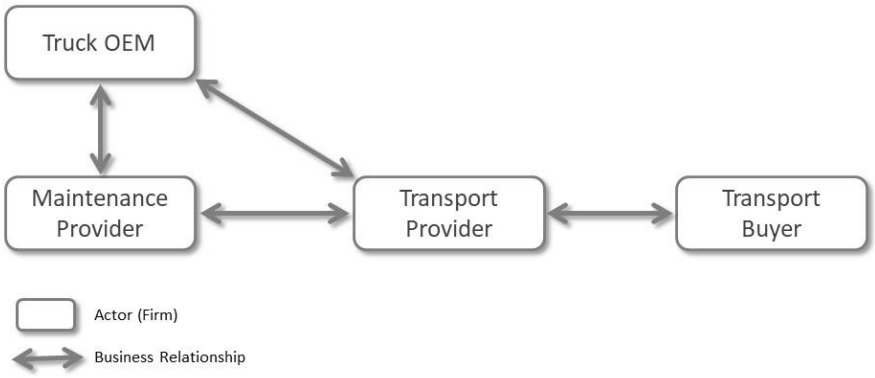

Figure 6.2: A simplified business network involving the key actor categories studied.

The research has encompassed a comprehensive study of the activities and resources of firms involved in, influencing, or being influenced by, the vehicle maintenance offerings. The simplified network of Figure 6.2., however, does not reflect the complexity of business networks studied by researchers. An example of a business network studied within the EMATS project is included as Figure 6.3 (For further details, see Hedvall, 2016).

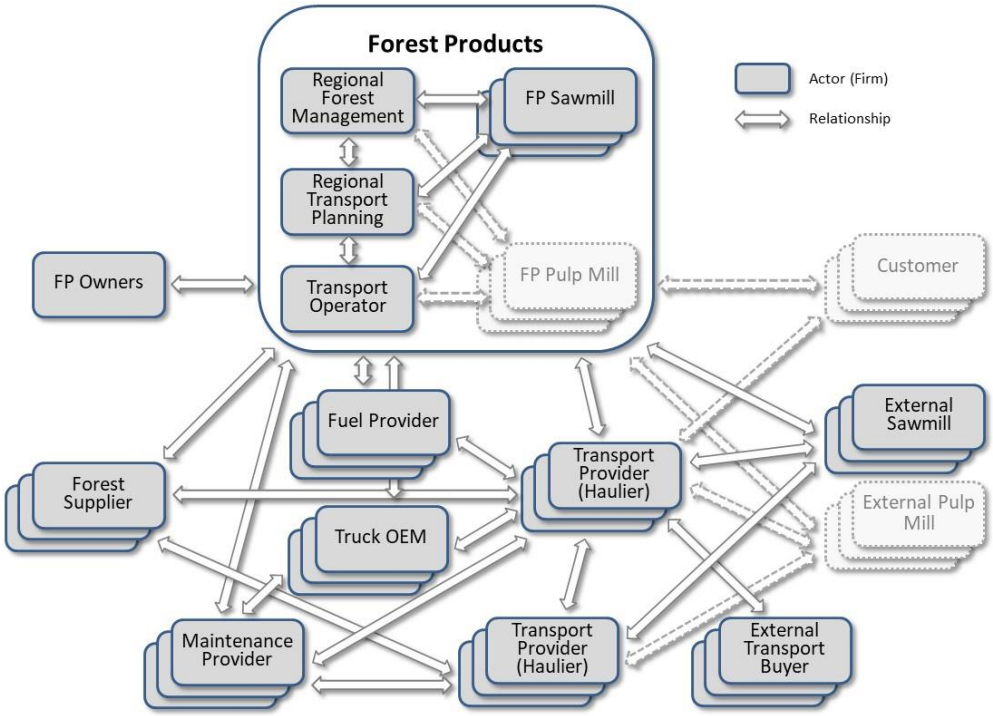

Figure 6.3: Example of a business network studied (Hedvall, 2016, p. 88).

Analyzing the connections and interdependencies among activities and resources of the firms in the business network (Hedvall, 2016), the maintenance offering has been situated in a context in which the efficiency of transport is a key concern of actors. However, even if the maintenance activities mostly are not seen as a focal activity part of the transport solutions, it becomes clear that the effectiveness and efficiency of the maintenance performed have a considerable influence on the transports being performed (Hedvall et al, 2016; Hedvall, 2016). The visualization in Figure 6.4, as an example of the analysis having been performed, point to how activity links result in that activity structures of firms are connected and the coordination of activities becomes critical for the firms concerned.

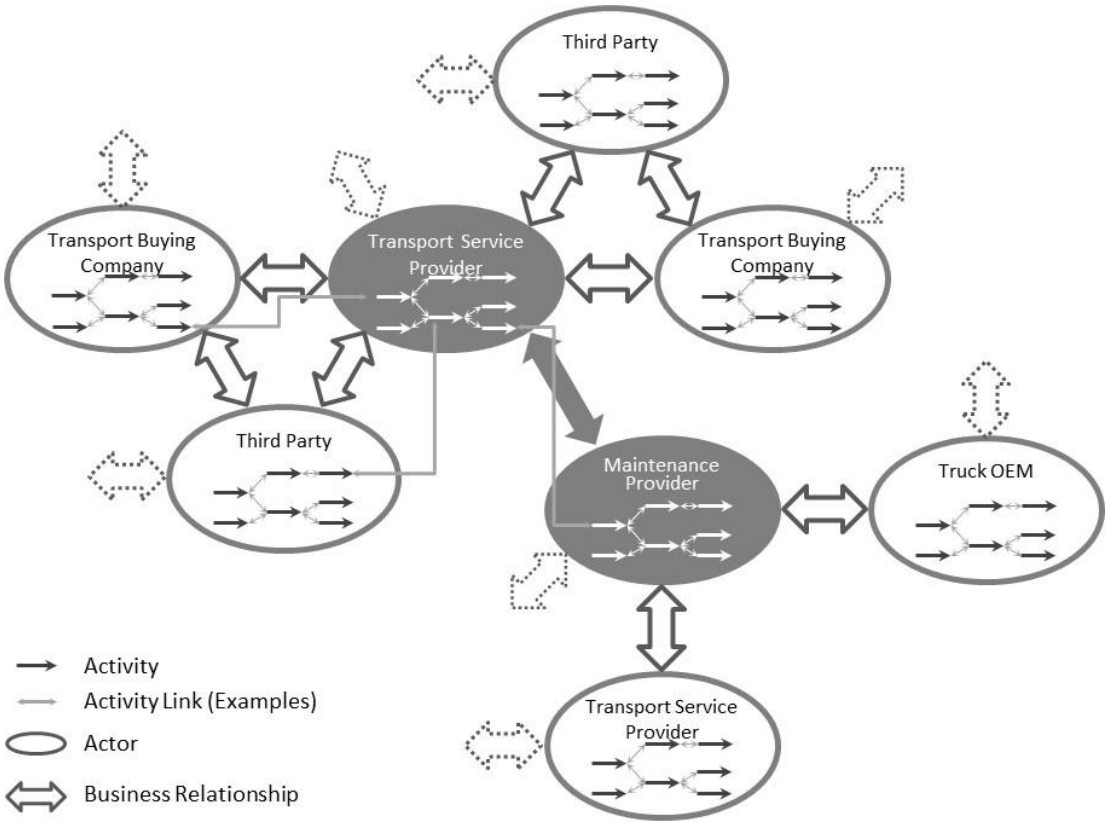

Figure 6.4: Example: activity links interconnecting the activity structures of companies (Hedvall, 2016, p. 102).

Compared to the product-centric perspective that firms often apply for vehicle maintenance solutions, the research performed as part of the EMATS project highlights the importance of viewing vehicle maintenance as a part of the transport solutions. The maintenance activities should be seen as embedded in a wider context of actors, activities, and, resources. Activities are connected to each other and subject to interdependencies; hence, to improve the efficiency of firms and operations, the actors must engage in coordination of the activities embedded in the activity pattern. Moreover, the resources involved in the maintenance being performed, e.g., vehicles, tools and technicians, often display interdependencies.

To conclude this section, some of the key implications from this research are listed below. For further, and detailed information, please also see the publications listed in the document:

- For improved efficiency and effectiveness of transport solutions, the vehicle maintenance solutions must be seen as an integrated part of the context.
- No single actor of the transport system has alone a clear view of the changes to come. The multitude of challenges that currently face industries and organizations should be addressed together in close collaboration.
- For better uptime and availability of the vehicles used for transport, the maintenance must be planned in relation to the transport related activities performed. To achieve this, planning should be seen as a joint responsibility of workshops, hauliers and transport buyers.
- Vehicle maintenance should also be seen as solutions that will take different forms over time. The needs of hauliers, as well as the capabilities and resources of workshops, are subject to the dynamic features of transport industry networks.

6.2 Integrated information flow and Connected and integrated workshop equipment

A concept workshop has been built for test and development of the integrated information flow for the workshop. Among other things has semiautonomous solutions been developed that improved the work environment in the workshop. Through improved administration and autonomous collection for data contributes to improved component health status estimation. With new type of vehicles, such as autonomous, new maintenance solution requirements will increase. The solutions developed through this project creates the preconditions for an efficient maintenance solutions and business.

Workshop setup

The concept workshop (Figure 6.5) was built to have a laboratory environment in order to test different system solutions in the workshop (connected to the objectives integrated information flow, and Connected and integrated workshop equipment in section 5). The workshop was a place for collaboration between the different actors in the project (Volvo AB, Post Nord, ARHO and Chalmers). Through integrating equipment and systems, which made it possible to roll the wheels, shake the vehicle and look under it, a semiautonomous solution was in place. The developed solution was designed to improve the work environment (both cognitive and physical) for the technician and ensure quality in the workshop.

Figure 6.5: The concept workshop.

A business solution was developed to support the integrated information flow. A daily maintenance solution was developed and tested with Post Nord in order to help the driver, haulage company and the technician in the workshop. The solution made it possible to get fast access to desired information at the right time. The solution increases objectivity and makes the information traceable.

During an oil filter change, which is manually done today, a technician needs to punch a hole into the filter and wait until all the oil is drained out. Only then, the technician can remove the old oil filter and replace it with a new one. It is observed that the oil spills and splashes around when a hole is punched into the filter leading to an uncomfortable working condition for the technician. This method is both time consuming and a very poor working condition for any technician to work in. To eliminate this tedious process, a method for automatic change of oil was demonstrated in the project.

7 Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	1) By seeing how the maintenance solution is part of the transport solution we have been able to better get information from the workshop visit that helps with the maintenance solution. 2) Digitization means that business models can change and how we interact between different actors in the transport solution. The project has clearly produced evidence and argued for changes business arrangement.
Be passed on to other advanced technological development projects	X	The reasoning surrounding EMATS has been transferred to projects where we are developing the maintenance solution and the workshop solution. The methodology of the EMATS project has transferred to other projects.
Be passed on to product development projects	X	The result in the EMATS project has shown how we need to work more with “Design 4 Maintenance” and this has affected our products, both hard products and services
Introduced on the market	X	Parts of what we have come up with within the EMATS project have contributed to one new service from Volvo trucks introduced in August 2018.
Used in investigations / regulatory / licensing / political decisions		

7.2 Dissemination through Publications, Workshop and Conferences

The project has resulted in a wide range of publications and presentation with various focuses. Additionally, the research performed within the project has resulted in one licentiate thesis published in 2016, and one doctoral thesis currently being finalized. Below, the key publications for are listed.

Dissertations:

Hedvall, K. (2016) *Heavy Vehicle Maintenance in an Industrial Network Perspective: Implications of Embeddedness and Interdependencies*, Licentiate thesis, Gothenburg: Chalmers University of Technology.

Journal Publications:

Lind, F. & Melander, L. (2019) Organizing supplier interfaces in technological development, *Journal of Business & Industrial Marketing*, 34(5), 1131-1142. 10.1108/JBIM-11-2018-0357

Hedvall, K., Jagstedt, S., & Dubois, A. (2019). Solutions in business networks: Implications of an interorganizational perspective, *Journal of Business Research*,*104*, 411-421. 10.1016/j.jbusres.2019.02.035

Melander, L., Dubois, A., Hedvall, K. and Lind, F. (2018) Future transport in Sweden 2050: using a Delphi approach, *Technological Forecasting and Social Change*, available online. 10.1016/j.techfore.2018.08.019

Jagstedt, S., Hedvall, K., & Persson, M. (2018). The Virtue of Customising Solutions: A Managerial Framework. In M. Kohtamäki, T. S. Baines, R. Rabetino, & A. Z. Bigdeli (Eds.), *Practices and tools for servitization* (pp. 291-308): Palgrave Macmillan. 10.1007/978-3-319-76517-4_16.

Melander, L. (2018) Scenario Development in Transport Studies: Methodological Considerations and Reflections on Delphi studies, *Futures*, 96, pp. 68-78. 10.1016/j.futures.2017.11.007

Hedvall, K., Dubois, A and Lind, F. (2017) Variety in freight transport service procurement approaches**,** *Transportation Research Procedia*, 25, pp. 806–823. 10.1016/j.trpro.2017.05.459.

Hedvall, K., Dubois, A and Lind, F. (2016) Analysing an activity in context: A case study of the conditions for vehicle maintenance, *Industrial Marketing Management*, 58, 69-82. 10.1016/j.indmarman.2016.05.016.

Publications for Conferences and Workshop:

Hedvall, K. (2018 Outsourcing of heavy vehicle maintenance: the implications of embeddedness, Conference paper presented at *IMP Asia Conference 2018*, Sri Lanka, 2-5 December.

Lind, F., Melander, L. and Svensson, M. (2017) Managing service contracts and customer relationships: the case of gold contracts, Work-in-progress paper, Technology Management and Economics Publication Workshop, November 24.

Lind, F. & Melander, L. (2017) Organizing supplier interfaces in technological development, *IPSERA Workshop* on Supplier Innovation, Århus, Danmark, 23-25 October.

Hedvall, K. (2017) Heavy Vehicle Maintenance in Road Transport Solutions: An Interorganizational Perspective on Efficiency Improvement, *Proceedings of the EurOMA Conference*, Edinburgh, July, 3-5.

Lind, F., Melander, L. and Svensson, M. (2017) Development of service contracts consequences for networked business models, Work-in-progress paper, *Nofoma Conference*, Lund, June 8-9.

Lind, F. and Melander, L. (2017) Developing supplier interfaces in technological development, 2nd Nordic Workshop on Supplier Relationships, Gothenburg, 31 May – 2 June.

Lind, F. and Melander, L. (2017) Developing supplier interfaces in technological development, 23rd Nordic Workshop on Interorganisational Research in Stavanger, 26-28 April.

Hedvall, K. (2016) Vehicle Maintenance - A Vital Cornerstone Of Future Sustainable Road Transport Solutions, poster presented at *Transport Research Arena (TRA)*, April 18-21 2016, Warsaw, Poland.

Hedvall, K., Dubois, A. and Lind, F. (2016) Variety in freight transport service procurement approaches**.** *World Conference on Transport Research (WCTR) 10-15 July 2016, Shanghai*.

Hedvall, K., Dubois, A. and Lind, F. (2015) Variety in transport service settings and the conditions for vehicle maintenance, *Proceedings of the 31st IMP Conference*, Kolding, Denmark, August 27-29.

Workshops and Seminars:

Results from EMATS project has also been presented and discussed at several workshops:

- 2 ”triple-helix” workshops have been held as part of the analysis of the results from the Delphi study performed. Participants from the academy, the transport industry, and the city of Gothenburg have participated.
- Results from the EMATS project has also been presented and discussed in conjunction to workshops organised by the research community ”Transportinköpspanelen”.
- Results from the EMATS project has also formed part of presentations at the ”Northern Lead Day” 180411 and the ”Initiative Seminar” 191026 organised by the Chalmers Area of Advance.

7.3 Dissemination through Teaching

The project, and examples based on the results from work package 2 in particular, has also formed part of the education performed at the department of Technology Management and Economics at Chalmers University of Technology. The following courses have included discussions and examples from the EMATS project.

TEK 261 Business Marketing and Purchasing

TEK 274 Projects in Supply Chain Management

TEK 275 Supply Chain Management

TEK 360 International Business Relationships

Moreover, connected to the project, 2 Master Thesis and 2 Project Reports have been completed by students at the university.

Mensah, B. and Liu, W. (2016) *The road to an automated truck maintenance workshop: opportunities and challenges*, Master of Science Thesis in the Supply Chain Management Programme*,* Chalmers University of Technology, Report No. E 2016:037

Dönmez, S. and Zemmouri, M. (2016) *Analyzing the Value of Vehicle Maintenance Activities*, Master of Science Thesis in the Supply Chain Management Program, Chalmers University of Technology, Report No. E 2016:036.

Dönmez, S., Kanatos, E., Mensah, B. and Zemmouri, M. (2015) *Identification of Future Transportation Scenarios and Implications for Truck Maintenance*, Project report, Project in TEK275 Projects in Supply Chain Management, Chalmers University of Technology.

Karl Abdallah, Aldin Avdic, Max Engvall, Victor Eriksson and Tristan Krohn (2016) *Maintenance Contracts and Business Models of Truck OEMs, Workshops and Hauliers: Interdependencies, Synergies and Implication,* Project Report, Projects in Supply Chain Management TEK275, Chalmers University of Technology.

8 Conclusion and future research

The purpose of EMATS (Efficient Maintenance for Sustainable Transport Solutions) was to investigate and develop new concepts for efficient maintenance of sustainable transport solutions. How we can ensure vehicle maintenance in the transport chain, linked to everything from the haulage's planning to the technician's work environment.

Vehicle maintenance and the workshop are both a part of the transport solution. This means that the maintenance solution is a subset of the transport solution. New technologies create conditions for new business solutions and vice versa. With new types of vehicles, the need for advanced maintenance and maintenance planning of the vehicles has increased.

In the EMATS project, we have developed workshop solutions with tools and integrated information flow (including digitalization) that streamline the activities in the workshop and improve the working environment. The result has been demonstrated in a physical workshop lab that was built for the project. The workshop can be seen as an innovation lab for all involved parties where we developed and validated our solutions. Among other things has semiautonomous solutions been developed that improve the work environment in the workshop. Tools that facilitate for the haulage and the driver, with daily inspection and reporting deviations have been developed. With new type of vehicles, such as electrical and autonomous, new maintenance solution requirements will increase. The solutions developed through this project creates the preconditions for an efficient maintenance solutions and business. Further, the project has delivered tools that facilitate the work for the haulage and the driver with daily inspection and reporting deviations. EMATS is the first step towards autonomous workshops.

In addition to the workshop solutions investigated and demonstrated, the project has also involved research with the aim to further our understanding regarding future transport solutions in general and the need of, and preconditions for, vehicle maintenance in particular. The research has highlighted the complexity and amount of challenges and changes that the transport industry currently faces. The results clearly points to that no single actor of the transport system has alone a clear view of the changes to come, and, even more important; the multitude of challenges that currently face industries and organizations have be addressed together in close collaboration. The same challenges also have implications for future maintenance offerings which, indeed, have to be seen as an integrated part of the transport solutions as a whole. For better uptime and availability of the vehicles used for transport, the maintenance must be planned in relation to the transport-related activities performed. To achieve this, planning should be seen as a joint responsibility of workshops, hauliers and transport buyers. To further improve the industry´s possibilities to develop efficient and effective maintenance solutions well integrated in the transport solutions, further research is suggested. In particular, issues related to the adaptive and dynamic maintenance planning required deserve continued scrutiny. Moreover, challenges involving the structure, roles and business models of the transport industry should be further studied. As part of this scope, the implications of – and opportunities enabled by – digitalization and servitization should be further studied. Above all, though, the continued research should reflect the interorganizational and interactive context that vehicle maintenance is embedded within.

Finally, EMATS has been a collaboration project between the academy (Chalmers), Volvo AB, ARHO, Post Nord and Vinnova. The project demonstrates the strength of collaboration and how research can be applied and acknowledge by the business.

9 Participating parties and contact persons

Mikael Andersson, Volvo Technology AB

Frida Lind, Chalmers University of Technology

Christer Dahlbäck, Post Nord

Andreas Rask, ARHO

10 Bibliography

Day, J. and Bobeva, M. (2005). A generic toolkit for the successful management of Delphi studies. *Electronic Journal of Business Research Methods*, 3, 103–116.
Dubois, A., and Araujo, L. (2007). Case research in purchasing and supply management: Opportunities and challenges. *Journal of Purchasing and Supply Management, 13*(3), 170-181.
Håkansson, H., Ford, D., Gadde, L.-E., Snehota, I., Waluszewski, A. (2009). *Business in Networks*. (1st ed.). Chichester: John Wiley & Sons.
Yin, R. K. (2014) *Case study research: Design and methods*. (5th ed.). London: Sage publications.

Energimyndigheten. (2016). *Dynamisk modellering ab kylning för elektriska drivsystem.* Projektnr: 37422-1. Retrieved https://www.energimyndigheten.se/forskning-och-innovation/projektdatabas/sokresultat/?projectid=18528 [2020-02-10]

European Uninon, 2006. *Communication from the Commission to the Council and the European Parliament - Keep Europe moving - Sustainable mobility for our continent - Mid-term review of the European Commission's 2001 Transport White paper.* SEC (2006) 768

Kindström, D., (2010) *Towards a service-based business model –Key aspects for future competitive advantage, European Management Journal,* Vol. 28, No. 6, pp. 479-490

Näringsdepartementet. (2012). *Fossiloberoende fordonsflotta –ett steg på vägenmot nettonollutsläpp av växthusgaser.* Dir 2012:78.

Palo, T. and Tähtinen, J. (2013) *Networked business model development for emerging technology-based services, Industrial Marketing Management*, Vol. 42, No., 5, pp. 773-782.

Smart Vortex. (2014). *Scaleable Semantic Product Data Stream Management for Collaboration and Decision Making in Enineering. Project Reference 257899*. FP7-ICT.
Retrieved https://cordis.europa.eu/project/id/257899 [2020-02-01]

Vinnova. (2014). *Remote Diagnotic Tools and Services*. Dir 2009-00256.

Vinnova. (2015). *InnoMERGE,* Dir 2011-03684. https://www.vinnova.se/p/innomerge/

Vinnova. (2015). *ToMM,* Dir 2012-03685. https://www.vinnova.se/p/tomm/

Vinnova. (2016). *In4Uptime,* Dir 2013-05545. https://www.vinnova.se/p/in4uptime/