Biomass Bulk Terminals

Simulation and Design of Large-scale Operations

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Due to its ecological advantages and availability biomass energy is set to become a key to the future, leading to new dimensions in handling and transport facilities. This may also include large-scale bulk terminals. Advanced simulation models help to develop terminal solutions with high reliability and economic efficiency.

Energy derived from biomass materials and products has become significant for the current and future development of mankind. Various research have shown that to meet the EU demand in the long term future, significant amount of biomass materials and products will be imported into the European Union. Within the research presented in this article it is assumed that there is a need for a large-scale terminal to receive the import freight. To optimise the design of such a terminal and see the effects caused by stochastic influences (e.g. ship arrival pattern), a simulation model is used to assist the design. This article presents the development of such a simulation model; the model is further verified with an analytical model, and the verification shows that the model reflects the theoretical outcomes.

1 Introduction

Many renewable energy sources have become increasingly significant in the world today under the concern for sustainability and the security of supply. Among them are the biomass materials and products. More and more biomass materials and products are traded internationally and transported over long distances. This is due to that some regions have better potential to export while others need to import biomass to fulfil their need [1]. Bulk terminals around the world have been dealing with biomass materials and products for some time in small scope. However, with the expectation of growing scale in the international biomass trade market [1], a large-scale bulk terminal dedicated to handle biomass materials and products is adequate and supports the picture of large-scale biomass trades and long distance biomass supply chains.

This research focuses on the design of a large-scale biomass bulk terminal. This large-scale biomass bulk terminal handles both solid and liquid biomass materials and products, and the yearly throughput is set at 20 to 40 million tonnes, with an estimated share of solid biomass as 40 to 50 per cent [2]. Challenges in terms of handling and storage are caused by the large scale, the wide range of material properties, and the differences in material properties compared to other commonly handled bulk materials such as coal [3]. In addition, the terminal also faces other design matters, such as the storage capacity (up to four times lower bulk density compared to coal [3]), the replenishment of the storage stocks (no transparent data on demand pattern), and the capacity and suitability of the handling equipment. It is a common practice in container terminal design and operation to use simulation as a tool to assist these design issues [4]. It is only a recent development to use simulation models in the design of bulk terminals however [5, 6].

For design purpose, a list of biomass materials and products, which terminal might receive, has to be determined in order to proceed the design with their material properties. Several selection criteria have been set [2], in this case seven material types are selected:

- wood pellets,
- wood chips,
- torrefied pellets,
- vegetable oils,
- ethanol,
- biodiesel, and
- pyrolysis oils.

Based on different conversion techniques, biomass materials and products are available in many types and forms, including solid shape (e.g. wood pellets, wood chips) and liquids (e.g. biodiesel, ethanol, vegetable oils) [7]. They can be used in energy sector (e.g. wood pellets in co-firing power plants), and for transportation purpose (e.g. biodiesel as a transportation fuel) [7]. Therefore, the large-scale biomass bulk terminal is designed to receive both solid and liquid cargoes [2].

The aim of this article is to present the development of a simulation model used to support the biomass bulk terminal design and to see the effects caused by the stochastic design parameters (e.g. vessel arrival patterns, fluctuation of demand patterns). The model is further verified with an analytical model, and the verification shows that the model reflects the theoretical outcomes.

1.1 Terminal Operation

The large-scale biomass bulk terminal serves as a buffer between the incoming (import) and outgoing (export) flows of biomass materials and products, as most of the bulk terminals around the world [6]. Therefore, temporary storage and handling of biomass will take place at the terminal. Storage and handling are two of the essential functions of a seaport terminal, since it provides uncoupling of incoming and outgoing material flows to overcome potential supply inconsistencies (e.g. seasonal influences) [8]. Based on the Delft systems approach [9], a 'black box' approach can be used to illustrate the logistic flows of a dry bulk terminal. Similarly, the large-scale biomass bulk terminal can be analyzed in the same way, as Fig. 1 depicts.

In principle, the terminal and processes can be divided into three parts, namely the quay side, the terminal side, and the hinterland side. Ocean going vessels deliver biomass materials and products to the quay side, the vessels are unloaded and the materials are further transferred and stored at the terminal. Demand/Hinterland transportation units such as barge, train, and truck from clients arrive at the hinterland side and are loaded.

It is crucial for terminal designers and terminal operators to have proper control over the logistic activities around and at the terminal, in order to make optimal use of equipment and land [5].

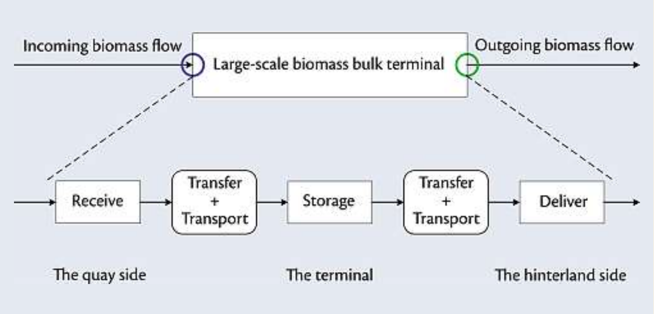

Fig. 1: Cargo flows of the large-scale biomass bulk terminal.

1.2 Input, Output, and Performance Indicators

In the following, the ocean going vessels are referred to as supply ships, while the transport units from the hinterland (i.e. barge, train, and truck) are called transporters. Some parameters are stochastic, for example the arrival times of supply ships and transporters [4]. Several input parameters, the configuration of the terminal, and required model output are shown as follows. Based on the output, the land size (in terms of square metre) and the general layout of the large-scale biomass bulk terminal can be determined.

1) Model Input:
- transporter arrival pattern and demand volumes,
- hinterland modal split, and
- arrival pattern and loads of the supply ships.

2) Configuration of the terminal:
- numbers of service points for loading and unloading cargo and their capacity,
- storage stock level management policy, and
- storage time and capacity of biomass materials and products.

3) Model Output:
- waiting time of supply ships and transporter (average, 95 per cent per centile, pattern),
- Average waiting queue length of supply ships and transporter, and
- utilization rate of equipment.

Comparing various input scenarios the initial terminal design can be improved. The quality of each scenario is assessed by comparing the Key Performance Indicators (KPIs). KPIs are model output or derived from model input.

Like most of the engineering design projects, overall cost of this design (in terms of land size, construction costs, etc.) should be taken into account. In addition, for a seaport terminal, penalty costs for the terminal operator are usually applied when the vessels need to wait to be served. Therefore, the KPIs defined to assess the outcomes from the simulation model are:

- waiting time of supply ships and transporter (average, 95 per cent per centile, pattern),
- average waiting queue length of supply ships and transporter
- utilization rate of equipment, and
- storage time and capacity of biomass materials and products.

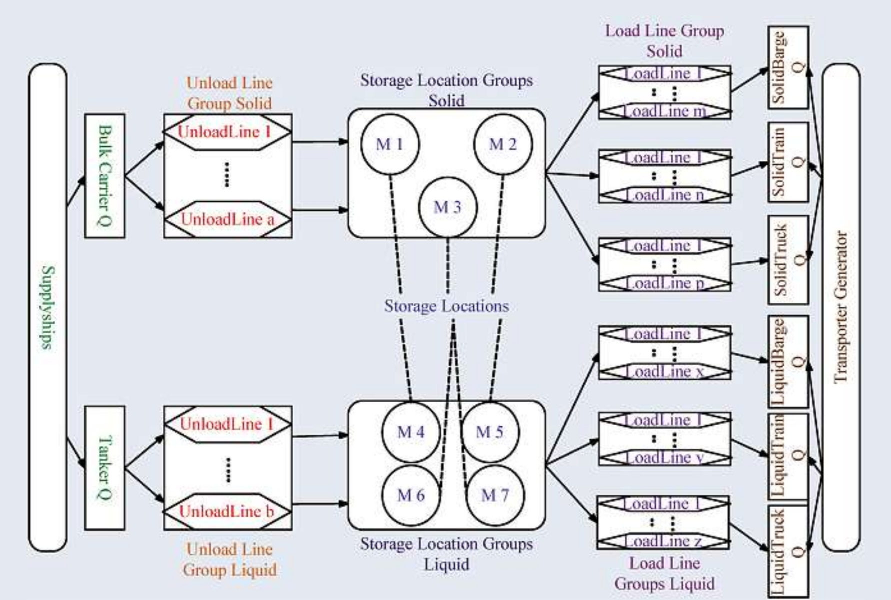

Fig. 2: Structure of the simulation model.

Table 1: System element classes and their attributes

System element class	Attribute
Transporter generator	• Demand material type • Type of transporter (e.g. truck) • Demand capacity [t] • Inter arrival time [h] • Arrival window [h] • Inter arrival time distribution • Corresponding load line group
Transporter	• Demand material type • Demand capacity [t] • Corresponding load line group
Load line group	• Capacity [t/h] • Transporter unit waiting queue • Type of transporter (e.g. barge)
Load line	• Capacity [t/h] • Corresponding load line group
Material type	• Own storage locations • Own storage location group • Total stock
Storage location group	• Material type • Capacity [t]
Storage location	• Material type • Capacity [t] • Corresponding storage group
Supply ship	• Carried material (e.g. biodiesel) • Capacity [t]
Unload line group	• Capacity [t/h] • Ship waiting queue • Type of ship (e.g. liquid cargo)
Unload line	• Capacity [t/h] • Corresponding unload line group

2 Simulation Model

A simulation model is built in order to work as a tool to cope with stochastic influences. This section describes the structure and the elements in the simulation model. Furthermore, the verification of the model by comparing initial results with theoretical values is presented.

2.1 Structure and System Element Classes

The element classes in the model are shown in Fig. 2 from which the biomass material types are excluded. The attributes of each element class and the processes of the generators and the (un)load lines will be explained in Section 2.2.

The simulation model is constructed based on discrete event simulation, using Tool for Object-oriented Modelling And Simulation (TOMAS) software [10]. It is a model that can be used both in demand-driven and delivery driven ways. Several choices are made to build the simulation model, they are as follows:

- The (un)loading equipment (e.g. grab) connected with belt or pipeline, forms (un)load lines. Several (un)load lines form a (un)load line group
- Each supply ship type has its own unload line group to unload the materials they deliver.
- Each transporter type has its own load line group to load the materials they demand for.
- Each material type has its own storage location group, within which various storage locations may be included.

2.2 Attributes of Element Classes and Processes

The simulation model consists of eleven different element classes (e.g. transporters, load lines), each with its own attributes, as presented by Table 1.

Four element classes have their own processes, namely the transporter generator, the load line, the supply ship, and the unload line.

2.3 Stock Level and Delivery Pattern

Storage is one of the main functions of the large-scale biomass bulk terminal [8]. To determine how big the storage area should be, in terms of tonnage and volume (in cubic metre), it is necessary to understand the storage strategy of the terminal and the delivery pattern from the supply ships.

In this model, the stock levels of each material stored at the storage yards can be further identified as the physical stock level (actual amount of materials stored at the terminal), and the reserved stock. In Section 2.2, the capacity of the storage locations and storage groups refers to the physical stock level of the materials; a safety physical stock level for each material can be set, to anticipate the best delivery schedule so that the materials will not run out at the storage. The most straight forward bookkeeping of the stock level is to add to the stock once the materials are delivered by ships, and subtract the loaded amount to the transporters. However, also reservations can be made for the transporters in the waiting queue, and this consequently affects the safety stock levels. Thus it is necessary to have a bookkeeping system to track down the physical stocks, the reserved stocks, and the stocks on their way to be delivered. The explanation of the bookkeeping system is shown in Fig. 3.

The procedure of 'Reserve(D)' represents the procedure that reserves materials to load on the transporters and triggers new supply ships, at creation of transporter. The procedures can be found in the whitepaper-section of www.bulk.solids.handling.com.

When the materials are perfectly delivered on time before the materials are running out, there will always be enough material to load on the transporters, and there will also be no over-stock or under-stock situation. Nevertheless, in reality supply ships do not always arrive according to schedule. There are two possibilities of supplyships arrival pattern:

- Just in time arrival: supply ships arrive perfectly on time to deliver the required materials to the storage.
- Scheduled arrival: a period of time (e.g. scheduled time ±5 hours) during which the ships will arrive.

Just in time arrival pattern of the supply ships together with the virtual bookkeeping are incorporated into the operation process of the simulation model at the moment. Based on the perfect arrival and operation windows, scheduled arrival is the next step to be implemented in the model. Through a series of experiments, an optimum storage capacity of the terminal can be obtained.

2.4 Verification

To prove the simulation model works properly, it is necessary to verify the outcomes obtained from the simulation model. Since the transporters arrive in a random arrival way while the supply ships have just in time arrival pattern, the verification is done by focusing on the interface between the terminal and the transporters. The quay side of the simulation model works accordingly as well.

The verifying method used in this paper is to compare the model output with theoretical values, namely the values obtained from queuing theory. This method is valid to verify the most straight forward condition in the model. However, when the model gets more complicated, the model outcomes are expected to reflect the functions installed and rational reasons can be used to explain the differences.

Queuing Theory and Simplified Model

The arrival and service situation for the transporters can be identified as the M/D/1 queuing model, with exponential distributed times between arrival events, and deterministic service time. Fig. 4 illustrates the situation of M/D/1 queuing model.

According to the queuing theory, the relation between the arrival rate and the service rate can be expressed as:

$$\rho = \frac{\lambda}{\mu} \qquad (1)$$

where:

ρ	occupancy rate	[-]
λ	average arrival rate	[-]
μ	average service rate	[-]

M/D/1 queuing model can be applied when ρ is less than 1. Under this assumption, the average length of the waiting queue [11]:

$$\overline{Q} = \frac{\rho^2}{2(1-\rho)} \qquad (2)$$

The average waiting time in the queue:

$$\overline{W} = \frac{\rho}{2\mu(1-\rho)} \qquad (3)$$

The input parameters used in the simplified simulation model and applied to the M/D/1 queuing performance equations are summarized by Table 2, assuming there is only one material per transporter type (e.g. wood pellet for barge solid, wood chips for truck solid). The arrival rate and service rate can be derived from Table 2 by using Eqs. 4 and 5.

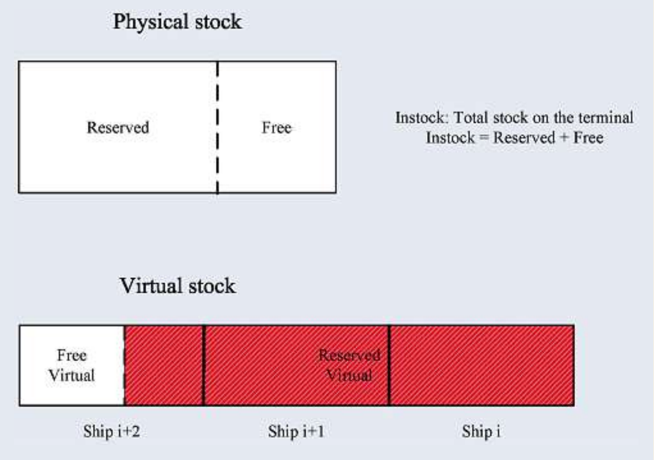

Fig. 3: The bookkeeping stock.

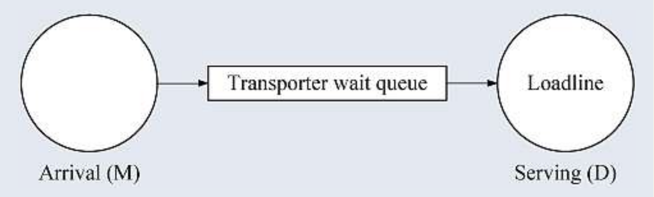

Fig. 4: M/D/l queuing model.

$$\textit{arrival rate}\ (\lambda) = \frac{1}{\textit{inter arrival time}} \qquad (4)$$

$$\textit{service rate}\ (\mu) = \frac{1}{\textit{service time}} = \frac{\textit{load line capacity}}{\textit{transporter capacity}} \qquad (5)$$

Table 3 shows the comparison between the model output and the theoretical values. The differences are relatively small. It is concluded that the model works reasonably well.

Table 2: Input parameters for verification with M/D/1 queuing model.

Transporter	Barge (solid)	Barge (liquid)	Train (solid)	Train (liquid)	Truck (solid)	Truck (liquid)
Transporter capacity [t]	6200	8000	4500	5200	2800	2400
Transporter inter arrival time [h]	11	13	14	12	15	12
Loadline capacity [t/h]	650	680	375	480	240	220

Table 3: Comparison between queuing theory and simplified model

Transporter	Barge (solid)	Barge (liquid)	Train (solid)	Train (liquid)	Truck (solid)	Truck (liquid)
Number of unit	198 694	168 817	156 606	182 625	146 448	182 415
Arrival rate (λ)	0.09	0.08	0.07	0.08	0.07	0.08
Service rate (μ)	0.10	0.09	0.08	0.09	0.09	0.09
Occupancy rate (ρ)	0.87	0.90	0.86	0.90	0.78	0.91
Av. queue length (theory)	2.8	4.3	2.6	4.2	1.4	4.6
Av. queue length (model)	2.8	4.3	2.6	4.4	1.4	4.4
Av. wait time [h] (theory)	31.1	56.0	36.0	50.3	20.4	54.6
Av. wait time [h] (model)	30.9	56.3	36.0	52.1	20.4	52.7

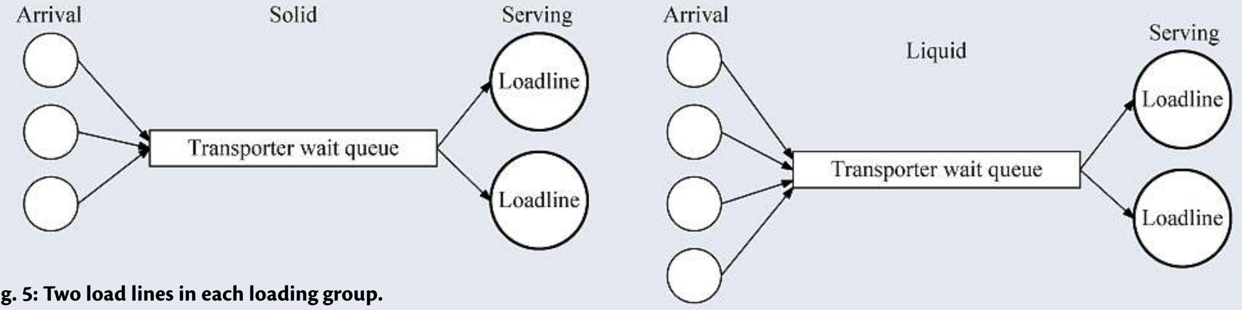

Fig. 5: Two load lines in each loading group.

Experiment with the Hinterland Part of the Model

As can be seen from Fig. 2, there are several load lines in one load line group to face one transporter waiting queue. Assuming that there are two load lines in one load line group, each one has half of the capacity as the M/D/1 situation to serve one transporter waiting queue, with three material types for each solid queue and four material types for each liquid queue. To be able to compare with M/D/1 situation, the inter arrival time of transporter are adjusted to three to four times longer. Fig. 5 shows the schematic drawing of the assumption, and Table 4 shows the input parameters for this scenario.

It is expected that the waiting time and waiting queue length will be more less the same compared to the simplified simulation model. Table 5 presents the results obtained from the hinterland part of the simulation model. It shows that as expected the waiting time and waiting queue length are approximately the same as theoretical values.

3 Conclusions and Recommendations

A simulation model has been developed to support the design of a large-scale biomass bulk terminal. The model is verified and initial runs are carried out. The verification is done by comparing output from the simulation model with the results from an analytical model, namely the M/D/1 queuing model. It shows that the model works adequately. Results from hinterland part of the simulation model shows the waiting time and waiting queue length are roughly the same as theoretical values, which is as expected.

The next step in the research project presented here will be to use the simulation model with different input scenarios. The parameters in these scenarios are: the number of storage locations (consequently affect the storage capacity), number of berths and their capacity, the hinterland modal split, the arrival pattern of transporters and their demand quantities, and the arrival pattern of supplyships (i.e. scheduled arrival) and their loads. By fine-tuning the input scenarios and using the KPIs to assess the model output, the design of the biomass bulk terminal can be improved.

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Table 4: Input parameters for the hinterland part of the model

Transporter	Barge (solid)	Barge (liquid)	Train (solid)	Train (liquid)	Truck (solid)	Truck (liquid)
Transporter capacity [t]	6200	8000	4500	5200	2800	2400
Transporter inter arrival time [h]	33	52	42	48	45	48
Load line capacity [t/h]	325	340	188	240	120	110

Table 5: Comparison between queuing theory and the hinterland part of the model.

Transporter	Barge (solid)	Barge (liquid)	Train (solid)	Train (liquid)	Truck (solid)	Truck (liquid)
Number of unit	199 300	168 897	156 536	181 922	146 235	183,025
Arrival rate (λ)	0.09	0.08	0.07	0.08	0.07	0.08
Service rate (μ)	0.10	0.09	0.08	0.09	0.09	0.09
Occupancy rate (ρ)	0.87	0.90	0.86	0.90	0.78	0.91
Av. queue length (theory)	2.8	4.3	2.6	4.2	1.4	4.6
Av. queue length (model)	2.6	4.2	2.3	3.8	1.2	4.4
Av. wait time [h] (theory)	31.1	56.0	36.0	50.3	20.4	54.6
Av. wait time [h] (model)	28.3	54.6	32.8	45.9	18.2	52.7

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