行政院國家科學委員會專題研究計劃成果報告

單一尺寸箱體棧版堆疊方法

A Three-dimensional Pallet Loading Method for Single-size Boxes

計劃編號：NSC-87-2213-E-009-072
執行期限：86 年8 月 1 日至 87 年 7 月 31 日
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一、中文摘要

箱體堆疊於棧板上使其箱體數最大的問題稱為箱體疊棧問題。如果箱體能以底面、側面或端面堆疊，棧板的體積使用率會增加，但單元負載的穩定度可能降低。為了量化單元負載的穩定度，本論文定義兩堆疊層之接觸面的穩定係數。根據穩定係數，本論文提出一單一尺寸箱體疊棧方法，使最大裝載箱數的單元負載能有最大的穩定度。

關鍵詞：配送、物流系統、包裝、棧板堆疊。

Abstract

The problem of finding an optimal loading layout for packing identical boxes onto a pallet is known as the pallet loading problem. If the boxes are stacked on their bottom, side, or end surface, the cube utilization of a pallet will increase, but the stability of unit load may drop. To quantify the stability of unit load, this research defines the stability coefficient between any two adjoined layers. According to the stability coefficient, a method with five phases that packs boxes of the same size onto one pallet is proposed. Incorporating certain practical considerations, the objective of this method is to maximize the degree of stability of a unit load based on the maximum cube utilization of a unit load.

Key words: distribution, logistics, packing, pallet loading.

二、緣由與目的

The problem of finding an optimal loading layout for packing identical boxes onto a rectangular pallet -- the so-called pallet loading problem (PLP) -- arises frequently in logistics. In the PLP, the size $l \times w$ of the box and the size $L \times W$ of the pallet are the two major parameters that determine the number of boxes that can be loaded on the pallet. In addition, a satisfactory solution to the PLP must take into consideration real-life factors such as product characteristics, the load capacity of the forklift, the operation of the pallet loading machine, and the load stability. Few researchers who have studied the PLP have paid sufficient attention to these other factors.

Carpenter and Dowsland [3] proposed three stability criteria that ensure the stability of pallet loading patterns that maximize the number of boxes loaded. Bischoff [1] considered the stability objective in the context of the PLP and examined approaches

for generating stable stacking patterns that are also optimal from the viewpoint of area utilization. By using **compacting**, **centering blocks** and **distributing gaps** procedures, Bischoff extended the Bischoff-Dowsland algorithm [2] to generate more stable layouts under the same criteria as those proposed in [3]

In both Refs. ([1] and [3]), stability is the secondary objective, and the primary objective is maximum area utilization. Once a layout pattern with maximum area utilization has been found, the stability criteria are used to determine whether the pattern is sufficiently stable. Unfortunately, many layouts with a high level of area utilization do not satisfy the stability criteria. Therefore, a method to form a unit load that achieves the highest level of stability is interesting.

This research presents a method with five phases that determines the number of boxes of dimension $l \times w \times h$ that can be loaded onto a pallet of size $L \times W$, subject to a loading height of H. The loaded pallet (unit load) is assumed to be handled by a material handling equipment with a weight capacity of M. The objective of the method is to maximize the degree of stability while achieving the maximum cube utilization of a unit load, under the following practical assumptions.

(1) We assume the boxes may be stacked on their bottom, side, or end surface, as shown in Figure 1. Steudel [7] proposed that the cube utilization of a unit load could be significantly increased by stacking boxes on their end or side surface within the best pallet loading pattern for bottom-stacked boxes. However, his method is suitable only for manual or robot operations, and not for mass production systems using automatic pallet loading machines.

(2) In the operation of an automatic pallet loading machine (Cox & Van Tassel [4]), the unit load is formed layer by layer, so the height of the boxes within one layer must be equal.

(3) The degree of stability between any two adjoining layers is mainly determined by the loading pattern. If the loading patterns are arranged properly, the unit load will be more stable, which will increase shipping stability, help to minimize transportation damage, and reduce the amount of packing material needed.

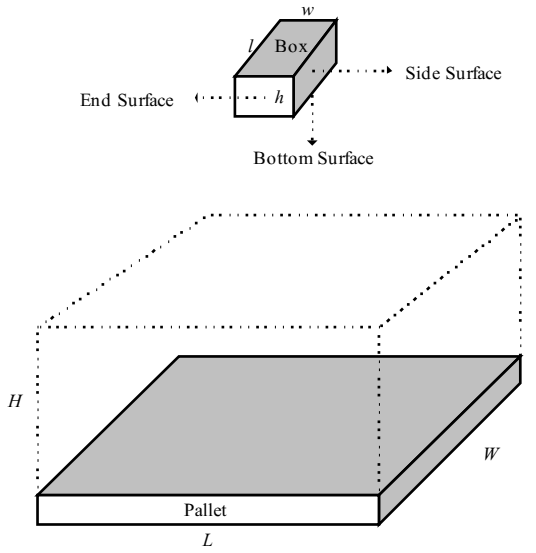

Figure 1: Box of dimensions $l \times w \times h$ and pallet of size $L \times W \times H$

三、結果與討論

In this research, a five-phase method with adjustment procedure is proposed to

solve the three-dimensional pallet loading problem. The method provides the greatest cube utilization and stability for the unit load. The method also arranges the stacking sequence of the unit load on the pallet. Potential applications of this method are numerous, since many products can be positioned and transported on their end or side surface without incurring damage.

In the five-phase method, we assume the boxes may be stacked on their bottom, side, or end surface. Actually, if the box can only be stacked on one or two surfaces, this method also can be applied to maximize the cube utilization and stability of the unit load.

The degree of stability between any two adjoining layers is assumed by the loading pattern in this research. The stability of a unit load depends not only on the loading pattern, but also on the physical characteristics of the boxes, the mode of transportation, and other factors. So the maximum stability of the unit load in the five-phase method does not guarantee that the unit load is absolutely stable. However, if the characteristics of the boxes and the material handling method are the same for two unit loads, the one which the loading patterns are arranged properly will be more stable than the other which do not use the five-phase method. Therefore, using an analytical approach to generate optimum loading patterns is deserved.

The five-phase method is a methodology. The approach in each phase will play a significant role to solve the pallet loading problem with maximum cube utilization and stability of unit load. The solution method of each phase deserves further study to improve the solution quality.

For simplicity, in Phase **1** we assumed that the layout of each layer type is unique. However, one box and pallet combination may have many different maximal forms. The greater the number of alternative layouts that can be selected, the closer to the optimum we can get. The complexity of the problem increases with the number of different maximal forms.

In the five-phase method, the stability of the unit load is the secondary objective, after the major objective, cube utilization. If stability is the major concern instead of cube utilization, the near-optimal solution in Phase **3** may lead to a stacking sequence with higher stability.

In Phase **5**, the heuristics of seeking the best sequence can be stated in terms of graph theory such as TSP, so we develop the heuristic approaches to solve the stacking sequence problem. Using the five-phase heuristic approach, the diversity of loading patterns can be generated in Phase **1**. Since the complexity of the heuristic for phase **5** is polynomial by the number of different loading patterns, enlarging the problem size to treat many basic loading patterns is allowed. A variety of heuristics about these problems could be applied to solve the problem of stacking sequence. A complete discussion of the means of solving this problem is worth studying. So we transform the stacking sequence problem in Phase **5** into the well-known Traveling Purchaser Problem (TPP), and use the TPP approaches

proposed by Golden et al. [5], Singh and Oudheusden [6] to solve the stacking sequence problem. Consequently, using the existing solution procedures for the TPP to find the desired stacking sequence are worth studying.

The five-phase method may be mathematically infeasible or may yield an impractical pallet loading design. We may scarify some cube utilization in Phase 3, then repeat the process until a feasible loading design is obtained.

The maximum stability of the unit load in the five-phase method is the reference for arranging the boxes in the pallet. The stability of the unit load obtained by the five-phase method should be tested before it is implemented. Especially for the unit load design will be used in quantity. One may design a shaking machine that simulates the movement phenomenon of the unit load. Testing the unit load on the shaking machine, the practicle stability may be obtained for a theoretical stability.

四、計劃成果自評

This research successfully completed the proposed objective. One might apply the result to the practical cases. Several related publications about this research done by our team also found in [6,7]..

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