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Optimal equipment deployment for biomass terminal operations

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A B S T R A C T

This paper investigates the optimization of biomass terminal equipment deployment. A mixed integer linear programming model is developed and applied to minimize the terminal's investment and operational costs related to dedicated and partially used or shared equipment between a terminal's operational steps. The results minimize annual terminal costs through equipment and infrastructure selection and utilization. Tipping points where the technology and equipment type or size change in relation to the increasing throughput are highlighted. Analytical results emphasize the importance of storage costs in all biomass terminals, as well as the critical influence of operational costs in larger facilities.

1. Introduction

Biomass use in the European Union (EU) is expected to significantly grow in the co-firing and heating sectors by 2030 (European Biomass Association, 2016). At the moment, 4% of the total biomass used for energy purposes in the EU is imported (Dafnomilis et al., 2017). However by 2030, this amount (both in percentage of total biomass and in absolute amounts) could substantially increase, taking into account potential supply gaps in electricity production or the closing down of coal power plants (Dafnomilis et al., 2017; Mai-Moulin and Junginger, 2016). The Netherlands has been relying on biomass (specifically wood pellet) imports in order to reach the renewable energy target for electricity production, and is expected to rely on them for the future as well. This corresponds to approximately 3.5 Mt of imports (Dafnomilis et al., 2017). The above throughput can substantially increase when biomass is imported to Belgium, Denmark and Germany. The Port of Rotterdam aims to handle up to 10 Mt of biomass by 2020, and as such assume a hub role for biomass imports to the whole of Northwestern Europe (Port of Rotterdam Authority, 2013) (du Mez, personal communication, May 2017).

Biomass is considered a bulk material, such as coal or iron ore. However, unlike these products, biomass requires specific equipment and techniques used during bulk handling, transport and storage (Hancock et al., 2016). Use of unsuitable equipment can lead to deterioration of the product or lead to health and safety hazards, such as dust production and explosions, self-heating and ignition or respiratory issues (Dafnomilis et al., 2015). The equipment at a port terminal handling biomass need to match biomass's specific properties. This includes specifically designed equipment (e.g. grabs) that minimize product deterioration; fully covered or enclosed transportation and storage facilities; spark detectors, fire detection and suppression systems and temperature monitoring through the whole handling chain. This is not entirely realized at the moment; traded volumes are low, so most terminal operators choose not to invest in specialized infrastructure (Dafnomilis et al., 2017). This can lead to a general degradation of the product and incur significant financial losses, as well as facility and personnel hazards (Dafnomilis et al., 2017). Increasing the service reliability, profit margins and reducing cargo damages are therefore essential to a biomass bulk terminal and are identified as some of the most

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List of acronyms

EU	European Union
MILP	mixed-integer linear programming
PPI	port performance indicator

Measurement units

Mt	million tons
tph	tons per hour
€	euros
h	hours
y	years
t	tons
kt	kilotons

important Port Performance Indicators (PPIs) (Ha and Yang, 2017; Talley et al., 2014).

Due to the above reasons, biomass terminal logistics are more demanding in terms of designing the terminal setup and selecting the suitable equipment to efficiently handle the product. The additional safety equipment and facilities increase the capital investments required, and, since only a handful of port terminals are dedicated biomass terminals, mostly in the US, Canada and the UK, terminal operators do not have a lot of information sources on which to base the required investment decisions. Despite the existence of dedicated biomass terminals and the expected biomass trade growth, there is currently no comprehensive method to assist terminal operators in optimizing equipment and facility selection when dealing with biomass. The scientific literature relating to equipment and facility deployment is minimal, and focuses on extremely particular cases or is applied on relatively small scale examples. The existing literature data, such as capital and operational costs of equipment and facilities are usually simplified approaches and do not reflect the actual situation within the industry. This is the scientific gap that this paper aims to address, by providing a model that can be used in the field of biomass terminal design, taking into account dedicated and shared equipment within the same terminal. The results can assist terminal operators and port authorities with strategic level planning decisions related to biomass terminal investments.

1.1. Literature review

A substantial amount of research has been performed on terminal design, both for dry bulk material and container terminals. Dry bulk terminals are usually characterized by the presence and size of the terminal jetty. Dry bulk vessels can have large draughts, because of the large cargo density and thus large tonnage, and as such, it can be more economical to realize a jetty/pier instead of a quay wall (Kox, 2017). Terminals located in deep waters however, such as the port of Rotterdam, can still make use of quay walls for bulk cargo handling without the need for a jetty (Port of Rotterdam Authority, 2018). The equipment used for each necessary function that a terminal performs, such as loading/unloading vessels, transport of material and storage is unique and more complex than the equivalent for container terminals (van Vianen, 2015). Most importantly however, the equipment selected and installed must take into account the numerous properties of the cargo, such as density, angle of repose, dust generation, hazardous and handling properties (Kox, 2017; Bradley, 2016). The selection of equipment differs per transport direction and depends on the type and quantity of the bulk material, space and environmental conditions and the intensity of operations. Dust generating materials like cement require enclosed transport and small terminals with low capacity requirements can make use of wheel mounted mobile installations (Kox, 2017). The type of storage selected is also completely dependent on the material handled, ranging from open storage, to covered storage (warehouses and sheds, to silos and domes) (Dafnomilis et al., 2015; Kox, 2017). Finally, the productivity of equipment used is measured in tons of material handled per hour of operation (Ligteringen, 2014; UNCTAD, 1985; PIANC, 2014).

A comprehensive design method that still serves as an important guideline on bulk terminal design was introduced by the United Nations Conference on Trade and Development (UNCTAD, 1985, 1991) in 1985 and again in 1991, focusing on the physical characteristics, management and operation of bulk terminals. At the same time, the Transportation Department of the World Bank (Frankel et al., 1985) published a comprehensive report on bulk terminal development, including information on terminal logistics and mathematical models used in evaluating preliminary design options. Memos (2004) provided planning parameters and other bases for estimating vessel queuing times, vessel service time and estimation of storage area needed for dry bulk cargo terminals. Discrete-event simulation for designing and improving the operations of dry bulk terminals was used by Ottjes et al. (2007). Lodewijks et al. (2007) discusses the application of discrete event simulation as a tool to determine the best operational control of the terminal and the required number of equipment and their capacity. Cimpeanu et al. (2017) introduced a discrete event simulation model as well to analyze bulk carrier unloading and material transport, storage and discharge. Taneja et al. (2011) suggested that Adaptive Port Planning methods, which value flexibility of design, are better suited in times of uncertainty than the traditional methods. van Vianen (2015) approached the issue suggesting an expansion of existing design methods, based on stochastic variations of the operational parameters, rather than developing a new design method. Bruglieri et al. (2015), Babu et al. (2015) and Robenek et al. (2014), among others, have investigated yard planning problems in bulk terminals. The berth allocation problem has also been extensively examined by Robenek et al. (2014), Ernst et al. (2017), Umang et al. (2013) and Al-Hammadi and Diabat (2017).

Scientific research into specific types of equipment used in dry bulk terminals has also been performed. Schott and Lodewijks (2007) provides an overview and analysis of the terminal facilities provided for handling, storage and processing of bulk materials. General information on equipment needs of dry bulk terminals has been provided by Negenborn et al. (2017). Research on types of equipment has been performed by Strien (2010), on equipment used in stacking, reclaiming or the combination of these 2 functions. Wang et al. (2011) developed a model for the optimum allocation of loading and unloading equipment at a bulk terminal. The