# Summary

Designing dry bulk terminals is one of the main activities conducted at Heavy Industries & Logistics, an advisory group at Royal HaskoningDHV. Due to the increasing demand of the dry bulk materials coal and iron ore, existing dry bulk terminals need to be expanded and new dry bulk terminals need to be designed. For this, the storage capacity is one of the main design parameters, as high investment costs are involved.

There are no clear guidelines available in literature about the required storage capacity of dry bulk terminals. Preliminary research of this study has shown that the annual throughput, which is generally used as the only guideline, does not have enough explanatory power. For these reasons, there is a need for a method that gains insight in the factors that determine the required storage capacity of a dry bulk terminal.

This focus of this research is to determine the required storage capacity of import dry bulk terminals that store their bulk materials identity-preserved. Due to stochastic influences, the storage level fluctuates at these types of terminals. For example, terminals have no or limited influence on the arrival times of ships. When ships arrive, service has to be provided within the pre-arranged time. In order to avoid all demurrage costs (and to handle the highest storage levels), a large stockyard is required. However, a large stockyard brings along high investment costs. Therefore, from an economical point of view, it might be better to accept some demurrage costs in order to have lower investment costs. In this research, it is assumed that the required storage capacity of an import dry bulk terminal is the storage capacity that involves the lowest costs; in other words, the storage capacity with the highest net present value (NPV).

First, in order to determine the required storage capacity, an extensive simulation model has been developed of an import dry bulk terminal in the discrete event simulation package TOMAS Delphi. In this simulation model is tried to capture all properties of the terminal as realistic as possible. The stochastic properties are included, like the inter-arrival times of ships (Erlang-2 distributed), the ship types, the ship capacities, and the storage time of the bulk materials on the stockyard (Erlang-2 distributed). In addition, all revenues and costs of the terminal are included in the terminal. As a result, the NPV is determined automatically for each simulation run. Moreover, it is possible for the user to adjust all parameter values (including the distributions of the stochastic variables), so many sorts of terminals can be configured.

Subsequently, the required storage capacity is determined for each configuration by optimizing the NPV of the simulation model: the required storage capacity is the storage capacity with the largest NVP. However, the most common gradient-based optimization algorithms are not suitable. When the NPV is optimized, two problems arise. On the one hand, the NPV is non-linear en contains thousands

of local maxima. On the other hand, the required storage capacity is influenced by the capacities of the quay cranes and the stacker-reclaimers. For these reasons, the "simultaneous perturbation stochastic approximation" (SPSA) algorithm with injected noise is implemented in the simulation model. This algorithm is able to efficiently optimize the NPV with respect to three variables simultaneously. Moreover, it can approximate the global maximum, as it contains a unique method to estimate the gradient.

The required storage capacity can be divided into two parts: a deterministic and a stochastic part. The deterministic part equals the average storage level and is determined by the multiplication of the annual throughput and the average time bulk materials spend on the terminal (Little's Law). The stochastic part is the storage capacity a terminals needs due to its stochastic properties and can be expressed as a percentage of the annual throughput. The largest influences on the stochastic part of the required storage capacity are the annual throughput and the storage time of bulk materials.

In the base configuration, small terminals (10 Mton annual throughput) need 7.6% of the annual throughput as storage capacity to handle its stochastic properties. This is only 3.1% for large terminals (50 Mton annual throughput). A storage time of approximately two months is assumed in the base configuration. When the storage time decreases to one month, the stochastic part of the storage capacity decreases by 24%. On the other hand, an increase of the storage time to three months decreases the stochastic part of the storage capacity by 12%. Out of the stochastic variables, the inter-arrival times distribution has the largest impact on the stochastic part of the required storage capacity. The effects of the ship characteristics and irregular storage times are much smaller.

Therefore, it is concluded that the required storage capacity can be determined by developing a simulation model in which the NPV is optimized. This way, the required storage capacity is the storage capacity that has the largest NPV. The stochastic influences have a smaller effect on the required storage capacity as the annual throughput increases. Depending on the type of terminal, 3 to 10% of the annual throughput is required as extra storage capacity for the stochastic effects in addition to the average storage level.