



# A simulation model for the management and expansion of extended port terminal operations



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## ARTICLE INFO

### Article history:

Received 5 July 2016

Received in revised form 17 November 2016

Accepted 11 December 2016

### Keywords:

Marine terminal operation

Infrastructure expansion

Strategic management

Computing under uncertainty

Discrete event simulation model

## ABSTRACT

This study introduces a discrete event simulation model for the analysis of bulk carrier unloading and material transport, storage and discharge at Europe's largest alumina refinery, RUSAL Aughinish Alumina. With novel features such as the integration of additional unloading functionality, auxiliary infrastructure units, as well as efficient maintenance scheduling into the material processing chain, the model is used to predict and evaluate the performance gain in the port system in the context of long-term investment and planning scenarios. Promising strategic directions in terms of large scale performance indicators such as berth occupancy and costs have been identified.

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## 1. Introduction

The Bayer process is the method by which alumina (aluminium oxide) is refined from bauxite. On Aughinish Island, located on the Shannon estuary in the south-west of Ireland, RUSAL use the Bayer process to refine bauxite into alumina. To do this, they import bauxite from countries like Brazil and Guinea, which, once refined to alumina, is then exported to different regions around the world. RUSAL operates and maintains a port terminal as part of their overall plant in order to meet these shipping needs. The port terminal consists of an outer berth and an inner berth. The outer berth is typically used for the importation of bauxite, while the inner berth is used for the exportation of alumina in addition to the importation of other raw materials necessary for the operation of the port. For details on how these ships arrive and leave RUSAL's port terminal we refer the reader to previous work on this system (Cimpanu et al., 2015).

Once a bauxite ship arrives at the port outer berth, the unloading process begins. From the bulk carrier, the bauxite is unloaded onto conveyor belts and is subsequently transported to storage facilities. The detailed steps in this procedure are highlighted in subsection 2.1. The material is then utilised and treated further in the production line with the final aim of it being refined into alumina.

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We construct a discrete event simulation model that reproduces and expands the functionality of the port terminal and its auxiliary facilities. This methodology is used due to the formation of queues before ships dock at the port, as well as the event-based nature of the port activities. Following a successful validation, a sensitivity analysis is conducted and the effects and benefits of investing in upgrading crucial port infrastructure such as unloading machines, conveyor belts and storage facilities are accurately assessed.

In previous investigations of this setup (Cimpeanu et al., 2015), a model of the port's inner berth has been presented. The model successfully captured the queueing of ships before their arrival at RUSAL's port and the unloading/loading of their cargo. Tidal constraints, stochastic arrival times and random events that delayed ship processing (such as extreme weather) have been taken into account in the respective formulation. The model was used to analyse the impact of variations in the port activity on several performance indicators such as berth occupancy and costs. In the present work, we develop a model of the outer berth which significantly, and, in contrast to previous work, also models the following non-standard features:

1. extension of the unloading infrastructure from a single- to a two-server system;
2. specialised maintenance scheduling;
3. the conveyor system of the plant;
4. storage facilities and discharge functionality.

The specific outer berth operations (originating from the much larger ships and the detailed manner in which the bauxite stored in the compartments therein is handled) also differ greatly from the inner berth modelling.

We perform a detailed sensitivity analysis focusing on the new elements of the system and identify the key aspects of material handling within the complex port network using recent real life data. The study addresses port logistics management and expansion considering interactions between the functional units highlighted above (berth operations, material unloading, transport, storage and discharge mechanisms) within an integrated large scale environment.

The paper is organised as follows: firstly, in Section 1.1, the literature on modelling shipping processes is reviewed. In Section 2, the discrete event simulation model is detailed. Section 3 is dedicated to the validation of the system and to the examination of designed test cases, presentation of results and their analysis. Finally, discussions and conclusions are presented in Sections 4 and 5, respectively.

### 1.1. Previous studies

Discrete event simulation models have been used successfully throughout the last several decades to tackle the dynamic behaviour of multi-component port systems. Angeloudis and Bell (2011) and later Carlo et al. (2014) present overviews of some of the most recent literature on the topic and outline the current industry trends and developments, with particular inclination towards container type ship explorations, as well as ship to yard transport operations (Legato et al., 2013; Petering, 2009). The essential aspect of these review studies is that berth terminal operation modelling is a rich and vibrant area, with immense scope for analytical and numerical investigations. In Dragović et al. (2016) a detailed classification of such applications is presented and the authors argue that simulation modelling offers the most realistic results when searching for solutions in the maritime and transport industries. A wide range of studies are discussed therein and in what follows we expand on some of the most relevant research related to the present investigation.

For instance, following a detailed statistical analysis, Carteni and De Luca (2010) use simulation modelling to analyse terminal operations at the Port of Salerno in Italy, where handling activities are modelled using well-defined stochastic variables. By contrast, uncertainty in the present work is modelled using sampling from empirical distributions. Longo et al. (2013) also use discrete event simulation modelling to replicate the activity of the same port in Italy. As we will also show later, they find that inter-arrival times and unloading/loading rates, amongst others, are crucial factors in seaport management. The large number of variables present in the system necessitates a stringent validation procedure, typical of informative simulation models in this area. Qu and Meng (2012) develop a similar model and apply it to ships movements in the Singapore Straits. Using experienced personnel they embed expert judgement into the model's decision-making process.

In typical real life scenarios, we find factors of uncertainty which are very important in the overall dynamics of the system (Legato et al., 2014). The integration of non-deterministic features plays a fundamental role in our proposed model as well. In practice operators and shipping lines often agree on arrival windows rather than arrival times, with far-reaching implications for the management of the port activity, as highlighted by Hendriks et al. (2010). Using the Antwerp terminal as an example, the peak loading and number of quay cranes are minimised. On a larger scale, Wang et al. (2015) emphasise the connection between the activity of port terminals and the shipping lines transporting containers from their origin to their destination ports. Port operators work based on requirements and information from the shipping lines, thus a collaborative mechanism is proposed to lower bunker and inventory costs, as well as ensure a robust assessment and transfer of knowledge between the two parts. Ship arrival scheduling with stochastic modelling has also been identified by Zhen et al. (2011) and Zhen and Chang (2012) as having a significant impact in improving the efficiency of port terminal operations (see also Du et al., 2011).

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