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Simulation-based Operational Control of a Dry Bulk Terminal

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Dry bulk terminals, located near the deep sea, are used all around the world to handle large quantities of bulk materials, like coal and iron ore. Bulk materials are transported within the terminal using routes of interconnected belt conveyors. Due to several sources of uncertainty, such as the delays of ships and trains and disturbances of terminal equipment, selecting routes is complicated and is now predominately based on the human operators' experiences. This paper focuses on route selection to transport the materials. A decision support system is proposed that assists a human operator in making the best decision. The proposed, so-called Dynamic Planner consists of a primary simulation model, that simulates the dynamics of the terminal, and within this primary simulation model, a secondary simulation model that simulates and proposes routes. The Dynamic Planner can be a useful tool for assisting terminal planners to select routes on forehand or to present alternative routes if a conveyor or machine breaks down. Practical experiments are carried out in order to assess the performance of the proposed Dynamic Planner. It is found that the determined routes generally correspond with at least the routes selected by the human operator, while in some cases even providing better alternatives.

Keywords: network of belt conveyors, dynamic planning, route selection, discrete-event modelling, dry bulk terminals.

I. INTRODUCTION

Dry bulk terminals are part of deep sea ports all around the world. These terminals transship large quantities of dry bulk materials like coal and iron ore. Dry bulk terminals are used worldwide as a buffer between an incoming flow and an outgoing flow of bulk materials such as coal and iron ore [1]. The purpose of dry bulk terminals is to store the bulk materials temporarily for their clients, coal-fired power plants or steel factories. In addition, the stockpiles at the terminals enable transportation facilities, such as sea transport or land transport by trains or trucks, with different times and rates of operation to function independently of each other, and hence, to avoid delays caused by one facility having to wait for another [2].

Fig. 1 shows an aerial view of a dry bulk terminal, in this case EMO, the largest dry bulk terminal in Europe [3]. This particular terminal is specialized in the unloading, storage and loading of iron ore and coal. These products arrive from all over the world and are mostly transshipped to the inland of Western Europe, especially Germany.

FIGURE 1: AERIAL VIEW OF A DRY BULK TERMINAL [3]

In a typical dry bulk terminal, large cranes grab material out of the sea-going vessels and dump the material via bunkers onto belt conveyors which transport the material to the stockyard. At the stockyard, large machines stack the materials on piles. After a certain time of storage, the material is reclaimed and transported again with belt conveyors to loading stations for barges or trains. After being loaded in a train or barge, the material continues its way to the end customers.

The operational control of a dry bulk terminal is complicated. This complication arises due to (i) a difference between the expected and the exact arrival time of vessels, trains and barges which makes it difficult to plan activities and (ii) the machines and conveyors can break down unexpectedly. Within a dry bulk terminal, bulk materials are transported using routes of interconnected belt conveyors. An important aspect of the operational control is selecting the best routes out of large number of possible routes.

The purpose of this study is to develop a decision-support system, called the Dynamic Planner, for support a dry bulk terminal. The Dynamic Planner must be understood and accepted by the terminal operators. Through extensive interviews with operators, the requirements for route selection are determined. These requirements are subsequently translated into filters that are used within the decision-support system. The decision support system proposed is a first step and makes it easier to apply more advanced methods in the future.

This paper is organized as follows. Section II discusses the difficulties of the operational control of dry bulk terminals. The structure and details of the Dynamic Planner proposed here are given in Section III. Section IV investigates the potential of the Dynamic Planner by comparing the selection of routes by the human terminal planner with the routes proposed by the Dynamic Planner. Section V provides conclusions and directions for future research.

II. Operational Control of Dry Bulk Terminals

Serving the sea-going vessels, i.e., loading and unloading vessels, and providing the right amount of dry bulk at the right time to the right barge (ship which sails at inland waterways) or train on the landside are the main tasks of dry bulk terminals. Bulk materials are transported from the seaside to the stockyard or from the stockyard to loading stations using a route at the terminal. A route consists of several conveyors, and many routes are possible to transport material. When selecting a route, several sources of uncertainty have to be taken into account, both on the seaside, internally, and on the landside of the terminals.

A. Sources of uncertainty

At the seaside, dry bulk materials are imported to or exported from the terminal by sea-going vessels. The arrival process of vessels exhibits a stochastic behavior, which means that the exact arrival time differs from the expected time of arrival (ETA). The ETA is agreed upon by the terminal operator and the ship-owner at least one month in advance. In most cases, the terminal operator receives an update of the ETA weekly from the ship-owner directly or by checking the ships' actual global position. The ETA changes often, due to bad weather conditions, swells and other natural phenomena due to unexpected failures or stoppages during sailing. Ship-owners and terminal operators also agree on the maximum time a ship will lay in the port (port time). If the port time of the sea-going vessel exceeds the agreed port time, the terminal operator has to pay demurrage costs to the ship-owner even if the vessel does not arrive on time. To investigate if the terminal is able to serve the vessels without paying too many demurrage costs even if vessels arrive later, the planning of terminal activities, like selecting the berths or routes, has to be updated continuously.

At the landside of the terminal, the terminal operator has more possibilities to control the arrival time of trains and barges. However, several circumstances, like the delays of trains on the public rail system or blockages of barges on rivers or at locks, also cause a difference between the actual

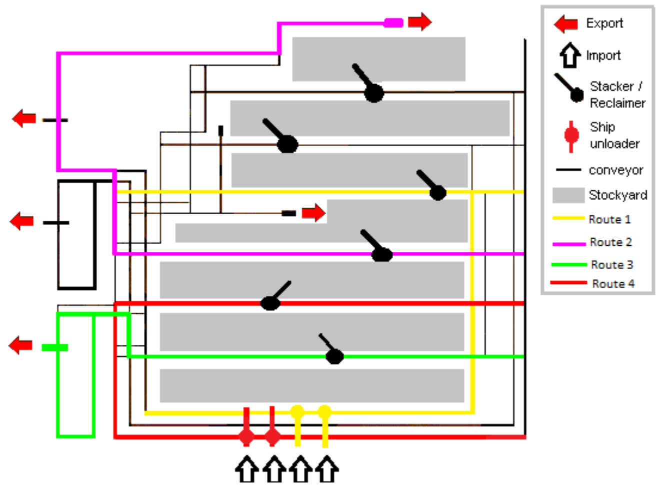

Figure 2: Network of belt conveyors

arrival time and the a priori expected arrival time, and thus will influence the operations at the terminal.

Large machines and a large number of belt conveyors are used for handling the materials. These machines break down from time to time. To prevent large stoppages due to technical malfunctions, preventive maintenance is required. Because these terminals operate almost 365 days per year and 24 hours per day, the maintenance of conveyors and machines has to be scheduled and taken into account in the operational control.

B. Operational control problem

A typical dry bulk terminal has a (complicated) network of belt conveyors, see Fig. 2 for an example (representing the network of belt conveyors at the EMO terminal). A route, which consists of a chain of interconnected conveyors, must be selected for transporting materials from the ship unloaders to the stockyard or from the stockyard to the loading machines. In order to be able to import and export the required annual volume of bulk materials, multiple routes can be active at the same time. Fig. 2 shows an example in which four routes are active at the same moment, although five or even six active routes operating simultaneously is no exception.

Currently, routes are selected by a terminal planner, a human operator. Because of all uncertainties, selecting routes in advance is unusual. The terminal planner selects a route at the moment a sea-going vessel, train or barge arrives at the terminal. A route consists of a start point and an end point. If material is imported into the terminal, the start point is one of the ship unloaders and the end point is one of the stockyard machines. For exporting materials, the start point is one of the stockyard machines and the end point is one of the loading machines. It is assumed that the start points and the end points are determined by the terminal planner and given as input for the Dynamic Planner. The terminal planner also considers the scheduled maintenance and the disturbances of the machines and conveyors.

Nowadays the selection of routes hardly takes into account future orders (materials that have to be transported) as a continuously updating of the planning is considered undesirable by the human planners. Thus it can happen that a route is selected which would better have assigned to the next order. This may cause unnecessary changeovers during one order or the use of less efficient routes.

Therefore, a dynamic planning approach is proposed in which all the above mentioned circumstances and complications are taken into account. Such an approach will help the planner to select routes.

III. SIMULATION-BASED DYNAMIC PLANNER

Section II made clear that a lot of parameters have to be considered when determining the routes. Because of the uncertainty in the arrival processes, disturbances of equipment and the variation in the duration of time an order takes, simulation can be a useful tool for selecting routes. The approach taken here is to select for all the materials which have to be transported (orders) for a certain period of time (planning horizon) routes, based on certain criteria.

A. Implementation

A discrete-event simulation package TOMAS [4] is used for logistics modeling. An important advantage of using TOMAS is that all elements with corresponding attributes can be programmed which results in no restriction in the simulation design. TOMAS is implemented in Delphi 2010 [5] and is based on a so-called process oriented approach [6]. This is a description method in which several events (state changes) are combined into a single process.

The Dynamic Planner is implemented taking into account the following requirements, motivated by input from human terminal planners of the company EMO:

- Use a network of the terminal with conveyors and machines.
- If a type of equipment breaks down, the following actions should be possible: wait until the disturbance has been solved, select another route, or select another machine.
- The determination of the duration of time an order needs must be based on experimental data of the terminal operators.
- Take into account that orders can be delayed or can finish earlier than planned.
- Plan again if new orders are being added during the planning horizon.
- Minimize the number of changes between routes for one order and minimize the number of changes of the seaside conveyors, which takes a lot of time (~45 minutes).
- Deal with priorities of orders; sea-going vessels have absolute priority because of the demurrage costs.

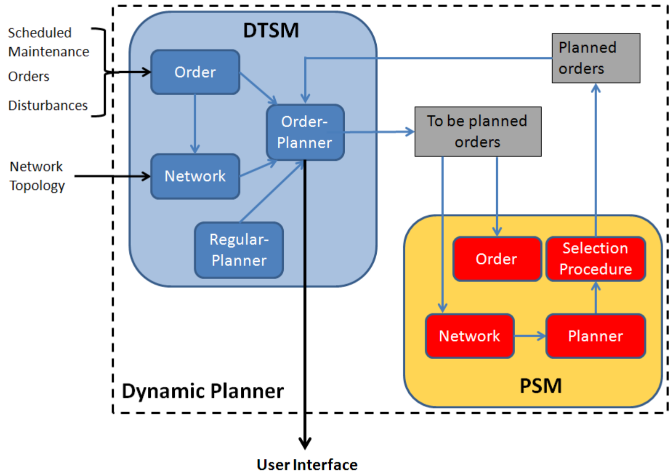

FIGURE 3: DYNAMIC PLANNER

The Dynamic Planner must determine the possible routes per order and uses a certain selection method to rate all possible routes and select the best ones. A simplified representation of the Dynamic Planner is shown in Fig. 3. The Dynamic Planner consists of the '*Dynamic Terminal Simulation Model'* (DTSM) and the '*Planning Simulation Model*' (PSM).

The Dynamic Planner uses as input the scheduled maintenance, future orders which have to be planned, the disturbances and the network topology, like the locations at the terminal and the capacities of conveyors and machines. The output of the Dynamic Planner is a User Interface which shows the network of the terminal and the proposed routes for the planned orders. This will help terminal planners to select the right routes in the real-world situation. Fig. 5 shows an illustration of the User Interface.

The Dynamic Planner consists of two simulation models which communicate with each other, the DTSM and the PSM. The DTSM simulates the real-time situation of the terminal. In the DTSM, the following main functions are implemented:

1. Order: the orders for which routes have to be selected are given as an input. The orders contain attributes like the priority of that order, the start time, the required start point and the end point, the material type, transport speed, etc. A scheduled maintenance or a disturbance is also used as an input.
2. Network: the total network of the terminal is loaded by reading the Network topology and together with the information about the scheduled maintenance and disturbances, the available network is determined.
3. OrderPlanner: the OrderPlanner sorts the orders and together with the data about the available network, it generates a set of orders to be planned. This set is also generated if a new order has to be planned or an active machine or conveyor breaks down or when the planning horizon elapses. The planned orders of the PSM are

imported, after simulating and selecting the best routes, in the OrderPlanner and shown in the User Interface.

4. RegularPlanner: the RegularPlanner is used to activate the OrderPlanner when the planning horizon elapses.

The Planning Simulation Model (PSM) is used to select a set of routes. The set of the planned orders, generated by the DTSM, is used as input of the PSM. Fig. 3 shows the main functions of the PSM:

- Order: collect the data of the orders which have to be planned.
- Network: read the data to determine which network components are active.
- Planner: define for all orders the possible routes and combine these routes into sets of routes. See for an example Fig. 4. For three orders, each order can be served by two different routes, 8 sets of routes are determined and the set of routes which fulfills the best, based on requirements which will be explained later, is selected. In the Dynamic Planner, the PSM is activated after which it will internally simulate all sets, which means that in this case 8 simulations are done to simulate the possibilities for transporting the three orders.

  After the internal simulations, the PSM selects the best set of routes out of many sets of routes using the following evaluation criteria; the total needed time [in hours], the total waiting time of the vessels at the seaside [in hours] and the total amount of electricity required [in kWh]. The first two attributes (total needed time and waiting time) are results of the internal simulation and the third attribute (total amount of electricity per set) is calculated in the PSM after the internal simulation. The total amount of electricity for a set is the sum of the electricity needed for each conveyor to transport the material. The electricity needed per conveyor relates directly to the conveyor length.

- SelectionProcedure: in this procedure the best set of routes is determined from all possible sets of routes based on the three attributes mentioned above (total time, waiting time and needed electricity) and presents these selected sets of routes to the DTSM, which simulates the real-time situation of the terminal and presents the proposed routes to the human terminal planner.

As already mentioned, the set of routes which fulfills the task of the terminal the best has to be selected. The terminals' task is to serve the sea-going vessels, trains and barges to prevent too large waiting times. As mentioned in Section II, the terminal has to pay demurrage costs to the ship-owners if the agreed port time is exceeded. Other tasks of the terminal are (i) to transport the materials at minimal costs and (ii) to minimize the total number of route changes per order. If during an order the route must be changed, the conveyors must run empty for 15 minutes to prevent contamination of materials and the conveyors must be decoupled from each other to realize new routes. These actions take time and can results in disturbances. Another task of the operational control of the terminal (iii) is to minimize the number of changes of the quay conveyors, which takes a lot of time (~ 45 minutes) and may also introduce disturbances.

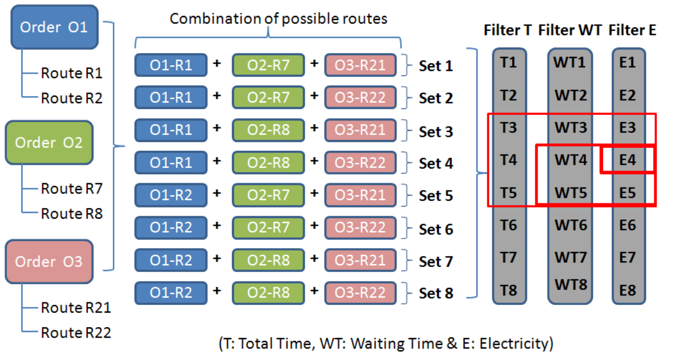

FIGURE 4: DETERMINATION OF THE POSSIBLE SETS OF ROUTES AND FILTERING THE SETS

With the determined attributes per set of routes (the total needed time, waiting time of vessels and the total amount of required electricity) a selection for the best set of routes is possible. The first attribute (needed time) indicates the performance of the terminal, with more needed time, less orders can be handled in a certain time period. But it also indicates the number of changes; the fewer time is required, the lower the number of changes because changes take time. The second attribute (waiting time of vessels) indicates directly the amount of demurrage costs and the third attribute (required electricity) relates directly to the operational costs of the terminal.

All sets of routes are passed through three filters to determine the best set of routes. The first filter (T) selects the sets with the minimum total time. The second filter only investigates for these selected sets the corresponding waiting time of the vessels (WT) and selects the sets with the lowest waiting time. Finally, the third filter evaluates the remaining sets on the required electricity (E) and selects the set of routes with minimal energy consumption. The best set is the set which remains (in Fig. 4: Set 4). If more sets remain at the end, a random set of routes is selected.

The order of the filters determines the selection procedure. Filter E (selection based on required electricity) must be the last filter. This filter will select the set of routes with the shortest length and proposes to put the orders in series instead of parallel. Orders in series result in a longer time to handle all orders and a larger vessel waiting time. The provisional results show that the order of the first two filters (Filter T and Filter WT) does not matter; a set of routes with the minimum needed total time does also results in the minimum waiting time.

B. *User Interface*

Fig. 5 shows the User Interface of the Dynamic Planner, consisting of the network of the terminal depicted in Fig. 2.

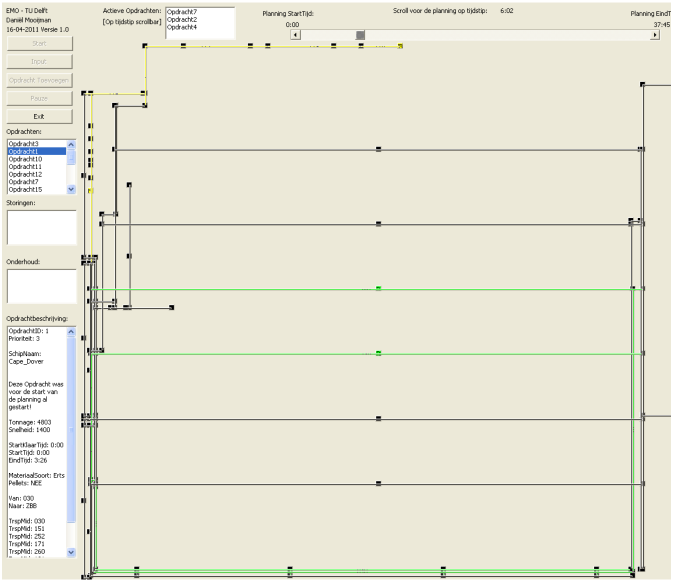

FIGURE 5: USER INTERFACE OF THE DYNAMIC PLANNER

On the left side, the planned orders with extra details are mentioned. If an order is selected, the suggested route is lighted on the network and more details of this route are shown.

The User Interface presents routes for future orders, based on the already mentioned evaluation criteria. The human planner can verify the proposed routes in the near future by using the scrollbar at the top of the User Interface. The orders and proposed routes are updated accordingly. The human planner is relieved from figuring out which route must be selected. Another advantage is that the User Interface can also been used for the terminal operators. With the Dynamic Planner, future routes are known in an earlier stage. Terminal operators can already prepare these routes which will lead to a minimization of the time for changing over to another route.

IV. EXPERIMENTAL EVALUATION

A. *Setup*

During 3 days, the performance of the Dynamic Planner has been evaluated at the control room of the EMO terminal in Rotterdam. This terminal has an extensive network of more than 22 km of conveyor belts and approximately 800 different routes are possible. In 2010, 30 million of tons of coal and iron ore was imported into the terminal by four large ship unloaders [3]. At the stockyard, 6 stacker-reclaimers are installed to stack or reclaim the materials. For exporting bulk materials, three barge loaders and two train loaders are used. During a day approximately 20 orders must be planned by the human terminal planners.

Actual orders of the 3 days are used as an input for the Dynamic Planner and the routes suggested by the Dynamic Planner are compared with the routes planned by the human terminal planner. The planner bases his selection of routes on his many years' experience.

B. *Results*

The following aspects became clear while evaluating the Dynamic Planner:

- In reality orders take a longer time than calculated by the Dynamic Planner.
- The start times of orders as scheduled by the Dynamic Planner differ from reality; the Dynamic Planner assumes that the order starts at the planned time. However, in reality orders are delayed because of paper work, breaks of operators, no machine available, etc.
- For the considered days, the planning horizon does not have to exceed 8 hours. A longer planning horizon is not needed because of the large uncertainties of the arrival of vessels, trains and barges.
- Even with a planning horizon of 8 hours, there may exist many sets of routes. During the experimental evaluation, 18 orders must be scheduled which results in 3136 different sets of routes. Determine the best set of routes has resulted in large computational times of the PSM (~ 6 hours). The Dynamic Planner has to be used dynamically as equipment can break down or expected arrivals postpone. The maximum time of selecting the best alternative route may therefore not exceed 10 minutes. These 10 minutes are considered as acceptable for the terminal planners.
- The most routes proposed by the Dynamic Planner correspond with the routes selected by the terminal planner. However, for a small number of routes the Dynamic Planner suggested better alternative routes to be able to transport orders without changing routes during the duration of an active order, see Fig. 6 for an example. The first order was to transport material from the sea quay to a certain stockyard machine (highlighted in Fig. 6A). However, during this order, material must be transported from another stockyard machine to the train loader. This can only be realized by using a conveyor which was already claimed for the active order. This order was stopped, and an alternative route was selected (see Fig. 6B) after being able to start also the second. The Dynamic Planner had already proposed to use this route for the first order because it already knew that the second order needs this particular conveyor.

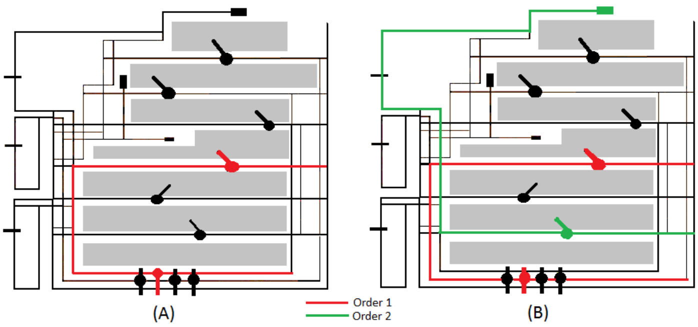

FIGURE 6: A ROUTE IS CHANGED DURING AN ACTIVE ORDER

C. Discussion

The preliminary results of planning orders and routes with the Dynamic Planner at a dry bulk terminal are promising. The Dynamic Planner is able to select routes for orders, while taking future orders, disturbances and scheduled maintenance of certain conveyors and machines into account. Compared with the actual situation, where routes are just scheduled when orders (vessels, train or barges) arrive at the terminal, the Dynamic Planner will assign and reserve routes for orders which will arrive in the near future of e.g. 8 hours. This results in less route changes during an active order which reduces the duration of time for orders, and reduces disturbances and maintenance.

It is expected that when using the filters for selecting the best set of routes, this will result in a lower waiting time of vessels which results in lower demurrage costs and lower energy costs of conveying the material by the belt conveyors. However, an estimation of the exact savings during a year cannot be made yet, as the data of orders with corresponding routes in the past has not been captured. However, already for the examined period, the Dynamic Planner shows already better alternatives of routes compared to the selected routes by the human terminal operator.

V. Conclusions and Future Research

At dry bulk terminals, the operational control is complicated due to several sources of uncertainty, like the delays of ships and trains and disturbances of terminal equipment. Especially selecting the route to transport bulk material from one location to another location is now predominately based on human operators' experiences. If machines and/or conveyors break down, the terminal planner must reschedule immediately to prevent that the lay time of the sea-going vessels exceeds the agreed port time, which results in high demurrage costs.

For the selection of routes for several orders at the same time, a Dynamic Planner is implemented in Delphi 2010 using Tomas. This Dynamic Planner is able to propose routes to the planner taking future orders into account. The Dynamic Terminal Simulation Model (DTSM) represents the dynamic behavior of the terminal (network of belt conveyors, active orders, status of machine and conveyors) and in the Planning Simulation Model (PSM) all possible sets of routes are determined and after an internal simulation, a set of routes is selected for implementation. Three filters are used for selection the best routes. The first filter is the minimization of the duration of time for transporting the orders, the second filter eliminates sets which results in large waiting times of the vessels and through the third filter the set passes with the lowest required electric energy to power the routes.

Tests at the EMO terminal have shown that the Dynamic Planner can help terminal planners to select the best routes. Especially simulating future scenarios and selecting routes based on these scenarios has shown good results compared to the current selection based on experience. However, more effort has to be spent on making the Dynamic Planner faster (to present proposals within 10 minutes) and more accurate to be a useful tool for proposing routes to terminal planners.

Apart from using the Dynamic Planner for planning it can also be used to investigate possible improvements of the conveyor network, which can easily be implemented by adjusting the network topology. An improvement of the terminal performances with a new terminal layout can be investigated by using data of orders that took place in the past.

Future research will focus on the following aspects:

- Investigate if more advanced approaches (e.g., graph-search algorithms, fuzzy-logic or multi-agents systems) can improve the selection of routes in the terminal network. A benefit must be that these approaches could require less computational time to determine the best route. The Dynamic Planner must propose sets of routes to terminal operators within 10 minutes.
- Collect data of actual orders and selected routes, which can be used to tune the parameters of the Dynamic Planner and to use as input for simulation runs to investigate terminal layout improvements.
- Take the actual location of stockyard machines into account, which will result in a more accurate calculation of the energy consumption. Now, the PSM assumes that the stockyard conveyors are filled over the entire length. If the machine is located near the start location of the stockyard conveyor, the material is just transported over a couple of meters instead of the entire length. This may result in another route selection.
- Provide suggestions to the terminal operator when a certain conveyor or machine can have maintenance based on planned orders.

Acknowledgements

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