Towards Digitalized and Automated Work Processes in Port Environments

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Abstract: Requirements for safety and productivity in container terminal processes are the key drivers for automation and digitalized processes. While automation development has so far been focused on large terminal environments and introduction of smart port concepts and utilization of digital technologies are to large extent limited to megaports and forerunners, there is an increasing interest in implementing automation and digitalization at smaller ports in profitable manner. Current paper discusses the enablers and barriers of automation and digital services at such ports, presents a framework for customer value in the contexts and outlines focal development targets.

1 INTRODUCTION

The ongoing trend towards larger container ship sizes has a significant influence on the capacity and management requirements of entire maritime end-to-end logistics chains. The traffic of big vessels concentrate in certain terminals as the operation require major investments in the port machinery, and the big vessels operate most economically in long-distance lines. Therefore, the ports that serve mega-vessels strengthen their role as transhipment ports while the other harbours mainly operate as feeder ports. While larger and larger vessels are being built and retired ships are circulated also smaller ports begin to receive larger vessels than before.

On the other hand, the continuous increase in the capacity of ships no longer reduces costs, and close to optimum size has already been achieved. Overcapacity in container shipping and hard competition altogether put pressure on the companies in the business. The influences of these trends have effects also on terminal ports of different sizes.

In terms of port efficiency, there are two focal trends with high expectations: automation and digitalization. While the cost factors are naturally among the most important drivers, availability of staff in certain locations is also a strong driver for automation. This also provides opportunities for remote services and remote operations. Furthermore, digitalization requirements are arising from the need to support decision-making in different functions and at different levels. In addition, younger generations demand better working conditions and are willing to operate in virtual environments.

Big vessels require particular investments in terminals such as the need for bigger cranes, deeper sea routes, etc. The requirements for managing larger volumes and capability to handle peak loads have effects on the quay cranes but also on all the assets at port. In general, the requirements for time-efficiency are increasing, e.g. the containers received previously in 14 vessels are now transported in 4 vessels, and simultaneously the time allowed for handling one ship at port is decreasing.

The logistics solutions should prove to be efficient and in addition, they are expected to be sustainable, with functions of high safety and quality. Customers require decreasing energy usage and zero emission ports. Avoidance of problems and hazards are an issue for competitive advantage of the port and result in economic effects. Improving the reliability and safety in port operations is regarded as a value-adding investment.

As said above, there is an increasing trend towards automated systems. Only 40 terminals out of

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~1,200 terminals (Chu et al. 2018) are currently automated or semi-automated globally. Major terminals have increased the level of automation, but most of the small and medium sized ports still lack a clear vision and digitalization strategy. New adaptive solutions are needed as examples of economically viable automation. Furthermore, one needs to understand and calculate customer value of the proposed solutions in terms of the key performance indicators relevant for the customer in his business environment.

This paper describes results of the AUTOPORT project and aims to pinpoint the slowing and enabling factors for port digitalization and automation, with a discussion on future directions for smaller ports. The overall goal of the AUTOPORT is to pave the way towards business renewal and operational excellence by developing ecosystem level approaches for port logistics.

2 DIGITALIZATION IN PORT ENVIRONMENTS

Requirements for port productivity are increasingly hardening and larger vessels require handling of larger volumes within shorter time windows. Digitalisation and automation could offer solutions to meet the demands.

2.1 Needs for Digitalization and Automation

Automation level is increasing at ports due to increasing labor costs, reducing workforce availability and higher demands for predictability. Internet of Things (IoT) replaces manual data collection and processing, which eliminates potential human errors (Hinkka et al. 2018). It is likely that the level of automation will increase gradually (see Section 2.2) and no dramatic change for manual labor is expected. However, work processes and functions should not be automated as such but processes should be first simplified and restructured (Chu et al. 2018).

Connectivity is a key enabling factor of the information exchange both locally and globally. Furthermore, development on the sensor data collection on the land and seaside and from the port operations is a key enabler for making analytics for different decision-making situations. Thus, there needs to be a holistic approach for from the collection of relevant data to all the way to the actual decision-making context and utilization of the refined information in practice. Tracking of all moving objects and humans at a port can be regarded as a vision for enabling the situational awareness for all relevant stakeholders. Situational awareness is linked to a variety of objectives that are related both productivity and safety.

From the viewpoint of the terminal, the focus should be on the overall performance of the port, instead of individual operation, condition, tracking, asset or function. The key performance indicators, utilization of the new data as well as the related management practices need to address different levels and the particular natures of the operations. In order to discuss and develop the working practices and efficiency of the assets, their operations need to be made visible to all the relevant stakeholders.

2.2 Phases of Digitalization

Many authors and practitioners have described the phases of digitalization. For port operations, Port of Rotterdam (Buck et al.) have identified four phases:

1. Digitisation of individual parties in the port
2. Integrated systems in a port community
3. Logistics chain integrated with hinterland
4. Connected ports in the global logistics chain

Automation in container handling develops also in phases that start from operator assistance and remote control towards full automation. Small seeds may end up resulting in significant improvements from the viewpoint of the end-to-end logistics system. Thus, companies could start with the solutions onboard the machine and integrate them with the larger solutions.

Current technologies applied at ports are typically a combination of old and new equipment and there needs to be flexibility in the proposed technologies to allow updates and investments in brownfield. Assets need to be ready for updates whenever technology develops. On the other hand, autonomous systems is not a realistic short-term target in a small and medium sized terminal. In those terminals, the key issue is to improve the operational efficiency by connecting the asset fleets and providing a holistic optimization approach based on the data gathered. Machines should be more seen as data-gathering assets that could produce increasing amount of information from their environment.

3 DEVELOPMENT OF SERVICES FOR CONTAINER TERMINALS IN AN ECOSYSTEM

The significance of software solutions in assets and technologies used at ports is increasing. This calls for new type of collaboration between companies.

3.1 Increasing Role of Software

Hämäläinen et al. (2018) stated recently that "*terminal automation as such does not radically change the current business models of the logistics industry, but the ever-growing software and service business, as well as the development of open and transparent global logistics chains does do so*". In the development ecosystems around machinery vendors there is plenty of room and even a particular demand on innovative software companies.

There seems to be increasing demand for integration capabilities in the development of automation and software. Lehto et al. (2017) state that a significantly higher level of standardization is required and "*once the connectivity is standardized, diverse industry players can come together to create robust ecosystems that further develop the capabilities of their equipment and software applications*".

Many complicated machines, such as forestry tractors, industrial robots, modern container movers and airplanes require software for functioning properly. Therefore, a proper software engineering is a success factor in many industries and not only in the software industry. A recurring strategic consideration for organizations evolving complex systems is the decision whether to develop the software internally or to acquire them from external sources. The software development process is distributed among people with different skills, because large software products require a lot of workforce and knowhow.

There is an increasing demand for utilization of AI for decision-making, considering the complexity and uncertainty of the modern ports. Thus, both researchers and practitioners are paying attention to the topic. For instance, a decision support system for the container storage assignment is proposed by Gaete et al. (2017). The proposed system specifically addresses the problem of container terminals where inland flows present high levels of uncertainty and variability.

3.2 From a Development Ecosystem towards a Business Ecosystem

In recent years, inter-organizational collaboration has increased, as even large OEMs do not have the necessary knowhow and expertise in their organization to develop complex products that require a wide range of expertise and knowledge. As a result, small specialist companies are becoming more directly involved in product development processes (van der Meer Kooistra & Scapens, 2015). When customer takes part in its supplier's product development, they ensure that the product will fit their needs. Organizations that engage in collaborative R&D efforts have the opportunity to combine their complementary knowledge sources, facilitating the generation of technological inventions that organizations could not achieve on their own (Belderbos et al. 2014).

For many years, vendors have been practicing the software development in relative isolation from other companies. However, at some point they realized the benefits of partnerships, and started to open their software products to co-development. Large-scale software products (e.g. operating systems) started to transform from single-vendor projects into platforms for co-development and software ecosystems. By bringing more companies into the software development process, they could gain increased functionality and keep customers satisfied with less capital investments. Collaboration generates many advantages, such as decreased software and business development costs, quicker time-to-market, and economic profit (Kourtesis et al. 2012).

Development of port automation and digitalization solutions require a variety of expertise from technology, process and domain perspectives and it can be argued that networked development activities are a necessity. Even port automation and digitalization represent large topics, they can be considered in even larger logistics chain development context. An automation and digitalization development ecosystem should then understand the whole logistics chain but particularly the ecosystem partners' roles in providing the specific solutions for the individual smaller parts in the chain. This also supports the transition from sub-optimization towards more holistic value creation.

Customer value-driven development activities are seen among the most significant enablers for asset management services (Ahonen et al. 2017). Thus, customer involvement in the development is crucial. It can be even argued that the more complex the technologies are, the closer customer collaboration is

needed to keep the focus on customer value creation. Ahonen (2019) states that it has been acknowledged that one should bring up the first versions, with all their limitations, very early in order to foster inspiration for further ideas and to start concrete development work together with the customer.

3.3 Sources of Customer Value

The stage of adoption varies among port technologies. While information systems for terminal and port management and basic monitoring capabilities are already widespread, the more advanced solutions for predictive asset performance, digital twins, location and motion tracking for safety and advanced communication are being development but are still in their infancy.

It is crucial to understand the desired value of the developed solutions from the beginning. Figure 1 highlights the importance of the information systems that, on one hand, are domain specific and, on the other hand, need to comprise an integrated set of solutions for the customer. Figure also brings forth three main areas of consideration: how to manage the assets at port in a sustainable manner, how to maximize the value creation by operations optimization and how to support the value creation by services provided in the ecosystem.

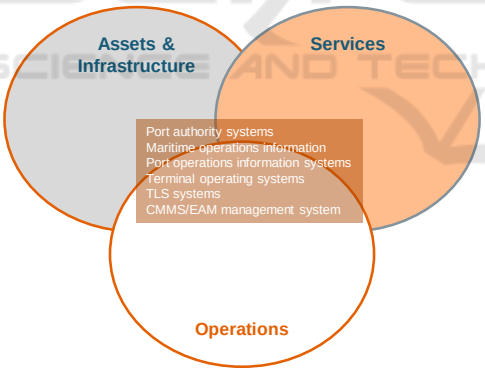

Figure 1: A framework for customer value creation.

3.3.1 Data Sharing for Quick Response

One of the focal bottlenecks of operational decision-making are the unpredicted occasions, related to e.g. traffic at the port. Thus, increasing the predictability of the operations by automation and data-driven solutions should be addressed. However, processes for exception handling need to be carefully considered since these activities have significant impact on the systems overall productivity. In their position paper, Rintanen & Thomas state that "*the key to exception handling is a fast detection and understanding of the situation and a swift intervention to get the process moving again*".

It is acknowledged, that one should understand the optimization challenges of the whole logistics chain for better utilization of data for individual optimization or decision-making problems. minimization of the turnaround time for the vessels, early sharing of information and minimization of the lead times for stakeholders, optimized and flexible use of the assets, fast reaction in exception management situations, minimization of the amount of housekeeping and operational delays.

3.3.2 Availability Performance and Resource Utilization

According to the recent study of Cederqvist, optimized maintenance, "automated terminals today are achieving on-demand equipment availability close to or above 99%". It is also stated that compared with manual operations, automated operations have a decreasing effect on the failure rates, resulting in lower maintenance costs.

Adoption of predictive maintenance technologies for port assets is still rather limited. A combination of failure diagnostics and predictive maintenance selected for the assets based on their criticality may decrease the mean time to restoration and the unavailability. It is proposed that decisions on new solutions are made by considering the minimization of the lifecycle costs by joint optimization of a) maintenance costs, b) maintenance investments, c) unavailability costs.

3.3.3 Performance-based Business Models

Business models for ensuring the availability performance of the assets are changing. There is a change towards capacity selling where a service provider is expected to take larger responsibility and is also required to better understand the variety of aspects influencing the performance. However, the business related to port environments is traditional and the change towards more holistic services is slow. Value-sharing contract could offer a potential solution for the problem that emerges from high cost of automatized machines (Kortelainen et al. 2019).

3.4 Enablers for Container Terminal Optimization through Automation and Digital Services

This far, higher level automation has been implemented mostly in the container handling systems of large ports. However, the level of automation could increase in all sort of container handling systems if automated solutions could provide lower lifecycle costs than the manual options.

Adoption of automation technologies at smaller ports is still a challenge from the cost-benefit perspective. Re-design is needed for the automation solutions to make them fit for smaller ports.

Major share of the new automation installations take place as brownfield investments since greenfield harbor investments are seldom. When existing installations are automated, special service offering is required to design and plan the replacement in such a way that costs and efficiency are optimized. There is also an increasing demand for thinking the re-use of the previous assets. Processes for installations need to be developed also to minimize interference with the terminal operations.

3.5 Factors Slowing down the Development of Automation

The terminal asset base can be very different in age, purchased from different vendors. This may hinder the consideration of the processes as a whole while automating them. Customers may have limited understanding on automation, which also impacts on the collaboration interests and capabilities.

Current technologies for automation are primarily suitable for repetitive tasks, while complex and varying tasks are more challenging for automation. However, the increase of the automation level brings predictability, planning ability and thus decreases the need for disturbance management. However, one of the key benefits comes from the development of the processes while automating them.

Chu et al. 2018 state that the lack of a structured, standardized and transparent data is a bottleneck for making most of digitalization at port environments. If the business needs and decision-making and optimization targets of the port as a whole are not thoroughly understood, the full utilization of the data cannot take place. Anwar et al. (2019) recognize the lack of *"empirical research on information exchange between the teams on ground and decision makers".*

4 SUMMARY OF THE IDENTIFIED DEVELOPMENT AREAS

We highlight the following topical issues and focus areas related to increasing the automation level and development of digital services.

Domain knowledge from R&D and services as well as understanding of the physical phenomena and system level thinking should be combined with analytics expertise when processing and refining the data received from different sources. The integration of the domain knowledge and deep experience is currently seen as a bottleneck in developing maintenance analytics. Lack of collaboration between software developers, data analysts and domain experts may concern the development of digital services at a more general level as well.

While there are still challenges in acquiring data from machines, logistics, and processes to be utilized for maintaining, operating and optimizing the systems as well as in creating data-driven services as described above, there is also a variety of non-technological challenges. Thus, development of data-based services is still rather internal-driven and stronger customer involvement is needed. Furthermore, the machinery suppliers and vendors have still not systematically structured their portfolios of data-based services.

Utilization of data offers a variety of opportunities from logistics chain optimization to machine level aspects. From the port environment perspective, we highlight the importance of the development of the overall efficiency of the port, fleet performance optimization and energy consumption optimization.

While in large ports and greenfields full automation may be designed right from the beginning, in smaller ports and brownfields the automation investments need to be carefully focused. The most important factors in the development of the solutions for small and medium-sized ports are the scalability and cost-efficiency of the proposed solutions.

For automatization of small and medium sized ports, small volumes without standard cargo, and machine fleet with multi-function work cycles make them difficult areas for full automation. From safety perspective, full automation is a desired option when compared with mixed traffic where regulation requirements and costly situational awareness systems bring challenges. However, for small and medium-sized ports, mixed traffic solutions are to be emphasized. Furthermore, alongside with larger

terminals smaller terminals are also facing increasing demand for productivity in the near future.

There may be a need to reconsider business models towards circular economy with regards to brownfield investments where one needs to manage the end-of-life and potential re-use models of the previous installed base. Furthermore, one needs to develop efficient operational models for implementing the investment at port so that the operational efficiency is not threatened.

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