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Dynamic stability metrics for the container loading problem

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ABSTRACT

The Container Loading Problem (CLP) literature has traditionally evaluated the dynamic stability of cargo by applying two metrics to box arrangements: the mean number of boxes supporting the items excluding those placed directly on the floor (M1) and the percentage of boxes with insufficient lateral support (M2). However, these metrics, that aim to be proxies for cargo stability during transportation, fail to translate real-world cargo conditions of dynamic stability.

In this paper two new performance indicators are proposed to evaluate the dynamic stability of cargo arrangements: the number of fallen boxes (NFB) and the number of boxes within the Damage Boundary Curve fragility test (NB_DBC). Using 1500 solutions for well-known problem instances found in the literature, these new performance indicators are evaluated using a physics simulation tool (StableCargo), replacing the real-world transportation by a truck with a simulation of the dynamic behaviour of container loading arrangements.

Two new dynamic stability metrics that can be integrated within any container loading algorithm are also proposed. The metrics are analytical models of the proposed stability performance indicators, computed by multiple linear regression. Pearson's *r* correlation coefficient was used as an evaluation parameter for the performance of the models. The extensive computational results show that the proposed metrics are better proxies for dynamic stability in the CLP than the previous widely used metrics.

1. Introduction

The Container Loading Problem (CLP) is a real-world driven, combinatorial optimization problem which belongs to the more generic combinatorial optimization class of Cutting and Packing problems. The CLP addresses the optimization of the spatial arrangement of cargo inside containers or transportation vehicles, maximizing the usage of space. In the CLP, a set of boxes (small items) of parallelepiped shape must be packed orthogonally in a set of containers (large objects) of parallelepiped shape, in such a way that the boxes do not overlap and all the boxes of the subset lie entirely within the container. Each box can be associated with a box type $k (k = 1, \ldots, K)$, which is characterized by its depth, width and height (d_k, w_k, h_k) and required quantity n_k. Each container can be associated with a container type C_j, characterized by its depth, width and height (D_j, W_j, H_j) and available quantity m_j.

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The typology proposed by Wäscher et al. (2007) for Cutting and Packing problems, classifies problems according to dimensionality, assortment of large items, assortment of small items, kind of assignment and shape of small items. The assortment of large and small items is related to the number of different types of items in the problem and is commonly classified either as strongly heterogeneous (many types) or weakly heterogeneous (few types). As an assignment problem, it can have two basic objectives: the maximization of the value of the cargo loaded, when the number of containers is not sufficient to accommodate all the cargo, or the minimization of the cost of containers, when there are sufficient containers to accommodate all the cargo.

The above defined CLP can be seen, in its essence, as a geometric assignment problem. Nonetheless, as it is a problem driven by real-world considerations, the solutions will be of limited applicability to real-world scenarios if real-world constraints are not considered. It is therefore of the utmost importance the development of operation decision-support systems that can be actually used by the transportations industry and thus contribute to the increase of the capacity of transportation (Crainic et al., 2009; Bierlaire, 2015).

Using the work of Bischoff et al. (1995) as a starting point, Bortfeldt and Wäscher (2013) recently reviewed the literature on container loading constraints and suggested a classification for the real-world constraints. They distinguish between: container-related constraints (weight limits, weight distribution); item-related constraints (loading priorities, orientation, stacking); cargo-related constraints (complete shipments, allocation); positioning constraints; and load-related constraints (stability, complexity).

The stability constraint was referred to as one of the most important, being addressed in 37.4% of the articles reviewed by Bortfeldt and Wäscher (2013) (surpassed only by the orientation constraint with 70.6%). Its high relevance reflects the impact on customer satisfaction and operational efficiency as well as the safety of both workers involved in loading operations and other persons or vehicles during transportation. These authors also note that there are two types of stability constraints, distinguishing between static and dynamic stability, and that only a small number of papers address dynamic stability. It is also claimed by these authors that the existing stability metrics are not sufficient to evaluate the stability of a container load and can lead to wrong assessments. They just measure the average lateral and base support of the boxes, simply implementing some rules-of-thumb that do not actually represent real-world dynamic stability. Without a set of dynamic stability performance indicators that can actually translate dynamic stability, and from which we can extract information to incorporate in container loading algorithms, the use of the existing metrics within the CLP will continue to lead to the development of container loading algorithms that do not meet the requirements of the transportation industry.

This paper focus on cargo dynamic stability. Its aim is to propose a new set of dynamic stability metrics for the CLP, reflecting real-world dynamic stability, to be used within a container loading algorithm.

The proposed approach to determine the new stability metrics is illustrated in Fig. 1. Firstly, two dynamic stability performance indicators are derived and proposed. These indicators try to measure and quantify the effects of instability in cargo arrangements after transportation takes place. Secondly, instead of the actual transportation process by trucks, a set of transportation scenarios is implemented in a specialised physics simulation tool (StableCargo). The simulation uses 1500 cargo arrangements, corresponding to solutions previously obtained for the well-known Bischoff and Ratcliff (1995a) and Davies and Bischoff (1999) CLP instances, employing the selected transportation scenarios; the outcome is then evaluated in terms of instability consequences by looking at the two dynamic stability performance indicators. Thirdly, measuring dynamic stability by transporting the cargo or running a simulation model is time consuming and infeasible to integrate into CLP algorithms that require the (partial or full) evaluation of thousands of solutions. Thus, a set of characteristics is proposed for the cargo and its arrangement which may influence its behaviour in terms of stability during transportation. Finally, two new metrics for dynamic stability are proposed which are applicable to cargo arrangements and capable of being integrated into CLP algorithms. These metrics are derived from a multiple linear regression analysis that models the relation between the two dynamic stability performance indicators and the set of characteristics for the cargo and its arrangements.

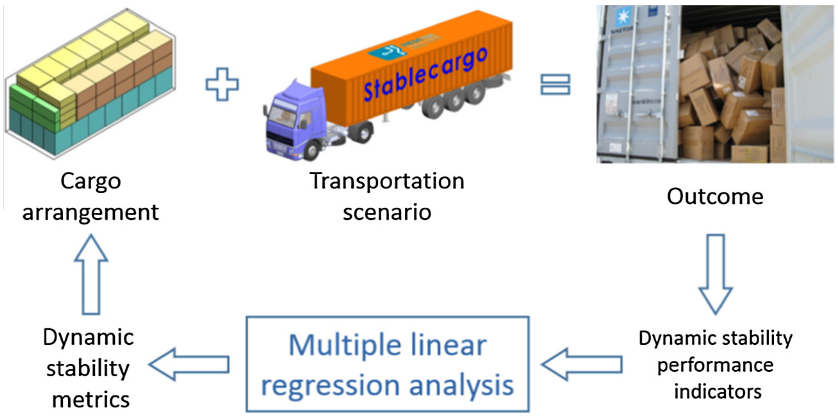

Fig. 1. Approach to determine dynamic stability metrics.