LITTLE BIG TRANSITIONS: ELECTRICAL CONSTRUCTION MACHINES ON SMALL SITES

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Apart from grand projects (e.g., bridges) with large material and diesel-related emissions, civil engineering mostly comprises small and medium-sized projects (e.g., roundabouts, parks), where climate impact must also be mitigated. Because equipment manufacturers have been slow in providing electric machines (e.g., +/-2,5 tonnes electric excavators, wheel-loaders, etc.), which supports the transition to emission-free sites, the following enquiry appeared: which are the relevant barriers, enablers, benefits, and perspectives. This paper adopts an interdisciplinary operation management framework for a Swedish urban park project, where an electric wheel-loader was used (study includes interviews, observations, energy measurements and assessment electric vs. diesel equivalent machines). Main findings show operators being modest in their expectations, electric machines performing as diesel-driven ones, and the difference in emissions being relatively significant. The considerable idle time indicated that a meta-level project portfolio planning would have huge potential - e.g., through involving machine rental companies in a sharing economy setup.

Keywords: heavy-duty; engineering; electrical; sustainable transition; Scandinavia

INTRODUCTION

In the areas of greater Oslo around 100 electrical construction machines over 10 ton are by winter 2022 in operation. Documented emission-free building sites in the Oslo area with electrical supply above 50% of the energy consumption both internally on site, and for mass transport to the site, now amounts to 6 and sites with more than 50% electrical power supply have reached 10 (Wiik *et al.,* 2022). This can be compared to one site in Oslo during 2019-2020 (Wiik *et al.,* 2021).

Internationally it was established in 2020 that small electrical machines up to 2,5 tonnes were available all over Europe (BBI 2021). And by 2022 37 machine types above 2,5 tonnes are available, from suppliers such as Hitachi/Nasta, CAT/Pon, Huyndai, Kubota, Komatsu, JCB, XCMG, Volvo, Valla Manitex, Takeuchi, Suncar HK , Snorkel, Sany, Liebherr, Futuricum, CIFA and Ahlmann (Bellona 2022), albeit in very limited numbers.

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On the other hand, in Sweden, some 14200 new diesel driven machines were sold in 2018-2020, which is record high figures. They are probably all at a high environmental standard (EU step 5), but still diesel driven. Others, some 20000 diesel machines from 2011-2018, are at a somewhat lower standard (Maskinleverantörerna 2022).

These figures are meant to demonstrate a slow sustainable transition. Sustainable transition theory (Köhler *et al.,* 2019) points to the incumbent regime which tends to prevent sustainable transition and in the case of civil engineering, the large public clients, the contractors, the machine renters, and the manufacturers of construction machines all have their share.

There are thus signs of sustainable transition, but still a reluctancy, the adoption is slow, and it is therefore relevant to ask

-which are the barriers, enablers, benefits, and perspectives for the adoption of electric construction machines?

This paper addresses this research question by analysing a case study of ground works in an urban park project in Sweden, which involved the use of two electric machines, wheel loader and an excavator, where the focus here is mostly on the wheel loader. We thus adopt a micro perspective on a macro issue, the needed global sustainable transition.

We do this appreciating that civil engineering activities in contemporary western societies are mostly constituted by a large amount of small and medium-sized projects such as playgrounds, roundabouts, and bicycle lanes, carried out for mostly public clients such as municipalities, regions, and the state.

The machines in the test were 4,9 tonnes battery wheel loader, with charging time between 2h and 12h depending on charger and an estimated operation time at 8h. And a small excavator at 2.5t, battery driven. With an estimated operation time at 8 hour and a charging time at 1-6h, depending on charger.

The paper adopts an interdisciplinary operational management approach, that combine operations management with activity study, work environment and technology studies. Methodologically, document analysis, interviews, site observations and power/fuel measurement were conducted, where the energy consumptions of the vehicles were measured. A systematic comparison between the use of diesel-driven and electric machines was done. Note that the material behind comes from an ongoing project and the concepts methods and results are all preliminary.

Framework of Understanding

The framework juxtaposes and (partly) integrate four different strands of concepts and theories that underpin a micro approach to sustainable transition: Operations management, activity study, work environment and technology studies. The framework is thus under elaboration, being at present multidisciplinary, but striving for an interdisciplinary framework (Strathern 2007).

Operation Management in Construction

Operation management offer a distinct micro perspective on how to carry out processes that transform material into products (Slack and Brandon-Jones 2019). When adopting an operation management perspective (Slack and Brandon-Jones 2019) there is a need to conceptualise construction operation specifics. Construction is a project-based production, which is (although its often claimed) not producing one of a kind, but where the element of repetition is considerable. Design and execution is normally separated economically, organisationally and geographically. It involves moving components, workforce, and equipment to the sites to carry out execution operations, whereas the assembled partial products remain fixed. (In contrast to manufacturing where the partial products are transported, whereas workforce and equipment remains fixed).

The attempts to understand, model and control operational processes and management in construction, be it building or civil engineering, have quite often ended up in to marked different poles. One widespread understanding draws on operational analysis and systems theory, relying on the classical transformations model input-transformation- output, picturing operations as pearls on a string (Koskela 2000). Another understanding describes construction processes as chaos. For Bertelsen (2002, 2003), “chaos-in-the-large” means a situation where the progress of the whole project cannot be predicted. Bertelsen and Koskela (2003) argues on the other hand that “chaos-in-the-small” may be managed. However, the “small” may very fast turn into the “large” if it is not observed, understood, and kept under control.

In other words, Berthelsen's preoccupation is to bring construction operations “back into” the controllable world of operation management based on systems theory. To do so the operation managers must balance dynamics and stress, such as budgetary limits and scheduling with the decision power of the operation manager team. Bertelsen and Koskela (2003) predicts/views this as working at the edge of chaos. Duc (2002) along with Carassus (2002) finds double variability to be central for the understanding of building processes. Double variability is the combination of external variability, which is due to heterogeneity of products and markets, and the internal variability which refers to handling live work with its flux in space and time. The external variability creates complexity through unclear and emergent demands from the client and the characteristic fragmentation amongst companies in the industry, between architects, technical consultants, and contractors and more.

The internal variability can be seen as occurring because of quantitative complexity, the products and process consist of a very large number of components and subsystems that need to be produced and assembled. Moreover, designs of details are usually occurring overlapping in time with the execution period. This in total creates multiple and parallel processes. Parallel operations are at the same time to some extent interdependent and can therefore be expected to interrupt and disturb each other. Building processes can be conceptualized as encompassing requisite parallelism and fragmentation due to their predominantly quantitative complexity. Construction processes therefore occur fragmented, interwoven, and with strong, but also less strong, interdependencies.

The operations share physical space, share abstract space (site operation management, negotiation, and coordination) and the conditions are dynamically transformed over time. Interruptions are planned and unplanned. The characteristics are shared with other complex product industries such as aerospace, shipyards, and capital goods, in having a limited repetitive element as the basis for operations management.

Activity Study

To better understand, order and distinguish the activities on site we adopt a combination of work sociology and works standards The work standards "Allmän Material- och Arbetsbeskrivning" (AMA) or "General material and workmanship specifications" encompass one standard for civil engineering, which is recurrently in use in Sweden (AMA-Anläggning Svensk byggtjänst 2019, just called AMA here). AMA suggests classifying civil engineering in main functions and side functions. AMA suggest that main functions in civil engineering should be ordered in 13 main categories and 187 subcategories. For example, main categories encompass preparation work, terracing, group topping, on site concrete moulding, brick walls. Side functions would then for example be: internal transport, idle engine, charging and tanking.

We suggest to precise the activity categories so they can be fitted to urban parks and playgrounds with the following main functions: Remediation, removal, disassembling and demolition, tree felling, removal of stumps and roots, excavation of earth, removal of cliffs, stone drilling, ground topping, mounting of asphalt layer, sand zones, ground topping for plant zones, erecting plant zones, seeding and planting, support and protection of plants, edge support, gutter valleys and surface water gutters and renovation of pipes (Svensk Byggtjänst 2019).

Work Environment

Work Environment is here conceptualised according to the Scandinavian traditions of working life studies that largely build in work sociology (Hvid and Falkum 2019). This implies among other thing adopting concepts of work as bases for understanding the environmental factors that impact on people active at the work. Here work environment is understood as the total set of factors that impact on the working persons wellbeing (Lindberg and Vingård 2012). The factors then include ergonomics, physical work strain, noise, chemical emissions, light etc.

Technology Studies

Science, Technology and Society (STS) studies offer a series of strong concepts to understand the interaction between broadly speaking people and technology. In this context we need to map expectations, experiences, and proposals of improvement of the technology, that is the electric construction equipment. Technology acceptance studies (Davis 1989) offer simple models to understand the related issue of employees having to accept technology implemented by their employer. If this is combined with a soft version of social shaping of technology (Williams and Edge 2004), it can be appreciated that users of technology through their interaction and experience, can contribute to shaping it and bringing it further in a healthier and user-friendly direction and therefore also contribute in cocreating them as improved tools for the enterprise.

Summarizing, by combining elements from operations management, work sociology (activity study, work environment), and technology studies a multidisciplinary operational management framework of understanding is established, that support the research interest of understanding micro sustainable transition. Moreover, the direction for future development is to strive for integration into a more comprehensively interdisciplinary framework.

METHOD

To support our research interest in micro contributions to sustainable transition, we adopt an interpretive critical sociological approach to operations management (Christensen 2002), which combine elements from operation management, work sociology (activity study, work environment), and technology studies, in a multidisciplinary operational management approach (Slack and Brandon-Jones 2019, Strathern 2007).

To understand the activities carried out, we have taken inspiration from a Swedish standard of civil engineering works AMA anlägg (Svensk Byggtjänst 2017).

For this paper we have selected the material and results from one site. As the project is ongoing, we still have limited empirical material, and the choice of this site is therefore done by quite pragmatic criteria and as a matter of convenience. It is our best described case so far.

We have collected empirical material from documents, interviews, site observations, and power consumption measurements.

Eight interviews were conducted, four before the test and four after. The foreman and two machine operators and one craftsman were interviewed before the test. After it was the foreman and two machine operators interviewed alone and the site manager and planning engineer together.

The site observations consisted of one work week for the diesel engine and one work week for the electrical machine. One work week would be 40 hours from Monday to Friday roughly from 7 o'clock in the morning until 4 o'clock in the afternoon (including breaks). During observations the power consumption, the engines activities, the operators' activities, and their work environment was observed and measured, and extensive field notes taken. The power consumption measurements were done with an ad hoc set up. The diesel fuel measured by using the machines indicator for the test week and the electricity was measured at the charging station for the test week.

A limitation worth noting is that our present framework of understanding does not directly address whether and how our micro understanding connects to and possibly even change the understanding of sustainability and how the contribution to sustainable transition is more precisely, than assuming that a substitution of diesel engines with electrical ones is indeed a sustainable transition.

Empirical Material

The site studied was a park and playground project with the city as client. The site has a rectangular shape roughly measuring 400 m times 600 m. A precursor project had taken care of industrial pollution at the site and the works consisted of excavating draining, installing piping and cloaks, reshaping the inclination of the overall site, erecting small hills (for children's sledging) preparing for and planting trees, seeding lawn, ground preparing of foot paths in a foot path system going north to south and east to west. Storage of masses of material, 23 different types of earth and stones, was established at the north-west end of the site.

The observations made it very clear how fragmented the activities were. The wheel loader served as mover of masses in a lot of situations, which is close to coordination function, making it possible to do groundwork at specific places on the site. Therefore, the wheel loader was used whenever there was a need for moving masses from A to B on the site. As table 1 shows below the duration of these operations are mostly rather short and they are interchanging with the machine standing still. This work pattern was largely identical for the electrical and diesel driven wheel loader.

Table 1: Excerpt of site observation electrical wheel loader

Time	Activity	Location	Duration
08.00	OP drives WL to new place	Point 9	1min
08.02	WL is in idle state		12
08.05	WL loads and transports earth from point 9 and unloaded to point 10	Point 9 -10	26 min 18 sec
08.30	WL is parked and shut down	Site hut	9 min
08.39	OP takes WL and drives it to point 10	Point 10	4 min
08.43	Unloading gravel at the point 11	Point 11	14 min
09.00	Break WL shot down not charging	Site hut	15 min
	WL shot down	Site hut	1 hour, 32 min
09.15	Not charging		
10.47	OP drives WL to point 9	Point 9	1 min

Label explanation: WL= wheel loader, OP = Operator. Point 9 = footpath north, Point 10 = grass lawn at foot path east, point 11 = large grass lawn centre. Distance point 9-10 = 10 meters, points 9/10 to 11 = 150 meters

Technology Expectancy and Experience

Expectations

The operators and site managers had consented to participate in the test when asked.

There was a diverse set of experience from previously operating electrical machines but most of them had limited experience and had relatively enthusiastically approved to be part of the test. The expectation of performance was expressed to be "as good as diesel".

There were expressed worries as to how the charging function would work - would it be a hassle, and would the machine run flat? Some had tried electrical vehicles before, where this was an issue.

Experiences

There was expressed overall satisfaction with the performance of the machine from operators and site management. The workers' crew had been asking for a wheel loader for some time, to support the activities, both for moving masses on site (from the corner depot to a particular place on the site for example) for receiving incoming masses, or for supporting the two other diesel excavator machines on site. This was forwarded as explanation for the good experiences. The machine fitted in the constellation of equipment which the site had and was needed for this reason.

The electrical machine was designed with a dual electrical system, one primary for the drive unit and one secondary for the remaining electrical function (i.e., lights, instruments etc). Charging these two systems at the same time in a few instances during the test meant discharging the secondary system, which made it impossible to start the machine. This was a particular predicament on Monday morning, where the secondary battery would be flat. This led to the decision not to charge the machine over the weekend, but only during the night between workdays. The manufacturer subsequently modified the engine to tackle this issue.

The machine did not have air conditioning in its cabin. It was quite sunny and hot during test operations and the machine operators preferred closed windows because of the dust generated when operating the machines. However, the fact that the machine did have a closed cabin became a large advantage, once heavy autumn rain set in.

The activities carried out in the studied project and in the two test weeks clearly illustrated that works in making public parks and playground are but a very small part of the activities in civil engineering.

The moving of masses was the main task for both the wheel loader and the excavators but smoothing out of earth ground and moving of smaller machines were also occurring as tasks for the wheel loader.

The activities carried out were very fragmented and mostly the machine was active less than half an hour at a time. The machines stood still for long periods of times. The electrical machine ran 17 hours during the 40 test week hours, whereas then diesel ran 11 hours. This is a very low activity level, compared to the sector's rule of thumb that a machine needs to be active more than 70% to be profitable.

The work environment for the operators and workers at the electrical machine was roughly like that of the diesel. The manufacturer has chosen to design the electrical machine with an identical body, cabin, wheels, add on equipment (buckets, forks, shovel etc), which are in sum largely determining the work environment for operators working with the machine, electrical or diesel. The differences in work environment were in the sounds the machine was making, and/or not making. Instead of a speeding engine, the operator would hear wining hydraulics, this could be understood as alarming sounds. For most operators and workers, the silence of the machine was experienced as an improvement. It was felt however that the silent operation of the machine did not improve the communication amongst workers as they already operated mobile radios installed in their hearing protection and continued to use this.

When the expectation of performance was expressed as "as good as diesel" it could be seen as a moderate expectation as the operators and site managers are used to being introduced to new diesel engines with improved performance compared to previous ones. As noted in the introduction the investments in new civil engineering machines in Sweden has been at a historically high level. Adding to this, it has become common that public clients demand new machines as the EU regulation implies reduced levels of CO_2, NO_x, soot, and unburned fuel for new machines (a regulation profile like a downwards going staircase with the years). The machine manufacturers and their reseller network do extensive marketing, demonstration, and training to convince operators and company investors that their next generation/version of machine are superior to the previous. On this background the expectancy and experience that the electrical machines would be and was "as good as diesel" is a modest evaluation.

It was expected with a feeling of insecurity that the charging might lead to difficulties. In general, the machine had electrical power to be taken in use immediately and used to solve a given task. However, the battery did run flat three times after the weekends, and the operators did not systematically manage to use pauses in use of the machine or personnel breaks to do charging (i.e., breakfast and lunch breaks).

FINDINGS

This paper asks: Which are the barriers, enablers, benefits, and perspectives for the adoption of electric construction machines? We answer this from a micro perspective and study how an electrical machine performs compared to a diesel in a contribution to sustainable transition.

The main barriers for providing a strong case for electrical operation are multiple. The fragmented activity patterns could be understood because of Laissez faire planning: Operational management activities were held to a minimum using only coordination meetings with workers, operators, self-employed and subcontractors. This operations management practice could be interpreted as explaining the large amount of idle time and consequently the large unused machine capacity on the site. However, the advantage of planning with over capacity of engines is to assure more optimal use of work force and optimising on the work force costs, rather than machine costs.

The trouble with charging procedures can be seen as a “children's” disease, that has been amended by the manufacturer after the test.

There was a slight tendency that the electrical machine had a reduced capability for certain operations (such as lifting masses), a finding like that of Wiik *et al. (*2021).

There was also a slight tendency among site personnel to question whether electrical engines with their batteries are really performing superiorly in term of sustainability.

In a future perspective, when sites become emission free and fully electrical it has been predicted that the electrical consumption would need meticulous planning and expansion by municipal operators. SINTEF (2021) is considering civil works in connection with house building, investigating whether the new building's future electricity system would suffice supporting the civil works in the early phase, thus providing a possible local source of electricity. They carry out simulations using civil works at a kindergarten building as example. They find that peak electrical consumption derived from several electrical machines running intensively in short periods would generate more electricity consumption than the electricity system for the future building, leading to a need for either more precise planning, taking limited resources into concern, or planning for other sources of electricity than that of the future building.

In the larger perspective, public clients/ cities have an opportunity to accelerate the transition by posing well-grounded demands for machines that are available on the European market. Some cities like Bergen and Oslo have ambitious goals for the climate. Oslo thus wants to reduce CO2 emission by 95% before 2030. And such demands would trigger and increased focus on electrical machines.

The enablers for electrification and realising emission free sites are the following:

The park and playground represent small sites where there are limited distances from one end to the other. This enables use of electrical machines because distances to charging facilities are limited. There is even increased possibility for using cabled vehicles. The electrical machines are designed as a copy of diesel engines - this makes it easy for operators to swiftly adopt competences for manoeuvring but might possibly involve other weaknesses compared to a more fundamental redesign of the electrical engines. The urban context means even shorter distances to other sites, which means possibilities for sharing resources.

CONCLUSIONS

This paper has analysed a case of a little big transition, namely adoption of electrical construction machines on small sites. We wanted to know which are the barriers, enablers, benefits, and perspectives for the adoption of electric construction machines? The main findings were that operators were right in being modest in their expectations, as electric machines performed just as well as contemporary diesel-driven machines. There was expressed overall satisfaction with the performance of the machine from operators and site management. Nevertheless, the considerable idle time involved during operations, indicated that a meta-level project portfolio planning, i.e. improved operation management of the use of the small machines would have huge potential - for example, through involving machine rental companies in a sharing economy setup between several sites. The difference in emissions is relatively significant when comparing diesel and electric vehicles, but absolute figures appear modest, risking users to neglect or downplay the positive effect on the climate and environment.

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