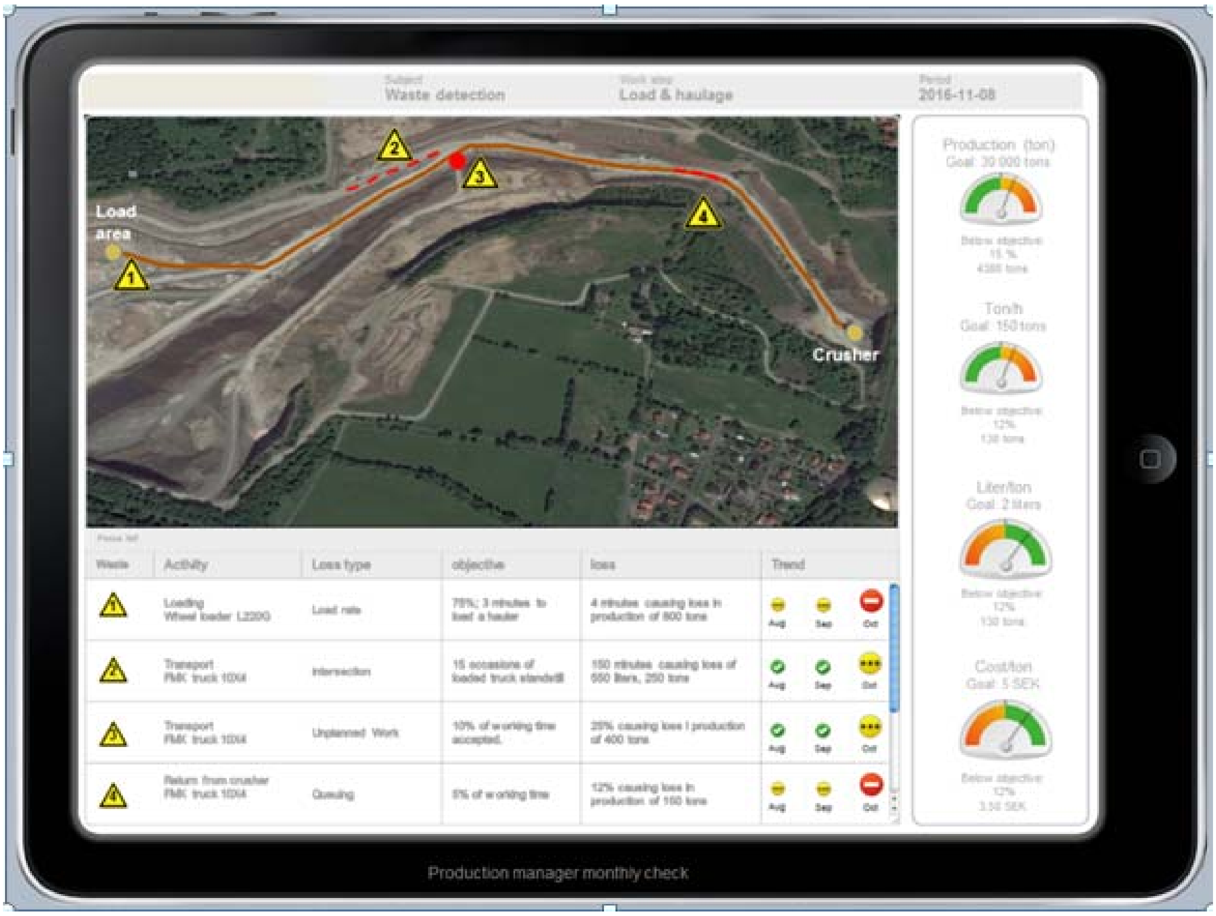
Optimal Earthmoving in Dynamic Environments

Public Report



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Projekt inom Transporteffektivitet

FFI Fordonsstrategisk Forskning och Innovation

Innehållsförteckning

1 Summary

This project was initiated as part of the results of the Vinnova financed project 'Total Cost of Ownership Simulation Tool' (project number 2009-04127). Furthermore it has been run in parallel with the research project described in (Rylander, 2014). In short the latter research aims at using lean principles for real time control of working machines in earthmoving applications – in order to address the declining efficiency of the construction industry.

The work carried out is split in two main parts:

1. Academic research with development of methods for working machine drive cycle points of interest and simulation, carried out at KTH, The Royal Institute of Technology. The data from this work was intended to be fed into a simulation system for long term perspective optimization and sensitivity analysis. These results could also potentially feed into a site control management system developed by Volvo as illustrated in the figure below.
2. Applied research / development of a framework for implementing a commercial product from an equipment OEM perspective. This works include field trials with a prototype site control management system including test of radio communication but also business model investigations and other initiatives such as development of virtual test environments and drone applications. This work has been carried out by Volvo Construction Equipment.

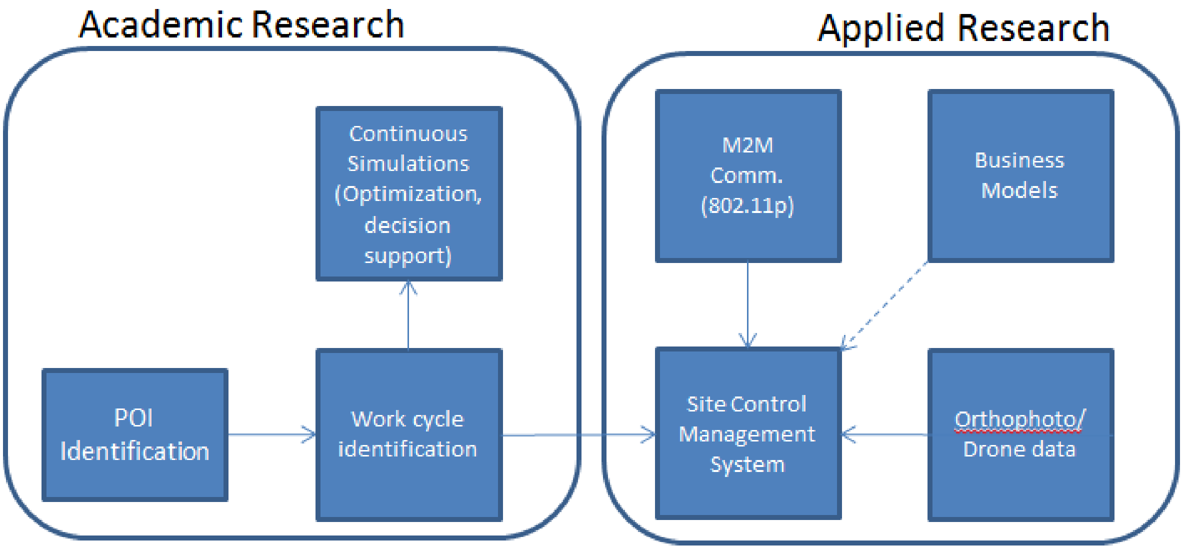

Figure 1 Project Anatomy

As Figure 1 illustrates, the site control management system is the central node within the project, with activities and methods delivering into it. The main target of the system is to improve transport efficiencies of earthmoving operations, mainly by reducing fuel consumption.

The results are mixed. Research proves that it is possible to extract quite detailed work cycle POI's from using only GPS sensors. Developed methods are robust and could become quite useful in large, dynamic earthmoving operations. However they are not deployed in any commercial products or services at present date. Neither has the work with continuous simulations for optimization, decision support and life cycle analysis been carried out. This fact is due to unexpected possibilities as well as interested from the universities with the GPS-based POI research, which also resulted in a number of publications.

As for the applied research, field tests in a European mining operation show great potential for the tested site control management system. These field trials have since then been repeated with similar results with a more matured product. However, the need of a robust communication system for M2M is critical. Additional field test shows that, perhaps not surprisingly, that a flexible network setup is desirable for high radio link quality.

In terms of method development, a study shows that a relatively cheap drone, together with a competent cloud service for data analysis is good enough for establishing 3d maps of work sites. Further work has proven it useful to implement these maps into virtual test environments connected to simulators. In such environments, for instance the research results can be verified and further developed.

A business potential / service offering study has also been carried out. Based on experience it is known that moving away from traditional machine sales into more service driven business is complicated. The study performed here shows the potential in value based pricing.

2 Sammanfattning på svenska

Anläggningsindustrin brottas sedan länge med låg effektivitet. Detta tros främst bero på bristande koordinering av aktiviteter och resurser i dessa processer, men även den ökande komplexiteten hos byggnadsprojekt. En studie visar att övriga industrier ökade sin produktivitet med 100% mellan 1980 – 2013. Motsvarande siffra för anläggningsbranschen är 10% (Trafikanalys, 2015).

Volvo Construction Equipment har startat ett antal initiativ för att adressera problemet som presenteras ovan. Ett är 'Total Cost of Ownership Simulation Tool' (Vinnova diarienummer 2009-04127). Inom ramen för detta projekt utvecklas ett optimeringsverktyg tillsammans med metoder för att förbättra TCO (kostnad per transporterat ton) i gruvor och bergtäkter, ett arbete som utgör grund för projektet som redovisas i denna rapport.

Parallellt med 'Optimal Earthmoving in Dynamic Environments' har ett annat forskningsprojekt, beskrivet i (Rylander, 2014) utförts. Kortfattat syftar det till att tillämpa lean-principer på arbetsplatser med anläggningsmaskiner, till exempel gruvor och bergtäkter. Kommunikation för styrning skulle här ske med WiFi-standarden 802.11p (Wikipedia, 2018). Ett resultat av detta projekt är en prototypmjukvara som kan användas till att i realtid ge en dynamisk hastighetsrekommendation till förare av dumprar för att minimera kö- och stilleståndstid.

Arbetet i detta projekt, Optimal Earthmoving in Dynamic Environments, är uppdelat i 2 huvudområden:

1. Akademisk forskning utförd på KTH. Detta arbete har i huvudsak behandlat identifiering av POI (points of interest) i arbetscykler för anläggningsmaskiner. I förlängningen skulle detta data kunna föda en simuleringssystem för att göra långsiktiga optimeringar och känslighetsanalyser.
2. Tillämpad forskning, fältförsök och annat arbete på Volvo Construction Equipment. Här har syftet varit att skapa ett ramverk för att implementera resultat från forskning i ett prototypsystem. Arbetet har varit fokuserat på fälttester och mätningar. Inom ramen för detta arbete har även en undersökning om affärsmodeller och –potential samt arbete med drönarteknik för kartläggning av bergtäkter kopplat till en virtuell testmiljö med simulatorer.

Resultaten har varit något blandade. **Forskningen utförd på KTH** visar att det är möjligt att utifrån enbart GPS-data går att robust generera såväl POI som transportvägsegenskaper (J Fu, 2016) (J Fu, 2017). I ett vidare perspektiv skulle dessa data kunna användas för att optimering på såväl fordons- samt arbetsplatsnivå. Ur en OEMs perspektiv är detta intressant, då det skulle vara möjligt att analysera processer med fordon utan tillgång till CAN-system (controller area network). Resultaten har dock inte implementerats i något kommersiellt system i dagsläget. Planen är dock att delar av resultaten kommer att ingå projektet Autonom Elektrisk Bergtäkt, ett av Energimyndigheten finansierat projekt som syftar till elektrifiering av transporter i bergtäkter (Uhlin, 2015).

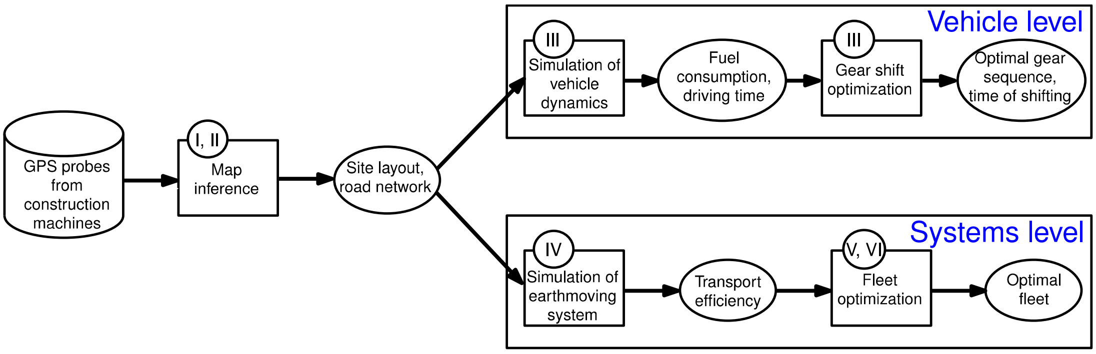

Figure 2. Konceptuellt förhållande mellan datahantering för optimering av fordon resp. arbetsplats.

Arbetet på Volvo CE har avlöpt relativt väl- Fältförsöken har utförts i en engelsk gruva där ett system för att ge väsentligt förbättrad hastighetsrekommendation till förare av dumprar installerats på fem midjestyrda dumprar. Dessa dumprar har körts i produktionen i gruvan under fyra veckor. En del av denna tid har åtgått till att installera, trimma och felsöka systemet som är i prototypstadiet. Resultatet av dessa fältstudier visar att systemets huvudprincip är korrekt. Kommunikationen mellan maskiner (M2M) och mellan maskiner och kontor/server (M2X) hade överlag acceptabel prestanda, men det är tydligt att det behövs en mer flexibel kommunikationslösning än enbart fordon utrustade med hårdvara för 820.11p. Under testerna blev ett tidigare påtalat behov av möjlighet till multipla last- och tipplatser tydligt, då logistiken på arbetsplatsen var mer komplicerad än förväntat. Även uppdateringar i HMI identifierades såsom möjlighet till att ändra skalor på kartor, men överlag fungerade funktioner som kartgenerering, ruttidentifiering samt skattning av cykeltider tillfredställande.

Vidare har en mindre studie I användning av drönare utförts inom projektet, där det visar sig möjligt att använda en relativt enkel drönare för att utföra mer eller mindre avancerade analyser av arbetsplatser. Det huvudsakliga användningsområdet för drönare i bergtäkter har varit att göra volymsanalyser på materialupplag. I detta projekt har utkomsten av drönarflygningen, den GPS positions-taggade kartan används för simuleringar. I samarbete med Oryx Simulations (https://www.oryx.se/) har kartorna lagts in i simuleringsmiljöer för simulatorer vilket medger att man kan testa algoritmer/system från såväl forsknings som annat utvecklingsarbete i virtuella, mer kontrollerbara och flexibla, miljöer än riktiga arbetsplatser. Detta sparar tid i tidigare faser av utvecklingsprojekt.

En undersökning av affärsmöjligheter har också gjorts. Denna har utförts som en kvalitativ intervjustudie på personal inom Volvo CEs försäljningsorganisation och dess stödavdelningar. Syftet har varit att undersöka hur Volvo CE bäst anpassar eller förnyar sina affärsmodeller för att kunna tjäna pengar på tjänster eller produkter baserade på systemen beskrivna ovan – versioner av site control management-system. Slutsatsen av detta arbete är att ’Value Based Pricing’ skulle kunna vara den bästa modellen för att öka Volvo CEs inkomster.

3 Background

The Construction Industry has for a long time suffered from low productivity improvement compared to manufacturing and process industries. This is largely a consequence of poor coordination of production resources, which is due to the very dynamic and moving processes used in construction production.

In figures other industries improved their productivity by 100% between 1980-2013 while the construction industry during the same time period improved by 10%. In the ecosystem of construction projects/production there are many factors contributing to this inefficiencies. Everything from the prospecting, bidding, establishing the site/plant, coordination of all resources needed, seasonal variations, weather to ordinary production efficiency and quality.

During the last years the technology development in areas such as internet of things (IoT) and Automation has come to a state where these enable this more dynamic industry to apply lean thinking in terms of production flows. However these dynamic production flows must be understood and modeled in order to fully utilize the technology enablement.

As mentioned on important aspect is the dynamics during production. These projects are being integrated in somewhat unknown geology and the logistics at site is a continuing moving target. Material are being removed and transported away, which means that the terrain is ever changing.

As one piece in this overall puzzle this project has focused on mapping these mass excavations to further understand how different Point-Of-Interest such as loading and unloading points change during the production lifecycle. With this knowledge logistic patterns can eventually be extracted that combined with new technology can make significant improvements in terms of productivity (Trafikanalys, 2015).

More specifically working machine operations such as hauling are often iteratively performed in cycles. Hauling tasks are often performed by several haulers in a work step in an overall production. Cyclic haul operations are common in mining and quarry operations where the haul work step purpose is to move mass short distances from the crushed rock supplies to the mass crushing and separation facility. The operation can include one or several haulers to perform the work simultaneously. The haulers are generally not synchronized in an optimized way and there are a large amount of variations and operative changes that affect the operation continuously. Variations can be that speed and timing vary over time depending on driver skills and machine capacity.

Changes can be that load position move over time leading to changed routes and varying distances that affect the overall capacity. The operational characteristics indicate that there rarely exists a static state that the operators can learn how to do efficiently without a support system. Published work has shown that haul operations have a fuel reduction potential of up to 42% of total fuel, depending on the operation characteristics and wastes such as unnecessary stops and waiting.

The site control management initiative has developed a cost efficient system to optimize speed to minimize operative wastes such as waiting and uneven capacities in the operation. The system includes a systematic architecture, self-learning algorithms and technology components purely developed in-house. The system is expected to decrease fuel consumption and increase productivity at customer site operations.

In a previous project Total Cost of Ownership (TCO) Simulation Tool (Vinnova nr 2009-04127), we have developed decision-support tools to improve the transport efficiency of earthmoving operations at both the vehicle level and the systems level. Earthmoving is the processing and moving of large quantities of soil and raw materials from the earth's surface (Halpin and Riggs, 1992). Three performance metrics are used to measure the transport efficiency of the earthmoving systems: productivity, Total Cost of Ownership (TCO) and resource utilization.

To be able to cope with the ever changing characteristics of earthmoving operations there needs to be a bridge between the off-line, non-dynamic simulation and optimization methods and tools previously developed and the real life operations. As these operations change over time optimization boundaries and simulations environments need to change with them. In this project we are performing academic research aiming to introduce more dynamics into earthmoving simulations. We are also doing more applied research to introduce more dynamic tools to improve on site efficiencies in earthmoving operations – by looking at methods for real-time speed advice to haul truck operator - as well as looking into novel business models. Furthermore drones have been used to be able to capture real on-site characteristics in simulations.

4 Purpose, research questions and method

For the academic research part of the project, the main work within this project has been to develop methods to extract the topographical and operating information using the latest sensing technologies in order to provide accurate and updated input to the decision-support tools at the vehicle and systems levels. The required information differs depending on the problem at hand. For the fuel efficiency problem at the vehicle level, the required information is the 3D topography of driving paths. For the simulation of earthmoving systems at the systems level, the necessary input is the context information of the construction environment, cycle time and fuel consumption of various activities. The research objectives are shown in the figure below.

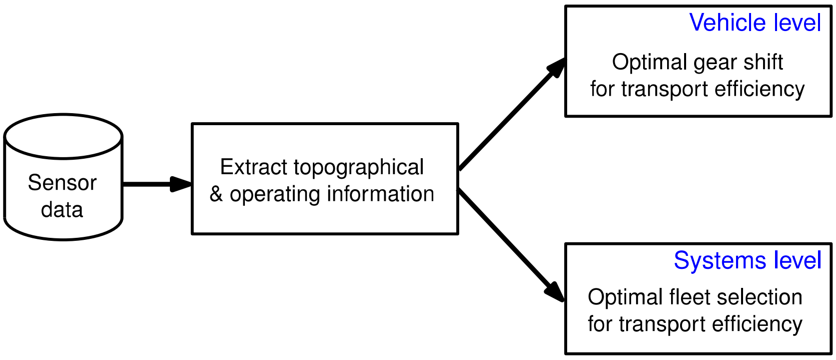

Figure 3 Overall academic research objectives

The project addresses the following research questions:

Heavy construction operations are highly dynamic and the underlying environment is changing constantly. How to use the latest sensing technologies to extract relevant information of the operation and underlying environment in order to provide accurate and updated input to decision support at both vehicle and systems level?

To address the research questions, a map inference framework is proposed in the project. Various machine learning methods are employed in the framework in order to extract relevant information for the decision-support at two difference levels. The framework is described more in details in Section 6.

On the applied research side, research questions have been straightforward. It's from experience reasonable to assume that it is difficult for classic industrial companies to expand their product portfolio towards service offerings, so a **suitable business model** for site control management system and related offerings is sought after. In terms of method, this has been performed as a qualitative survey study.

For the system development perspective, validating the prototype system is crucial, since real operational data together with operator feedback are extremely valuable. Hence, the question to be answered is how **the prototype system functions in a realistic real world scenario**. Field trials and -test have been carried out.

M2M communication is crucial for the above mentioned system to function. In order to understand different what-if scenarios a field study has been carried out at a Volvo CE test track. **Here difference in package loss has been investigated for different radio frequencies**.

Yet another study has been carried out to understand how **3d maps from drone data can be utilized in virtual environments**, coupled to simulators, to test the above mentioned site control management system in lab environments.

5 Targets

Below are the targets as stated in the application, with slight modifications:

1. <u>A list of new business potentials, such as leasing and machine scheduling, including field trials and test of a prototype site control management system.</u>

This very much relates to the applied research carried out. Work has been focused on working internally within the Volvo Group with interviews and qualitative research on how to create revenue streams from products/service related to work site optimization based on real time control. Several field studies have also been carried out.

2. <u>A simulation environment for lifetime optimization of earthmoving projects – a dynamic process model for waste elimination.</u>
    a. Lifecycle estimations of carbon emissions from earthmoving operations.
    b. Tradeoff curves and decision-aiding material in the cost/risk for earthmoving operations with focus on up-time services.

As mentioned before, the focus for the academic research has been to incorporate macro dynamics of earthmoving operations into optimization and simulation. This work has started with developing methods for identifying work cycle characteristics, that in a later stage would be incorporated into simulation and optimization. During the course of the project, it turned out that the initial work had more challenges and interesting aspects than initially thought. This fact in turn led to that the second research step, life cycle simulation analysis (see Figure 1 Project Anatomy) has not been carried out.

3. 1 PhD degree.

6 Results and Target fulfillment

Target 1:

As for business models: Customers are increasingly asking for 'Smart Connected Machines' that allow for broader services and solutions. This is changing the nature of the industry and value is shifting more and more from discrete machines to fleet and site management solutions.

Some OEMs in the construction industry are offering the customer more complex site management solutions and adaption from Volvo is necessary in order to capture the customer need and match the competition.

Within the scope of this project, we have developed a technical solution called Speed Advice which is one module within a larger site control management concept that is under development. This solution could be part of the transformation needed in order to match competition and in order to reach the goal to go from being a machine manufacturer to be world leading in sustainable transport solutions and it needs to be brought to the agenda.

In total four different business models are evaluated to sell the Speed Advice, namely

Organic growth – Standard fit
Organic growth - Spare part/soft products
Organic growth - Value based pricing
Venture/Partnership/Third part supplier

The conclusion here is that alternative 3 would be the best choice given the organization studied.

This part of the project, as discussed above, has also covered field studies of a site control management system, giving real time speed advice to hauler operators. These field trials where conducted on a customer site in real production. The prototype site control management system was evaluated on the following sub-components of functions: *basic components, communication, map- and routing functions and system anatomy.*

Basic Components such as CAN data interface, GPS, power supply, packaging and mounting as well as HMI usability, System design/Configurability and HW robustness worked without any major issues throughout the test period..

Communication: The communication protocol 802.11p worked as expected. In the local work site the M2M Communication therefore worked reasonable good, even though possible improvements such as multi-hop features was not implemented. The coverage for cellular communication used for office back end monitoring and control was not sufficient at the site. Different antennas and systems as well as cellular operators where used without major success. The area is simply not well covered for cellular technologies. At the best GSM/GPRS was available in the site surroundings. Only at well used highways/motorways we observed 3G connectivity.

Map and routing functions: The system available worked as expected, even though several features not implemented where clearly missing for a product system. Such features are improved continuous map segment updates, HMI scaling features. The map matching, map creator, route identification, travel time estimation functions worked without observed issues.

System Anatomy: The system available worked as expected. Unfortunately: time, budget, resource limitations had made us to limit the feature level to only support single destinations in each process, (e.g., that one load area only has one unload area) and that road bottlenecks was not included in the SW tested and pilot quality verified. These two components was missed since the operation often included both characteristics of road bottle necks and multi destinations. Therefore most days/pilot operational time gave poor data collection of the system implementation.

To finalize the field study, a survey was performed with the involved operators. The results from this investigation were that the system, according to operators has the potential to save fuel and improve operational efficiency.

For a the speed advice system to function properly, a functioning M2X communication system is crucial – proven by the issues in the field trial above. During the course of this project, an investigation has been carried out to evaluate the performance of the 802.11p protocol over 2.4GHz and 5.9 GHz in realistic field trials.

The test setup included three Volvo A40-series articulated haulers, which were equipped with 802.11 radios. The radios transmitted packets at a rate of 10 packets per second, in both the 2.4 GHz band and 5.9 GHz band (802.11p). The packets size where alternated to understand how that affect the communication range.

Below are examples of result graphs. The data chipsets in the test use different conventions for received signal strength indication (RSSI) but are scaled to “decibels above the noise floor” with the same color scales. Missed packets are indicated by a value at the noise floor and included in the gradient calculation in that way.

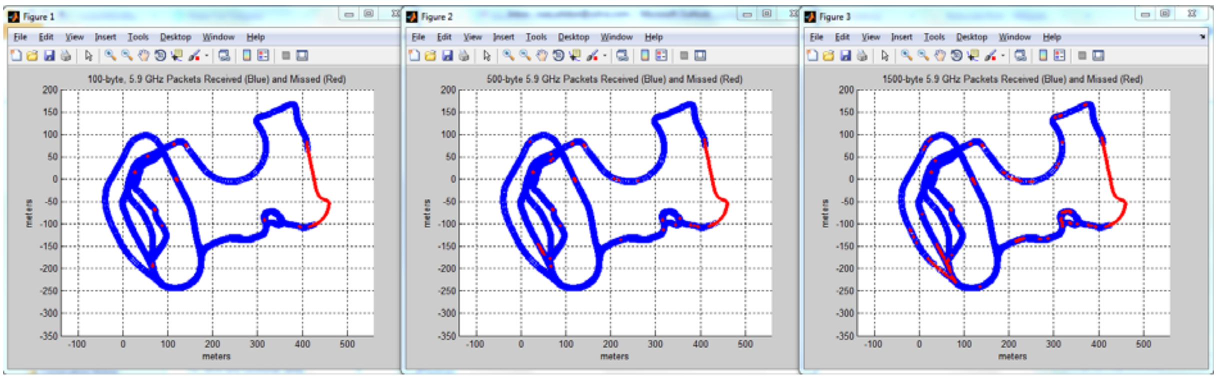

Figure 4 Position 1 (Base of Hill) Received/Missed by Packet size (100, 500, 1500) at 5,9 GHz

In Figure 4 package drops are shown in red along the driven route for different packet size in bytes with 5.9 GHz. Figure 5 shows the same data for 2.4 GHz.

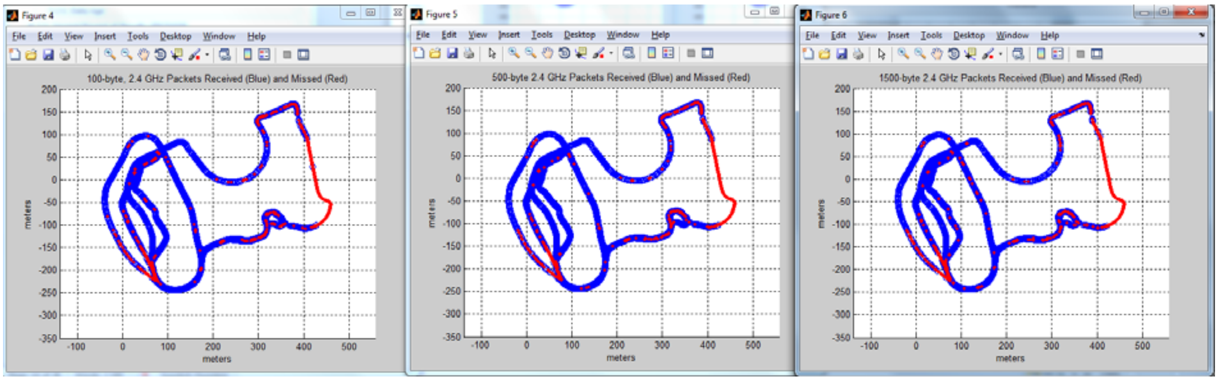

Figure 5 Position 1 (Base of Hill) Received/Missed by Packet size (100, 500, 1500) at 2,4 GHz

To conclude, the Differences between 2,4 and 5,9 GHz communication range is small. Both communication technologies show the same overall characteristics and similar range. At longer obstructed ranges and less machine density areas the communication coverage is not expected to be complete. This knowledge need to be included in the communication strategy for the different applications and data flows needed to support different customers, operations, site characteristics and segments.

Drones have since the start of this project become increasingly important to capture the dynamics of working environments of construction machines. To be able to map and quantify work sites, such as the one used in the field trial described above, drones can be used. As part of the framework for implementing a commercial product a set of 2 investigations of drones has been carried out. In these investigations, relatively cheap, of-the-shelf drones from DJI have been used in combination with image processing software from different suppliers, currently commercially available. One of the software was a downloaded, local installation, and the other using cloud based technology.

Drones for this application are using stereo vision. By detecting the same points in different images taken at different points in space, it is possible to calculate the coordinates of the points in three dimensions. This way a three dimensional surface can be generated.

The drone tags the images with GPS coordinates, so the analysis software knows how to combine the images. Here, a drone with a low precision GPS receiver was used. This does not create any problems for detecting points or generating 3D-models, but the scale of the model will be incorrect as well as the coordinates compared to real the real world. This problem can be solved in three ways. First alternative is to normalize the model by using reference points on an object with known measurements, but this would still not put the model correctly in world coordinates. Second alternative is to use ground control points where the real world coordinates has been collected with a high precision GNSS/RTK system. Third alternative is to use a UAV with high precision GNSS receiver onboard that tags the position of the photos with centimeter precision. This is technology is only available on expensive drones.

In this project, we choose to use a ground control points. Results in general are surprisingly positive. Precision is on a centimeter level, and is most likely good enough to estimate for example material pile volumes at quarries and mines, for planning and estimation in tender preparation etc. It should also definitely also be sufficient to use models with this level of precision as input for autonomous applications like calculating possible routes for autonomous haulers or trucks.

Target 1 is estimated to be fulfilled.

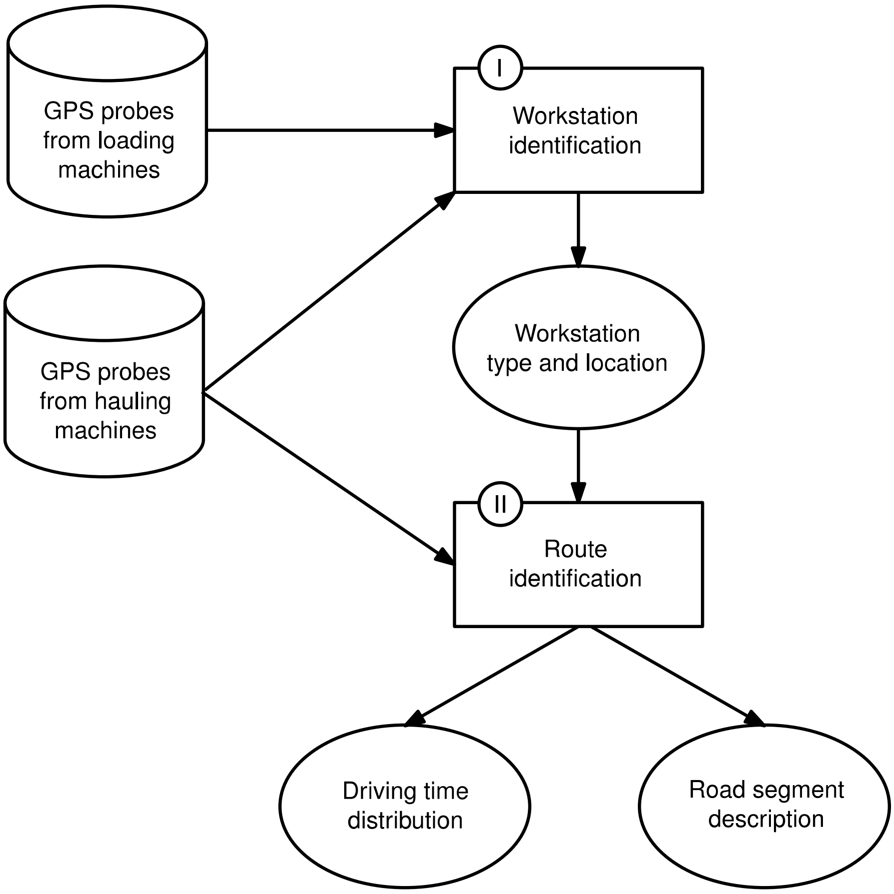

Figure 6 The framework of the map inference methodology

Target 2:

A map inference methodology developed in the project and is briefly described in the following:

The site layout and driving path change continuously in the development of heavy construction projects. Paper I (Fu, Jenelius and Koutsopoulos, 2017) and Paper II (Fu, Jenelius and Koutsopoulos, 2016) together form a map inference framework (shown in Figure 6) for generating and continuously updating the layout and road network topology of the construction environment using GPS probes from construction vehicles. The results from the map inference framework will provide accurate and updated input to the decision support at both the vehicle and systems levels developed in the thesis.

The map inference framework makes use of "free" GPS trace data from daily operations, and requires neither other signals from vehicle Controller Area Network (CAN) buses nor prior knowledge of the operating environment. Compared to the commonly employed methods (manual collection or manually identifying workstations and site layout from aerial photographs), the proposed approach does not require input or experience in the construction field on the part of the users. Furthermore, it is less expensive to maintain and update.

The map inference methodology consists of two building blocks: workstation identification (Paper I), and route identification (Paper II).

In the first block, a generative probabilistic model is proposed for inferring the locations of different types of workstations in heavy construction environments as probability distributions over the site geometry. In earthwork operations, various units of equipment interact with each other to perform different tasks. Indicators based on vehicles' driving patterns and the interactions between different vehicles extracted from GPS measurements provide valuable insights into the type of activity undertaken at a particular location. Hence, such indicators may be utilized to identify different workstations with high precision.

A methodology is first introduced in Paper I and is then applied using GPS probes from both loading and hauling machines to infer the locations of the two most important types of workstations in earthmoving operations, i.e. loading and dumping stations. The probabilistic model infers the locations of loading stations, where excavated material is loaded onto hauling trucks, based on interactions between loading and hauling vehicles, and the locations of dumping stations based on hauling vehicles' turning movements. The proposed probabilistic model yields the probabilities of various workstations as continuous functions over the site geometry, and provides a clear interpretation of the results associated with uncertainties. Further, a clustering method is designed to calculate the number of workstations and the spatial centre of each workstation.

Continuing the work presented in Paper I, Paper II proposes a methodology for inferring the driving time distributions and generating detailed driving paths between workstations using GPS data from hauling trucks. In general, hauling trucks perform the transport tasks and their paths therefore represent the main road network in a heavy construction environment. From the results obtained in Paper I, the workstation pair is first ordered as an origin/destination (OD) pair, for instance from a loading station to a dumping station. The procedure of the driving time distribution module consists of the two following steps:

1. Extract vehicle trajectories between each workstation pair (assuming no differences in driving pattern between different operators)
2. Identify and filter trajectory outliers and compute driving time distributions between workstations from the remaining trajectories

The identified vehicle trajectories are then used to derive a directed path between each OD pair, with detailed segment information. The procedure is made up of three steps:

1. Generate clusters along vehicle trajectories between each workstation OD pair
2. Link clusters into directed edges for each OD pair
3. Compute detailed information on path segments

The resulting path between each workstation OD pair is represented as directed road segments with information on segment length, grade, curve radius, etc.

The proposed map inference framework is applied in a case study at a heavy construction site in Sweden. GPS data are collected from a group of construction vehicles working together. The experimental results indicate that the proposed framework is able to extract workstations and the road network in the underlying environment. The credibility of the resulting digital map is validated through observation at the studied construction site and confirmed by the site manager.

As a result, the proposed map inference framework does not rely on pre-defined thresholds regarding the time spent at workstations or a fixed number of workstations. Further, it creates an interpretation of the earthmoving operation, including both transport activities and detailed topographical information of the transport paths. Compared to the commonly employed methods in construction engineering using manual effort or scanning techniques, the approach is fully automated and less time-consuming. For a group of construction vehicles collaborating on carrying out earthmoving operations, the map inference methodology is capable of extracting the locations of important workstations using GPS data from loading units and an arbitrary hauling vehicle. In the case of earthmoving using one loading unit as in the case study, GPS data are required from the loading unit and one of the trucks. For earthmoving with multiple loading units, it is necessary to have GPS data from all loading units in order to detect all loading stations. It is common in earthmoving operations for each loading unit to operate at workstations relatively close to each other and hauling units to serve all loading units in the operation. Hence, the cost associated with this approach is the GPS devices, which are currently the standard configuration for construction vehicles.

Contributions

Methodological contribution
Together with the previous project, four methodological frameworks have been developed to evaluate and improve the transport efficiency aspects in earthmoving operations on both vehicle and systems level.

- Map inference framework for heavy construction environments
    - Workstation extraction (Paper I)
    - Driving time and path generation (Paper II)
- Optimization of earthmoving operations at the vehicle level (Paper III)
- Simulation of earthmoving operations at the systems level (Paper IV)
- Optimization of earthmoving operations at the systems level (Papers V, VI)

The proposed methodology employs machine leaning, simulation and optimization techniques, and each method is presented in detail in the corresponding paper(s). Figure 2shows the conceptual relationship between the methodologies developed in Papers I-VI.

An important contribution of the project is the collection and analysis of data in connection to earthmoving operations. Much effort has been put into establishing contacts and collaboration with companies, understanding the characteristics of the operations and obtaining field data. The empirical analysis enhances the understanding in studied logistics operations.

Target 2 is estimated to be partially fulfilled

Target 3:

The industrial phd student successfully defended her thesis in May 2017.

Target 3 is estimated to be fulfilled

7 Distribution and Publications

7.1 Knowledge and result distribution

Hur har/planeras projektresultatet att användas och spridas?	Markera med X	Kommentar
Öka kunskapen inom området	X	Systems for real time control, based on M2M is completely new to Volvo CE, and this project has increased experience and expanded our knowledge base.
Föras vidare till andra avancerade tekniska utvecklingsprojekt	X	Parts of the results from the project, such as POI identification will be carried over to the Electric Site project.
Föras vidare till produktutvecklingsprojekt	X	
Introduceras på marknaden	X	
Användas i utredningar/regelverk/ tillståndsärenden/ politiska beslut		

7.2 Publications

I. Fu J., Jenelius E., Koutsopoulos H. N., (2017). Identification of workstations in earthwork operations from vehicle GPS data, *Automation in Construction*, 83, pp. 237-246.

II. Fu J., Jenelius E. and Koutsopoulos H. N. (2016) Driving time and path generation for heavy construction sites from GPS traces. *Proceedings of the 19th International IEEE Conference on Intelligent Transportation Systems*, 1141-1146.

III. Fu J., Jenelius E., Uhlin E., Macroscopic and Microscopic Simulation Modeling of Earthmoving Operations and Applications, (in working process)

IV. PhD thesis (April 2017) with title "Evaluating and improving the transport efficiency of logistics operations".

V. AE Investigation Report – Pre-Study report VCE (commercial pilot). Confidential Internal Volvo Report. Maria Forsberg, Henrik Munck, Volvo ATR

VI. Site Control – Off-Board solutions as an enabler for customer digitalization. Confidential Internal Volvo Report. David Rylander et al.

VII. AE Investigation Report – Site Control Communication. Confidential Internal Volvo Report. David Rylander et al.

VIII. AE Investigation Report – Site Control Pilot (Customer field trials). Confidential Internal Volvo Report. David Rylander et al.

IX. Construction Factory. Application within InfraSweden 2030. Peter Eriksson et al.

8 Conclusions and continued research

Through this project we have gained an understanding of the dynamics of the mass excavation logistics. Coming research will further nuance this logistics dilemma (seasonal effects, weather effects and variability in different sites) combined with performing optimizations on the models already developed.

More research needs to be put into the communication between machines. The M2M approach utilized for the prototype system in this project has many advantages, one being the fact that not infrastructure needs to be installed on site. However, research and tests show that it has its drawbacks as well, where coverage is one – where lack of infrastructure is one. Other types of meshed network protocols needs to be evaluated, as well as 4G/LTE/5G which has proven useful in real time applications. One example being the PIMM project: (https://www.sics.se/projects/pimm).

Drone usage in the construction industry is growing and is also expected to grow ever further. It assumed that we are currently only scraping the surface on what is possible to do. Examples of possible research that came up during this project is combining high resolution ortho-photography to evaluate haul road quality. Potentially this could be combined with speed advice algorithms. Another is the potential to use cloud based analytics to automatically discover resources in quarries and construction sites. Future work could also be focusing on improved usage of work site maps in simulator usage. Applications could vary from operator simulator training in targets environment, to tailor made machine software based on drone data in machine simulations.

As for the site control management system, parts of this is currently being taken forward within Volvo Construction Equipment in various forms.

Academic research could in the future focus on POI identification with even sparser data. Also joining the results from this project even further with the results from other optimal control projects focusing on haul road characteristics could be interesting. As mentioned above, the goal of building a macro simulation system for decision support as well as lifetime CO2 emissions and optimization was not met. Naturally this is something that Volvo Construction Equipment could work towards.

9 Partners and contacts

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