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Life cycle feasibility of a new type of container handling system

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Abstract

Container handling at container terminals can be done with several old and new types of container handling systems, like straddle carriers or Automated Guided Vehicles and Automatic Stacking Cranes. A third type is introduced, based on units with a frame and a belt that runs around this frame by two rolls. This study investigates the economic feasibility of the new system by comparing it with the other two by means of a cost effectiveness analysis over a 20 year period. It was found that the new system is a feasible alternative, so the development of this system should be continued.

1 Introduction

Traditionally the logistic process of handling containers at a deep-sea container terminal starts with quay cranes that put the containers on the quay for further transport into a containers stack with for instance straddle carriers. A more advanced and also proven container handling system uses Automated Guided Vehicles that each will position itself under the quay crane and automatically transport the container towards a stack lane, where an Automatic Stacking Crane will place the container in the container stack. In this study a third type of container handling system is introduced, based on several units that consists out of a frame and a transport belt, that runs around this frame by two rolls. The quay crane puts the container on the transport belt that will roll the container into a stack lane, where a special designed Automatic Stacking Crane will place the container in the container stack. The aim of this study is to investigate the economic feasibility of

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this new container handling system by comparing these three systems by means of a cost effectiveness study for a period of 20 years. ECT (Europe Combined Terminals) the largest container handling company in the Port of Rotterdam agreed to provide the necessary data for the two existing systems. The engineering company (ILS) that designed the transport belt system provided the other input data.

2 Container handling systems

The container as a containing unit makes it possible to transport cargo around the world in a unified way, and container handling systems are put in operation to facilitate the de-coupling point in the world wide cargo flow. Containers vessels, with a carrying capacity up to 6000 Twenty-foot Equivalent Units (expressed in TEU's) travel in line-services over the world. A container vessel stores containers (generally 40 feet containers) in the holds between vertical guides that provide sea-fastening of the cargo without special means and also guide the containers when being loaded and unloaded. This latter is done in a vertical sense either by cranes mounted in board or, more general, by special container quay cranes. Also above deck special cells that can hold containers are available, which make the stowing of the cargo much faster (Atkins, et.al.[1])

The sizing of container vessels is important for the right scale-advantages. On routes like those from Europe to Singapore or New York very large container vessels travel in line-services. During their stay in Europe vessels will only stop at one or two deep-sea ports, otherwise they will loose to much time in a port. To reach this very short turn time in a container terminal, loading and unloading is limited to one or two days at the most. Container vessels are relative fast and the loading and unloading time in a port is often the bottle-neck in the total logistic and transport process of these container vessels. To load and unload large container ships in a very short service time is one of the competitive advantages a container port can have. The above situation makes it clear that innovation in container handling systems and the materials and equipment they are made off, is essential for container liners, ports and its stevedores. All the equipment infrastructure and services provided are focused towards achieving maximum efficiency when handling these containers.

The container stack is the de-coupling point in the loading and unloading process, and can be seen as a separate part of the container handling system. But if the equipment at both sides of the container stack is the same, sometimes scaling advantages can be made. Currently the following four types of container handling systems are most widely used in the port of Rotterdam: (1) Container Handling Systems with Reach-Stackers, (2) Container Handling Systems with Straddle Carriers, (3) Container Handling Systems with a Multi Trailer System (MTS) & Straddle Carriers, and (4) Container Handling Systems with Automated Guided Vehicles and Automatic Stacking Cranes. Besides a new type of container handling system only the two last systems will be compared and briefly discussed.

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3 Innovations in container handling systems

Competitive advantages between container terminal operators is on speed and cost. Ocean liners only choose one of several container ports on a continent and want as less disturbance as possible. Innovations are of the utmost importance for container terminal operators. Some operators belief in flexibility and operate container terminals with straddle carriers, other believe in automation, also driven by the high wages of container terminals personnel in the Western seaports and experiment with fully automated container handling systems for loading and unloading container vessels with capacities of 8.000 TEU and 10.000 TEU in a reasonable time slot are analyzed, such as FAMAS (First, All Modes, All Sizes).

In 1997 Intermodal Logistic Solutions (ILS) a small firm specialized in new maritime and logistic engineering solutions, designed a container handling system under the name of Promoteus. Promoteus is a fully automated system for the transport of containers from a quay under a portal crane to its designated positions in the stack. Transport from the quay position is performed by putting a container on special units that consists a construction frame and a special designed transport belt, that rolls around the construction frame, like a conveyer one might know from baggage handling systems on airports. The units are put in-line with each other in lanes in several directions. When the container is in the stack, a special designed Automated Stacking Crane will take the container from the belt to place it at their designated stack-position. Normally (in the case of the AGV-ASC system) containers are stacked in the length direction. With the ASC needed for the Promoteus system, containers are stacked in the opposed direction. Each of the transport belts is operated by an electromotor. The length of a transport belt is 40 feet, for a 40" container, but can also hold smaller containers. The concept is extendable to very large container terminals and probably useful when large volumes and personnel costs are high.

4 Economic feasibility study based on life-cycle costing

The research question is: *"Is the Promoteus container handling system a feasible alternative compared with the straddle carriers system and the AGV-ASC system?"* The inbound flows and the way the containers enter the process, as well as the outbound flows and the way the containers leave the process are kept the same. In reality the three systems have their own characteristics, and advantages and disadvantages in the way the inter-modal handling is organized, but these are set aside in the analysis.

In this research an economic feasibility study of the Promoteus system was performed by making a Cost Effectiveness and/or Life Cycle Cost comparison between this Container Handling System and those based on Straddle Carriers and Automated Guided Vehicles together with Automatic Stacking Cranes. As is often the case with durable exquipment, see for example Blanchard [2], the investment

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costs in container handling systems are very high, but the operating and maintenance costs of the container handling systems are much higher, especially when both are considered during the time these systems are planned to operate, namely for a period between 10 and 30 year. In such a case, a life cycle cost calculation will provide better results than a simple calculation based on return of investment. The cost-effectiveness of the three systems is compared for several realistic yearly throughputs. The results give a clear, but of course not a very detailed picture of the competitiveness of the three container handling systems.
After several discussions with the initiators, it was decided, that Promoteus was to be compared with two container handling systems already operational with container terminal operators in the port of Rotterdam.
Straddle Carriers (gasoline/electric): (1) Transport from the container vessel with a portal crane with a theoretical maximum capacity of 60 containers per hour; (2) Transport between the vessel/quay and the container stack with straddle carriers; (3) Transport in the container stack for repositioning if necessary and to different non-quay side modalities (land or water) with straddle carriers.
AGV-ASC: (1) Transport from the container vessel with a portal crane with a theoretical maximum capacity of 60 containers per hour; (2) Transport between the vessel/quay and the container stack with unmanned (pre-scheduled) Automated Guided Vehicles and a transponder grid; (3) Transport in the container stack for repositioning (if necessary) and to different non-quay side modalities (land or water) with standard Automatic Stacking Cranes.
Promoteus: (1) Transport from the container vessel with a portal crane with a theoretical maximum capacity of 60 containers per hour; (2) Transport between the vessel/quay and the container stack with transport belts (units); (3) Transport in the container stack for repositioning (if necessary) and to different non-quay side modalities (land or water) with heavy Automatic Stacking Cranes.

5 Life cycle cost model

5.1 Building the LCC-model

The life cycle costs of the container handling system are defined as: *"All costs that may be caused by the container handling system or all the costs that may arise for the organization by operating the container handling system, to keep the container handling system in a desired state, during the whole life cycle of the system from the first conceptual ideas of the system till the system's end of life."* For the economic feasibility study a life-cycle costing tool is developed tool for the necessary calculations. During the development of the Life Cycle Cost Model the following six steps were performed:

1 Divide the container handling process in the following activities:
  - transport activities from quay to stack;
  - positioning the container in the designated stack position;
  - taking the container from its stack position;

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- transport and placement of containers on outbound modalities.

2 Make a Hard Ware Breakdown Structure (HBS) of the system;
3 Model the HBS for all the life cycle phases in the LCC-model:
4 Define the cost equations for all distinguished parts of the LCC-model;
5 Gather all date necessary for the variables for use in the LCC-equations;
6 Perform the necessary LCC-calculations and LCC-analysis.

5.2 Data gathering

To acquire the necessary data for the input of the LCC-model real life data was elicited from interviews and documents of two comparable container handling systems of the same organization, namely ECT in Rotterdam. For the gathering of LCC-data for the Promoteus system, design data and data of suppliers of known sub-systems was used.

5.3 Starting-points of the capacity calculation

Before a life cycle cost calculation can be made the necessary maximum capacity and the operational aspects of the process have to be defined. This means that the speed of the individual equipment items have to be calculated and the distances and heights the containers have to be transported within the container handling system have to be known. Besides the operational capacity the availability of these systems have to be known in respect to the maintenance requirements of each of the systems. Results of this calculation is a detailed configuration of number, position and capacity of the total basis container terminal and the equipment that is part of it.

Normally there is no limitation of transporting a container from the position of every portal crane to a stack-position. In this study two basis terminal were configured, each operated by four portal cranes and a container handling system that will move the container to a stack position of the container stack that is directly related to the two portal cranes. So two separately functioning basis terminals are modeled. The LCC-model and the made calculations are a combination of two of the same basis terminals. Each basis terminal has covers an area of 360 meter quay length, enough for 4.000 TEU container vessels, and 500 meter broad for container handling movements and the container stack. The strip between quay and the beginning of the stack is 90 meters. The capacity of the container stack of each basis terminal is 10.000 TEU, at least 5.000 containers (40" containers). Stacking height of the stack is three containers. The containers have maximum platform dimensions of 12 meter x 2,5 meters.

The dimensions of the each total container handling system are enough for a handling capacity of 900.000 container moves each year, for the two quay locations equally spread over the year or sequentially processed. The maximum capacity of the container handling system is operational when both portal cranes are used and operating at full capacity. In the model two basis container handling

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systems are dimensioned to this maximum capacity. Quay peeks and inland stack peeks are sometimes simultaneously. To make this possible the container handling system is over-dimensioned with an additional capacity between 20% and 25% depending on the configuration and capacity of the subsystems or separate equipment. In the chosen configuration two vessels can be processed simultaneously. To make this possible two times four portal cranes must be available for each basis terminal, each with a theoretical capacity of 60 container moves per hour. In the model the capacity is set to a more realistic operational capacity of 50 container moves per hour. So one container move every 72 seconds.

5.4 Basic terminal with straddle carriers

The average transport distance a straddle has to travel from the portal crane to the stack position and back is 810 meters. The average speed for covering this distance is 268 seconds. The input for the system is one container every 72 seconds. The minimum capacity is 15 straddle carriers. If an additional capacity of 25%-30% is added; the capacity should be 18 straddle carriers for each basis terminal. Due to maintenance the system needs reserve capacity. The MTBF (Mean Time Between Failure) of a Straddle Carrier is 530 moves. These Straddle Carries will be replaced immediately, and repaired during another period. The time necessary to replace the Straddle Carrier is expressed by the MTTR (Mean Time To Repair), and is 30 minutes. To keep the container handling system within the necessary additional 20% capacity an extra Straddle Carrier is needed. Total for a basis container terminal operated with straddle carriers, 19 pieces of this equipment are necessary.

5.5 Basic terminal with AGV's and standard ASC's

The theoretical minimum and maximum number of stack lanes for the basis terminal with a driving space of 90 meters, with the given dimensions and a capacity of 10.000 TEU is receptively 9 and 14. The capacity of a stack lane and its Automatic Stacking Crane is determined by the average time of the ASC to pick up a container from the AGV and put it at an average stack position. If enough AGV's are used, the ASC does not have to wait to place a container on an AGV. If the number of necessary ASC's is determined, the capacity of the 10.000 TEU determines the depth of the container stack. The average distance an ASC has to travel is determined by the depth of the container stack. Together with an additional capacity between 20%-25% all ASC's together will have to transport a container every 14.4 second. A calculation showed that 12 stack lanes are needed to reach this capacity. The MTBF of an ASC-standard is every 1.122 move. Non-functioning ASC's will be replaced within 15 minutes (= MTTR). Also with the possible extra capacity for the MTTR the 12 stack lane just stays above the additional capacity of 20%, so 12 stack lanes for each basis terminal will be sufficient. After the minimum capacity of the ASC's stack lane configuration is determined the number of necessary AGV's has to be found. The average distance

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an AGV has to travel is 280 meters. With the average speed, time an AGV stands still under the portal crane or ASC, this would add 20%-25% additional capacity 19 AGV's for each basis terminal will be sufficient. The MTBF is 1.480 moves. The MTTR is 12 minutes. The MTTR does not lead to an additional AGV, so 19 AGV's are sufficient for each basis container terminal.

5.6 Basic terminal with promoteus roller belts and heavy ASC's

For the Promoteus system the capacity of the heavy ASC's and its stack lane configuration have to be determined first. The available space on a basis container terminal determines the minimum and maximum possible number of stack-lanes. We can use the minimum of 3 stack lanes, if the total available depth is used and 5 stack lanes, it the total available length is used. Because an very innovative control system will be used together with the Promoteus system, the ASC only has to travel 20% of the stack length every container move. The configuration with 5 stack lanes has an additional capacity of 4,7%. The MTBF of the heavy ASC's is estimated at 1.122 moves. This situation would lead to the fact that actual 6 ASC's would be necessary, though on the hypothetical available space, there is only room for 5 ASC stack lanes, and with 6 ASC's the ASC-system would be heavily over dimensioned. Because the Promoteus is still in the preliminary design stage, another interview with the possible developer of this not yet existing ASC was held. Concluded was that the average speed could most probably increased. In the LCC-calculation the basis terminal was estimated to operate with a 5 stack lane configuration. The average speed of the transport belt system is estimated at 0.5 meter per second. On the average 175 meter have to be covered. So every container needs on average 350 second to reach its stack position (that is position under the ASC). Every 1.000.000 movers all transport belt units have to be replaced. The basis terminal configuration needs a total capacity of 663 units.

6 Life Cycle Cost Analysis

6.1 Design of the model

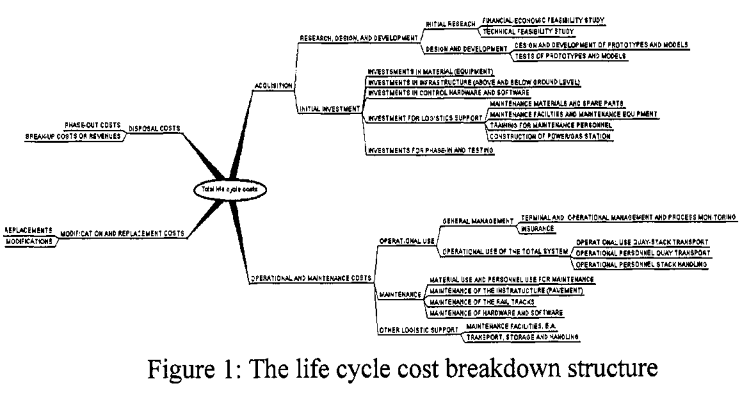

Figure 1: The life cycle cost breakdown structure

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For all three alternatives; the phases, all means, all activities are part of the LCC-model. Three scenario's are included in the model, namely a 300.000, a 600.000 and a 900.000 container moves per year scenario. Also included in the model are all the necessary equipment, the necessary personnel to operate the terminal and the maintenance facilities necessary for the repair of the equipment. The figure below summarizes the costs that are included in the LCC-model. Some cost are found by the total of others, but on the lower levels in the Cost Breakdown Structure each cost-item contains an equation with several input variables, see the figure 1.

6.2 Gathering the necessary data and designing the LCC-model

The eventually designed LCC-structure represents a generic structure that can be used for all three alternatives. At the start of the study it was assumed that the availability, detail, and reliability would be much higher, than it actual was. The development of the LCC-structure and investigating the availability and quality of the necessary data turned out to become an iterative process. The iterative approach resulted in a more realistic LCC-structure and outcome of feasibility analyses than the use of a full generic LCC-model would give.

6.3 Types of LCC-analyses

After the first set of calculations it turned out that cost for operational personnel is very high, if this personnel would be available 24 ours a day the whole year. The container handling process is more a peak related process. Some days it is very busy and some days there are no vessels to handle. In reality such as is the case in the port of Rotterdam, only a part of the personnel is on the pay-roll of the container terminal company. To analyze the effects of the cost of the operational personnel, three types of calculation were performed, the last one being the most realistic.

- all operational personnel is permanent and actually on the pay-roll of the container terminal company;
- all operational personnel is flexible and will be hired if there are vessels;
- 70% of the operational personnel is permanent and 30% of the operational personnel is flexible (note that from the overall personnel costs approximately 75% is operational and 25% is supportive).

It should be emphasized that a full LCC-analysis was not performed, but only the differential costs were compared, so the real cost will be higher. The following tables show some results.

Costs per container move with 100% permanent operational personnel

Number of moves	Straddle Carrier	AGV-ASC	Promoteus
A 300.000	f 227,25	f 137,85	f 124,45
B 600.000	f 117,03	f 71,67	f 65,40
C 900.000	f 80,29	f 49,60	f 45,72

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Costs per container move with 100% flexible operational personnel

Number of moves	Straddle Carrier	AGV-ASC	Promoteus
A 300.000	f 63,24	f 68,90	f 57,33
B 600.000	f 42,64	f 37,40	f 32,97
C 900.000	f 35,77	f 26,90	f 24,85

6.4 Conclusions from the LCC-calculations

From all the comparisons and analysis can be concluded that the Promoteus system has the lowest life cycle costs. The tables show the costs per container move for the 100% permanent and the 100% flexible alternatives of the three scenario's. The costs per container move are the lowest for the Promoteus system and the highest for the Straddle Carriers for the 100% permanent. If personnel cost increase the AGV-ASC and Promoteus container handling systems are better solutions. The costs per container move for the 100% flexible and 300.000 container moves per year are the lowest for the Straddle Carriers. If personnel costs are lower the Straddle Carrier alternative may also be better for 600.000 container moves per year scenario. The cost of Promoteus system are 10% lower than the cost of the AGV-ASC system. Only detailed analysis would show the real differences between these two systems.

The total throughput in containers moves per year is the main revenue driver. The cost do not increase significantly with each container move. This is certainly the case in the 100% flexible scenario.

The operational and maintenance costs cover the larger part of the life cycle cost. The acquisition costs are not significant in the 100% permanent personnel alternative, they only make up 10% to 20% of the total costs. In the 100% flexible personnel alternative they become more important. The acquisition costs of the Promoteus system are the highest. But because the system is still in its preliminary stage the possibilities to use for instance value engineering and try to redesign the system or components of the system, to make it less expensive with the same functionality, is still possible. The disposal costs of all container handling systems over the total of 20 years are of no real significance. If the percentage of permanent personnel is high the costs of the straddle carrier system become unacceptable high. Straddle carriers are more competitive in countries with low wages.

6.5 Other comparisons

During the total research also other cost related aspects were included in the comparison of the three container handling system. The main conclusions are:

- The surface area requirements for the AGV-ASC system are the lowest;
- The Promoteus system needs 7% more space than the AGV-ASC system;
- The straddle carrier systems has the shortest through-put time;

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- The through-put time of a container for the Promoteus system is three time the time needed for the straddle carrier system, but this does not influence the capacity because the transport belt functions as a moving buffer in the system;
- On-manned container handling is safer than manned container handling;
- Because of the powered by electricity and a more environmental friendly system than the other two, the straddle carriers has the highest CO2-emmisions.

7 Conclusions & recommendations

7.1 Conclusions

The LCC-calculations showed, that the life cycle costs of the Straddle Carrier Container Handling System (above +/- 400.000 container moves per year) are the highest (for both the 100% permanent and 100% flexible personnel alternative).
The life cycle costs of Promoteus are between 8%-20% lower than the cost of the AGV-ASC container terminal. Based on calculation performed and the reliability of the input data this difference is not very significant.
Looking at the criteria for the scenario's in relation with the necessary 20%-25% percent additional capacity it can be concluded that the Promoteus system needs a quay length above the 360 meter, and an additional heavy ASC to provide the necessary capacity. With this capacity the Promoteus system may handle even more than 1.000.000 containers per year without trouble.

7.2 Recommendations

From the calculations and comparisons must be recommend to advance in the design and development of the Promoteus system. It is worthwhile to construct a test side were a small number of Promoteus transport belt units can be tested for their performance and RAMS-requirements. The results of this study were shared with ECT, the organization that provided as with the larger part of the data. It is recommendable to perform a more detailed LCC-analysis in joint research between ECT and the developers of the Promoteus system. The author sees great potentials for the Promoteus container handling system.

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