A Simulation Based Approach to forecast a Demand Load Curve for a Container Terminal using Battery Powered Vehicles

Nico Grundmeier  
Carl-von-Ossietzky Universität Oldenburg  
Oldenburg, Germany

Axel Hahn  
Carl-von-Ossietzky Universität Oldenburg  
Oldenburg, Germany

Norman Ihle  
Carl-von-Ossietzky Universität Oldenburg  
Oldenburg, Germany

Serge Runge  
Carl-von-Ossietzky Universität Oldenburg  
Oldenburg, Germany

Claas Meyer-Barlag  
Carl-von-Ossietzky Universität Oldenburg  
Oldenburg, Germany

Abstract — This article presents a simulation based approach to provide a short-term energy demand load curve forecast in a container terminal. While common methods for forecasting electricity consumption are working well in industrial enterprises with continuous and recurrent production cycles, in a container terminal the processes are highly dynamical. That is why the most common methods are not working well, and a simulation based approach is chosen. If the energy consumption can be forecasted precisely it is possible to benefit from cheaper energy purchase prices. If the container terminal uses battery powered vehicles additional strategies to use the forecast can be employed. One possibility is to reduce the costs by using intelligent strategies for charging the batteries in a battery-exchange station where the energy consumption can be forecasted as well. The important fact is that with the exchange station the load curve can be influenced without interfering in the logistic processes of the terminal because the energy consumption of the transport vessels is decoupled from the logistic processes by the use of batteries. This is why methods like load shifting and peak clipping can be applied quite easily. First, a simulation based approach is introduced to calculate a reliable load forecast of the entire terminal and of the battery changing station. Second, several use cases are presented for how the terminal benefits from this forecast.

I. INTRODUCTION

Industrial customers usually negotiate contracts for energy supply individually with the supplier based on their specific demand situation. These contracts most of the times include tariffs based on time of use and peak loads. In order to do establish these rates long term historical data is commonly used due to lack of any data. With the availability of a more exact prognosis the energy supplier would be able to purchase the electricity more accurately and therefore reduce the risk of price and quantity fluctuations considerably. In the best case a demand load curve can be forecasted exactly. In this case the supplier would be able purchase the exact amount of electrical power at the time of the best price to do so. Due to the dynamic process and uncertainty depending on external factors an exact forecast is rarely possible. Therefore usually minimum or maximum power consumptions or load curve margins are agreed upon between the supplier and the customer. In an industrial enterprise with continuous and recurrent production cycles the forecast can be calculated with rather simple methods like trend- or comparative-, extrapolation or econometric models [1][2]. However in a container terminal the daily processes are highly dynamical depending on the number of ships and containers to be handled. This makes a forecast of the energy demand more difficult than in industries mentioned above. The mentioned methods are most of the times not applicable. Since it is not possible to forecast the energy demand theoretically or based on mathematical rules, a simulative approach is used, which calculates a demand load curve based on the expected number of container handlings, task lists and further influencing factors.

The developed simulation model represents a complete system environment of a container terminal and is therefore able to forecast the energy demand based on the logistical processes of the harbor. This model can be evaluated against the Container Terminal Altenwerder (CTA) which is located within Germany’s largest port Hamburg. Due to the ability to forecast different operating strategies in regard to energy demand can be evaluated and potentials for load shifting can, if profitable, be applied. This can be particularly helpful when some of the heavy duty logistic processes are executed by battery-powered vehicles, which is the case at CTA. With an already planned increase on the numbers of these vehicles
used and the further extension of E-Mobility, the meaning of the energy forecast raises for the terminal significantly due to growing demand of energy.

In the following sections the general setup of a container terminal is introduced. Second, the design of the specific Container Terminal Altenwerder in Hamburg is presented. CTA is the terminal where the energy demand forecast is applied. In the next section the simulation environment to forecast the energy demand is described. First, the general use without electric mobility is shown and then the specific use including electric mobility is presented. In the last section several use cases for possible economic benefits of the energy demand forecast are discussed.

II. CONTAINER TERMINALS

A. System description

Container terminals typically execute many logistical processes, e.g. container loading and unloading from or to vessel and feeder ships for import and export purposes, internal container movement from ships to stacking areas and vice versa, stacking containers in dedicated areas distributed in the terminal area, container inspection for customs requirements, reefer handling and storage, stuffing, etc. All these processes need several shared and reusable resources and equipment, to fulfill the tasks involved in handling and transporting containers: quay cranes (QC) or yard cranes (YC), transport vehicles, yard stacking deposits, automatic stacking cranes or automated storage/retrieval systems, railway tracks, human operators. All processes and operations are usually planned, scheduled, monitored, and controlled by a central control and make use of information technologies, to allow fast ship operations, optimization of the usage of facilities, and the reduction of lag times [3]. To achieve the objective several logistic processes have to be planned and integrated. Figure 1 shows a typical terminal layout.

B. Planning and logistics control challenges for container terminals

Following main tasks have to be planned in the container terminal:

- Berth allocation: Before an arrival of a ship, the required berthing space has to be allocated, taking the expected time the ship spends in the terminal into account. Additional constraints arise from the availability of cranes – not all quay cranes can be operated at all ships - and the berthing and crane requirements of other vessels which already lay at the quay or are expected to arrive shortly.

- Crane split: Various quay cranes can be used to load and unload container vessels. The allocation of the cranes has to be planned. First, it has to be decided which cranes are to be assigned to the sundry ships considering the accessibility of cranes at the berth and the impossibility to passing other cranes at the berth. Second, the cranes operating at one ship have to be assigned to different sections or hatches of the ship.

- Storage planning on container vessels: Shipping lines have to decide which positions within the ship are assigned to a container. Shipping lines not act with specific containers identified by numbers; they act with specific categories of containers considering attributes such as destination, weight or type of the container. E.g. for stability reasons, heavy containers should be stored below containers having less weight. Based on this given assignments, it has to be deciding which container has to be stored at the specific slots within the vessel. The final slot assignment heavily affects the loading and unloading sequence of containers. The final loading and unloading sequence for inbound containers and outbound containers is described by the stowage plan. The unloading and loading sequences represent a major input for determining the yard crane’s, quay crane’s, and vehicle’s schedules [4].

- Storage and stacking logistics: Stacking logistics has become a high importance because more and more containers have to be stored as container traffic grows continuously. Large container terminals in Europe store a total of several 10,000 containers with average storage times of 3-5 days daily. This is resulting in about 15,000 container movements a day. The storage area is separated into different blocks, which are organized into bays, rows and tiers. The policies for assigning individual storage locations and stacking of containers are ruled by the objective to expedite the necessary storage and retrieval operations as fast as possible and to avoid reshuffling on containers within the block. Specific issues include the reservation of dedicated storage areas for import and export containers [5].

- Workforce scheduling: Workforce scheduling is another important task in container terminals. Rosters and schedules for workers to operate equipment must be generated in advance.

Container terminals represent highly dynamic and highly stochastic logistics processes, which do not allow pre-planning of detailed transportation and handling activities for a look-ahead horizon of more than 5-10 minutes. Hence, real-time control of logistics activities is usually used. Real-time decisions include the assignment of transportation orders to vehicles and routing and scheduling the vehicle trips for land-side transportation as well as for transportation between the berth and the storage yard, the assignment of storage slots to individual containers, and the determination of detailed schedules and operations sequences for quay and stacking cranes [6]. This is the biggest problem in forecasting

Figure 1: General example for a terminal layout [3]
the energy consumption of a container terminal.

III. ENERGY CONSUMPTION IN A CONTAINER TERMINAL

Due to the high complexity of logistic processes in container terminals it is very difficult or even impossible to predict the energy consumption by mathematically or analytically methods. Difficulties arise mainly from the unpredictability of vessel arrivals. It is hard to predict whether they arrive in time, too early or too late. Technical problems can lead to misperceptions e.g. due to incorrect storage plans or human factors of influence such as the operating speed of a quay crane leader.

There are different processes that consume energy and are dependent widely on the ship arrivals. If the arrival and departure time of a container vessel is exactly known as well as the procedures in the terminal the logistics processes and the energy consumption can be simulated.

For this purpose it is necessary to know the relevant consumers of the terminal. These are:

- Static consumer like lighting
- Quay cranes and storage cranes
- Consumer on the hinterland
- Refrigerated containers
- battery-powered transport vessels (if used)

If E-Mobility is used, the consumption of the battery-powered vessels has to be added to the list. Either the vehicles are charged directly exchangeable batteries systems are used [7]. At CTA the second case is applied. The transport of the containers from the quay cranes to the stacking area is in parts done using battery powered vehicles. So the following consumer is added: the battery exchange and recharging station.

To gain benefits from the energy forecast it is not necessarily required to forecast the overall energy consumption of all consumers. It is also possible to gain benefits from only forecasting parts, e.g. the battery exchange station, in order to optimize the energy supply. However the overall forecast offers more possibilities for optimization and is of high interest for the supplier since he supplies the complete terminal.

IV. SIMULATION MODEL ALTENWERDER

A. Structure

In the following section the structure of the investigated container terminal Altenwerder is described.

On the eastern side of the terminal area a 1,400-meter-long quay wall is located, which is divided into four equal-sized berths at which feeder and large container vessels can be moored. Fourteen dual-trolley container bridges take care of the container loading and unloading. The crane driver in the main crane boom is responsible for transporting a container to the lax platform of the bridge, where lax workers remove twist-locks. One smaller container bridge is used to handle container from feeder vessels. After unloading from the ship, the fully automatic handling begins. As soon as one of the 86 fully automated guided vehicles (AGV) places itself on one of the designated waiting positions on the land side of the bridge, the smaller crane boom moves the container onto the vehicle. The bulk of the vehicles are actuated by a diesel-powered drive chain. Since spring 2011 two vessels are provided with a battery-powered electric motors were deployed. In the course of the BESIC project, more vehicles will be retrofitted.

For the short- to midterm container stocking 22 block storage areas are available. Each is handled by 2 Double Rail Mounted Gantry Cranes (DRMG). Having different heights the cranes can path by each other directly driving over- or respectively underneath the other. This makes it possible that the two cranes of each storage area can operate independently and an area can be handled by one crane only, e.g. in case of break downs.

The onshore import or export of the containers is handled by trucks or by railway. This area of the terminal is referred to as hinterland connection. Trucks can pull directly onto the western part of the block storage areas and are handled by one of the DRMGs. Overall there are 104 handover spots; each area equipped with 6 or 7 spots. Other carriers can take containers to the railway reloading site which is located behind the hinterland connection for trucks. For loading the containers onto the railway cars seven tracks are available which are handled by 4 local container cranes [8].

B. Modeling

A virtual complete system environment has been developed which offers the possibility to evaluate different operating strategies and their impact on performance figures, e.g. dispatching times or the energy consumption. In particular operating strategies can be changed and the influence on the logistic processes and the continuous energy consumption can be surveyed.

To reach the goal of forecasting the overall demand load curve it is necessary to adjust the operating strategies in a way that the logistic processes of the simulation are as close to the realistic processes as possible. Thereby not every detail has to be regarded but the duration of the single logistic processes is of high importance to be able to calculate the forecasted load curve. Short-term deviations might have impact on logistic processes but not so much on the energy consumption if the energy consumption is regarded as the mean power demand of 15 minutes. This fact is explained in the following example:

10 containers for import have to be unloaded from the bay. After 10 Minutes in the simulation 3 containers have been unloaded using 3 restacking operations. In reality the position of the containers differed from the manifest. After 10 minutes only 2 containers have been unloaded using 5 restacking operations. The logistic system of the reality has a different state than the simulation. But in both states the crane has permanently worked and therefore used permanent power. Only small differences occur due to the over- or undertake consumption during the container pick-up (See figure 5). It is assumed that a temporary delay only has little influence on the overall unloading process.

The simulation registers the power consumption of the terminal permanently and calculates from it a forecast of the demand load curve in 15 minute values. The simulation
consists of three modules which represent different parts of the terminal: Storage/Stacking area, loading/unloading area and seaward in-/outbound transport. The hinterland connection area is not simulated since it has not necessarily a variable impact on the overall energy consumption; it is therefore defined as a static value.

Figure 2 shows the three main modules of the simulation. The container stacking area represents the storage, the horizontal hauling area the container transport area and the crane area represents the loading/unloading area and the seaward in-/outbound transport.

The single components are configured in a modular way and possess defined interfaces. This way it is possible to combine different levels of details of the single modules. These modules can be built up rather simple, e.g. through keeping different components logical apart, or quite sophisticated by differentiating between territorial and chronological models. These way single strategies for the planning tasks in the container terminal can be tested and optimized on target. One example would be to create a very high amount of import container to test the upper limits of the horizontal hauling area. The different software systems of CTA were modelled as single components to support easy switching between different operating strategies.

C. Logistic processes and energy data acquisition

In this section the functionality of the energy data acquisition and the logistic processes is described. The electrical power consumption of the consumers is constantly protocoled. From this data the load curve in 15-minute values is calculated as it is the standard for energy data in Germany. The consumption of the single electricity consumers are applied as static value or as an input load curve.

1) Static consumers

Static consumers, e.g. the lighting of the terminal, are allocated constant power consumption. It is differentiated between consumption at day time and consumption at night time, which is higher than at day time. At the time of sunrise and sundown the consumption is adapted within three quarters of an hour in three steps up respectively down. The upper and lower value for the power consumption is fixed. Realistic values for this have been extracted from historical meter data of CTA. The times for sunrise and sundown are calculated using a mathematical time equation.

2) Battery exchanging station and AGV routing

The routes of the AGVs are static and marked by sensors as shown in Figure 3. The main routes proceed on the side of the stacking area. Overall there are 6 main lanes which can be alternately used in northern or southern direction. Between the main lanes and the sea-side lanes waiting positions for the AGVs are installed. Of the 4 sea-sided lanes two are used in northern direction and two in southern. The crosswise lanes can be used in both directions. There are some traffic rules to be regarded which are specified by the routing system and some technical restrictions apply:

- Sea-sided lanes are only used to reach the loading point of the quay cranes. AGVs leave these routes as fast as possible and use the main lanes to reach their destination
- Vehicles on the crosswise lanes have to yield to vehicles on main lanes or on sea-sided lanes
- For a complete turn an AGV needs to pass at least 3 lanes

It must be regarded that the flow path layout is static. This means that the direction of a route cannot be changed during operations respectively during the simulation. However it is possible to change the flow path layout if needed because of the used sensor implementation. The entire transportation system described above is simulated. An example of the simulation model of the transport area is given in figure 4.

Currently only two battery-powered AGVs are operating at CTA, the remaining AGVs are equipped with a diesel-powered engine. For this reason the consumption of the battery charging-station is not taken into account today because its share of total consumption is negligible. Nevertheless, in the near future, as more vehicles are equipped with a battery-powered engine the energy consumption will reach a relevant level. So the consumption of the vehicles has to be captured as well. For this reason the horizontal movement described above is simulated in order to determine the moved distances and the corresponding energy consumption of the vehicles. The observed AGVs are using an exchange battery. If the charging level of an exchange battery drops below a certain value the AGV is automatically directed to a special battery exchanging station to exchange the empty battery with a fully charged one.
battery is recharged in the station and stays there until the next usage. The energy consumption of the battery powered AGVs has only indirect influence on the overall energy consumption of the terminal. The number and the kind of the transport orders have impact on the battery charging time and the needed charging intensity. The AGVs therefore influence directly the power consumption of the battery changing station which is responsible for charging the batteries. A battery stored for charging can either be charged with constant power consumption or with intelligent strategies for managing the charging. These strategies for charging then have an impact on the time and the quality of the power consumption of the station and can therefore influence the overall load curve. It should be noted that AGVs have different energy consumption levels at hibernation and during operations which are considered in the simulation. The energy consumption is determined in a previously conducted project and is 1.39 amps at hibernation and 47.1 amps during operations [7].

3) **Quay cranes and yard cranes:**

The power consumption of a gantry crane is described as a load curve. When picking the container up a higher consumption is applied as at the time of dropping off or at the time of moving of a container. An example for such a load curve is presented in Figure 5. Very important is the time which is needed to load or unload a container from a container vessel. First, this time can be described by a constant, so every container needs the same time to be loaded or unloaded. But the use of a constant can cause that the system state may be different from the reality in any time. Therefore, it is better to use a probability distribution which maps the reality more precisely. An example for such a probability distribution is shown in figure 6. If a complete storage plan is available the entire load and unload process can be simulated. But this is a difficult problem due to the fact that every crane driver got a different working speed and unaccepted factors cannot be simulated. In a probability distribution all of these influences are considered.

In the simulation model four different types of energy consumption are set. Consumption at

- container lifting
- container movement
- lifting without a container
- put down a container

Quay cranes starts working if a container is taken or picked up by an AGV.

4) **Hinterland connection**

For the hinterland connection an average power consumption level is applied which varies based on the utilization of the container terminal.

5) **Refrigerated containers**

When starting the simulation a constant value is chosen representing the number of refrigerated containers stored in the stacking area. In the best case this number can be extracted from real terminal data. An interface to the terminal managing system is planned to be realized. Every refrigerated cooling container has constant power consumption as soon it is stored in its final position in the stacking area. The current power consumption is depending on the outside temperature. The consumption per temperature is stored in a database. With every ship loaded or unloaded the number of refrigerated containers stacked in the storage changes. Simplifying a constant percentage of all containers handled in the context of one ship is declared to be a refrigerated container.

D. **Configuration of the simulation**

At simulation time the only dynamic input parameters are taken from the sailing list which includes information about ship arrival times, departure times and the containers to handle. The needed number of quay cranes, yards, etc. is determined as well as their power consumption which is constantly recorded.
E. Results

Based on the sailing list stating the arrivals and departure of ships including their scheduled times and with knowing the planning and operating strategies of the terminal the logistic processes and the resulting energy consumption can be simulated precisely. Figure 7 shows one of the first results where the consumption of the static consumers was still not well regarded. The static consumers and the energy consumptions of some other consumers are estimated in the current model as well as some of the operational strategies are still not completely in line with the strategies used at CTA. So the simulated and real energy demand curves are still dissimilar. But already in the first approach a similar shape of the curves can be detected. One result of this forecast is that the consumption value of static consumers (lighting, office buildings, etc.) has been chosen too low. Raising this consumption improves the result significantly. Furthermore, a slight displacement on the time axis is seen. This can be explained by the fact that the yard cranes begin to work even before an arrival of a container vessel. During this time the stock is prepared for the incoming vessel. Soon needed containers will be moved to the top of the stack so they can be reached immediately if they are needed. In the further process this is taken into account. Therefore it has to be investigated as ship arrival times and yard crane operations are related. Also the energy consumption of every single consumer of the terminal needs to be metered in detail to calibrate the model for single consumers. For example the consumption of the four different states of a quay and yard cranes are estimated at the moment. The operating strategies of the terminal have to be evaluated and transferred into the model more precisely.

V. Forecasting of Battery-usage

If battery-powered AGVs are used, the energy consumption of the vessels has to be added to the forecast. By simulating the logistic processes the point of time for the battery exchange can be captured. Besides the entry time of the battery to the exchange station, the exit time from the exchange station for the next usage is of interest. These two times are significantly influenced by the chosen battery replacement strategy and the container handling volume. A simple but effective strategy is to exchange the battery when the charging level drops below a certain threshold value. Knowing this level and the maximum charging rate, the time needed to charge the battery can be calculated. Along with the expected exit time a time can be determined when the charging process has to be started at latest to charge the battery fully. The time period between this time and the entry time can be used, for example, for load shifting or smart charging strategies. Figure 8 shows an example for one battery. The overall residence time of the battery in the exchange station is about 14 hours while just 7 hours are needed to charge the battery fully. So the moment to start the charging can be shifted for 7 hours or it can be charged with a lower charging rate using more time.

VI. Use cases

Besides being able to calculate the overall consumption of the container terminal, the simulation makes it possible to apply different operating strategies even on the level of different modules. One of the components of special interest is the battery changing station. Introducing heavy load E-Mobility at CTA and by the same time separating in large parts the battery charging from the actual logistic processes new possibilities to optimize the energy supply can be applied. Since a battery is stored in the changing station longer than it is needed to be charged completely possibilities for load shifting and peak clipping are introduced at the terminal. By knowing the forecasted demand load curve the battery changing can be optimized to have a maximum economic benefit. Four use cases have been identified which will be described in the following.

A. Load shifting and peak clipping

When price signals for the energy consumption are sent from the supplier to the terminal it is possible to optimize the battery charging in regard to the times with the cheapest price. The time a battery is stored in the charging station is known and must not be changed since the logistic processes are fixed but the time and quantity of charging can be shifted. So it is easy to adapt the charging strategy to the price.

Since the price for energy supply often contains a component which regards the highest power demand at one point of time or the highest power demand in one 15 minute block it is possible to shift battery charging to times when the overall power consumption is not at the highest point. Knowing the overall consumption from the simulation the battery charging strategy can be changed to avoid peaks. This strategy can be combined with the strategy for the price signals by calculating if it is cheaper to shift the peak or having a peak but having the cheapest energy price.
B. Confirmation of the forecast to the supplier

Usually the supplier calculates his own forecast for every industrial customer. Most of the times this forecast is based on historical data, since the supplier does not know the processes and its constraints behind the business of the consumer.

When a supplier sends price signals to the consumers he furthermore cannot be sure if the load demand is changed or shifted. And if it is changed he does not know in what way respectively what quantity.

Having calculated an overall forecasted demand load curve or a new adopted load curve the terminal can communicate the data to the supplier. By confirming this new forecast to the supplier, the suppliers risk for wrong purchasing is reduced significantly which will eventually lead to further discount.

C. Offering balance energy

In the German electricity market the energy generated/purchased and consumed/sold of a group of points of deliveries is kept in a balancing group whereby offtake and consumption should be equal. During the day of the delivery it might be that the consumption of the customers changes in regard to the forecast. This way the supplier is forced to get active in the market, e.g. by purchasing new energy from the exchange or the balancing group coordinator will get active and purchase/sell the energy (balancing energy). Since this a risk for the supplier, he might also ask the terminal to shift the load according to the imbalance in his balancing group. This might be more efficient than buying or selling the energy difference on the market or letting the balancing group coordinator do it to a possibly not optimal price. In this use case a direct communication between the supplier and the terminal would be needed and the adaptation of the consumption pattern, and with this a recalculation of the battery charging strategy, must take place on rather short notice.

D. Offering operating reserve

While balancing energy is used on an economic level, the operating reserve is used on a physical level. It is needed every time feed-in and take-off of the grid is not in balance and the power frequency is not stable. The terminal can offer parts of the load shifting availability as operating reserve. This is economical attractive but has high barriers in regard to requirements in amount of the reserve to be offered and the reaction time to be granted. Therefore one option is the pooling with other providers to be able to meet these requirements. As well as on all the other use cases an automatic communication should be granted between the supplier and the terminal in order to automate the handling of the cases as much as possible.

While the use case load shifting and peak clipping is not really new in the context of energy management, usually described in the context of Demand Response [9], the other use cases are fairly new to the German market and standards and processes for these use cases are still under development and are referred to in the context of Demand Side Integration [10]. Especially the communication from the consumer to the supplier lacks in standardized implementations. Some standards like IEC 61970/61968 might be a basis, but architectures for using it are rarely implemented [11]. Some studies have named the overall potential for demand response and Demand Side Management to 60 GW in the European Union [12] and 8,5 GW in Germany [13]. Therefore the use cases not only have not only an economical benefit for the container terminal, they might also be able to support a grid wide stable energy supply in times of fluctuating feed-in related to the growing share of renewable energies. While the studies also name some industry divisions where they see the most potential, the division of logistics is never mentioned [14] [15]. By introducing E-Mobility in a heavy load logistic company like the container terminal and being able to forecast the energy consumption the terminal is now able to take part in the energy market. This is especially due to the fact that we have growing amount predictable load shifting potential for the battery charging. Yet the practical market processes still have to be defined.

VII. OUTLOOK

In the future energy consumption of the single consumers, meaning the quay cranes, portal cranes, refrigerated containers, battery exchange station and static consumers have to be recorded in detail at the terminal itself. Besides, data of the logistic processes are needed in a more precise manner like loading and unloading times of the cranes, travel times of the AGVs, moor times and storage times in the battery exchange station. Using this data, the simulation model can be calibrated and adapted even more specific to the terminal equipment. As a result, it expected to achieve a higher prediction accuracy of the simulation. Further methods need to be developed to handle delays of container vessels.

Additionally we want to focus on the optimization of battery charging strategies, not only in regard to economical features but also on technical features like the battery aging when applying different charging strategies.

REFERENCES


