

OPTIMAL SCHEDULING AND LOADING OF TRUCKS FOR DISTRIBUTION OF SOFT DRINKS

L.C. Masinga*, C. Myburgh† and S. Povey‡

Abstract

The problem of loading a truck with the objective of minimising delivery time is investigated. We pose this as a constrained global optimisation problem. A nested genetic algorithm is used that takes into account the delivery sequence of the customers, and works out an optimal configuration of the truck load that will enable savings on off-loading time and hence the turnaround time of the trucks. An example is given to illustrate the effectiveness of the algorithm.

1 Introduction

Given that the company is satisfied with the current software (Road Show) in as far as meeting the objective of allocating a prescribed group of customer orders to a particular truck for a particular route, the group reached consensus that in order to meet the objectives of maximising the number of trips per truck per day and minimise the offloading time per truck, the following two questions should be addressed. Firstly, whether a truck can be packed in such a way that the unloading procedure consists only of removing cases from the top of the multi-stack? Secondly, if this is possible, can this be done to minimise the packing effort?

To answer the first question requires the use of the available information regarding delivery sequence of the orders, which is assumed to be currently

*School of Computational and Applied Mathematics, University of Witwatersrand, Private Bag 3, Wits 2050, South Africa. *email: londiwe@cam.wits.ac.za*

†School of Computational and Applied Mathematics, University of Witwatersrand, Private Bag 3, Wits 2050, South Africa. *email: cmyburgh@cam.wits.ac.za*

‡School of Computational and Applied Mathematics, University of Witwatersrand, Private Bag 3, Wits 2050, South Africa. *email: stephen.povey@supergrp.com*

not utilised. The worst case scenario of mixed pallets was considered since it is the most difficult. However, while answering the first question could result in substantial savings on costs for offloading, it is possible that it will impact on the picking and packing time. The idea is to try and answer the first question by making use of the prescribed delivery sequence, as well as the available data on the stock keeping units (SKUs) of the various products. This would be achieved by working out an optimal configuration of the truck load that will enable savings on offloading time and hence the turnaround time of the trucks. This procedure would be based on global optimisation techniques. Once this configuration has been worked out, it is reckoned that focus would then be turned to the picking and packing process, particularly at the staging point. It may be necessary to change the current picking list in a way that may require pallet-based picking and packing instead of the current product-based approach. At the end of the exercise, the procedure should try and balance the costs of picking and packing against the costs of offloading time. If a good balance is reached, it is hoped that the objective of increasing the number of trips per truck will be met, thus saving on truck hiring costs.

2 Similar problems

The problem at hand is related to packing problems that have been studied widely in the literature. The basic packing problem has been studied in the context of the knapsack packing, bin packing, pallet packing and container loading problems. In the earlier studies many of the models were two-dimensional. Methods of tackling three-dimensional packing problems have been investigated in the last decade [2]. Two aspects of interest are the packing of non-identical items onto pallets [1] and with limited load bearing strength [2] have been considered. Both these presentations, and many related, are based on container loading.

This is the point of departure for this study, where the problem is to load a truck with pallets packed with prescribed customer orders. Apart from the fact that the pallets are packed with non-identical items, and the other constraints pertaining to crushing limits and stack heights, the order in which the pallets will be loaded onto the truck and off-loaded at the destination points, has to incorporate the route that the truck will take during delivery. This route has been prescribed ahead of the packing process with the objective of minimising transportation costs. A lot of costs have been associated with off-loading of the orders and hence the packing and the

truck loading has to be done in such a way as to minimise off-loading time. This leads to a multistack, pallet packing problem that allows off-loading from the top.

3 Algorithms

The knapsack algorithm and its variations has been used extensively in the studies of the packing problem. Among the latest development in this area has been the use of heuristic algorithms such as genetic algorithms, which have also been used in tackling the knapsack problem.

In his paper focusing on limited bearing strength, Bischoff [2] uses a heuristic approach that makes use of pure random search techniques, Simulated Annealing and similar local search procedures to determine the loading arrangements.

3.1 Our approach

Assumptions

- The constraint of maximum truck load and is accounted for in the truck allocation.
- The current routes take into consideration the problem of varying operating times for the customers.
- Customers can only order whole layers of products, that there is a minimum of one order and that only whole layers can be removed from the truck. Thus our problem is two-dimensional.

Objective

The objective of the algorithm developed is to minimise the cost of violating the various constraints of maximum truck height, maximum crush weight, the number of split stacks, and off-loading sequence. A penalty function is used as a performance index that tells us how "good" a truck loading, zero being the perfect truck. Thus the performance index is the sum of the height, crush weight, the split stacks and the off loading sequence. The off-loading sequence constraint counts the number of times a product is re-packed when removing a client's order off the truck.

4 The model

The variables involved in the problem are product type, the client identification, the order composition, the stack identification, and the truck identification.

Let

T = generated truck

S_i = i -th stack of T , $i \in N$

$P_h(S_i)$ = height penalty for stack i

$P_w(S_i)$ = weight penalty for stack i

$P_s(S_i)$ = splitting penalty for stack i

$P(T)$ = penalty of truck T

$P_o(S_i)$ = off-loading penalty for truck T

Then the problem is

$$\min_T J(T) = \sum_i (P_h(S_i) + P_w(S_i) + P_s(S_i)) + P_o(T) \quad (4.1)$$

The respective penalty functions have the form:

$$P(x, \bar{x}) = \begin{cases} 0 & \text{if } x \leq \bar{x} \\ \alpha + \beta(x - \bar{x}) + \gamma(x - \bar{x})^2 & \text{otherwise} \end{cases} \quad (4.2)$$

where x is measurement variable with threshold \bar{x} , and α , β , and γ are parameters.

- The height penalty measures how far above the maximum height a stack is and is given by

$$P_h(S_i) = P(h_i, \bar{h}_i) \quad (4.3)$$

where h is the observed height of stack, and \bar{h} is the maximum allowed height.

- The weight penalty measures the extent of the crush of items and is given by

$$P_w(S_i) = P(w_i, \bar{w}_i). \quad (4.4)$$

where w_j and \bar{w}_j are respectively the observed weight acting on layer j and crush weight of product at layer j .

- The splitting penalty measures how many times a stack has been split (that is, is not of one type), obtained by counting the number of times a stack changes product type. This penalty is denoted $P_s(S_i) = n$.

- Finally, the off-loading sequence constitutes a secondary (nested) optimisation problem given by

$$P_o(T) = \min_q P_{\text{sequence}}(T, q)$$

where $P_{\text{sequence}}(T, q)$ is the number of items repacked when removed from T in sequence q .

4.1 Algorithm

Apart from the genetic algorithm used in this study to solve the problem, the nature of the problem is such that it could be solved by Simulated Annealing. Here we chose to use a genetic algorithm approach since it is well suited to discrete problems, particularly South Africa in our case. Both the optimisation problems of minimising the total penalty and that of minimising the penalty on off-loading were solved by this technique, the latter being nested in the former.

Program outline

The input is a matrix representation of the clients' orders. The rows of the matrix refer to the clients and the columns refer to the product type. The matrix entries refer to the number of layers each product client needs.

The population is that of a permutation list, generated from the input order. For the initial population the order is first written as a list, permuting it and defining where the tops of stacks are.

The breeding stage consists of breeding the trucks from which the permutation lists are created. By so doing we guarantee that the contents (the orders) will remain the same and hence that a truck will have all the products for all the clients on the designated route.

4.2 Example

We illustrate the implementation of the algorithm by way of an example. Three inputs would be used to construct the input matrix: the product which consists a total of four items that have been ordered; the client which represents three customer orders that have been assigned to the particular truck; and the stack identification which is characterised by various constraints on the products.

Truck U can be loaded with up to 4 stacks. The system at hand is summarised as follows:

Product={1,2,3,4}

Client ={1,2,3}

Stack={1,2,3,4}

The constraints for four stacks each of height 20 units are

Product height = {2, 2, 4, 1 } (units of height)

Product weight = {1.5, 1, 2, 0.5 }

Crush weight = {6, 4, 10, 4 }

A typical order would be

Order={ (2,1,1), (4,4,1) (3,1,2), (1,2,2), (2,3,2), (6,2,3), (1,3,3), (3,4,3) }

where each triple (i, j, k) translates to i layers of product j ordered by client k . For example $(3, 1, 2)$ stands for 3 layers of product 1 ordered by client 2. Thus in this particular example the consignment has deliveries for 3 clients. Client 1 ordered 2 layers of product 1 and 4 layers of product 4. Similarly, client 2 ordered 3 layers of product 1, 1 layer of product 2 and 2 layers of product 3. A similar interpretation can be derived for client 3.

A matrix representation of this order would be

	Product			
	1	2	3	4
1	2	0	0	4
Client 2	3	1	2	0
3	0	6	1	3

A solution of this problem would have the following configuration:

Stack 1	Stack 2	Stack 3	Stack 4
1			
1			
4			
4		2	
4		2	
4		2	1
4	3	2	1
4	3	2	1
4	2	2	3

The configuration suggested by the above solution is as follows:

On Stack 1 start by loading 7 layers of product 4, followed by 2 layers of product 1. On Stack 2 only 1 layer of product 2 should be loaded first, followed by 2 layers of product 3. Stack 3 should be loaded with 6 layers of product 2 only. Finally, Stack 4 should be loaded with a layer of product 3 first then 3 layers of product 1 on top.

5 Conclusions and recommendations

It has been demonstrated that it is possible to solve the problem of optimally loading a truck to minimise turn around time by global optimisation techniques. In particular genetic algorithms are useful in this task. The algorithm was tested on a small example involving three customers and has been found to work. This is a small scale problem when compared to the real situation. Further work would be needed to test the algorithm for loads consisting of a larger number of clients. It has been assumed that time to design the truck loading is not critical since this can be done in advance. Also, the time available to load the truck has been assumed not to be a problem since the trucks are loaded overnight. It is interesting though to note that the way the truck is loaded may affect the way the orders are picked, which may be different from the current practice of picking the full order of a particular item at a time for staging. This seems to constitute a different problem in itself, which may lead into the need to investigate the trade-off between picking time and off-loading time. Moreover, in a manually operated loading environment, the capacity of the loading personnel to carry out the prescribed truck load sequence may be of concern. This may require more specifications on the side of the planner, such as the sequence of the stacks at staging, that take into account the truck route.

In solving the problem, only two-dimensional stacks were used. In reality, pallet loads are three dimensional. Hence further work needs to be done to accommodate three dimensional aspects of the situation.

Acknowledgements

We would like to thank the Industrial Representative of Amalgamated Beverage Industries who made a substantial contribution to our understanding of the problem.

References

- [1] Bischoff, E.E., Janetz, F. and Ratcliff, M.S.W. Loading pallets with non-identical items. *European Journal of Operational Research*, 84 (1995), 681-692.
- [2] Bischoff, E.E. Three-dimensional packing of items with limited load bearing strength. *European Journal of Operational Research* (2004), (in press).

- [3] Hartmann, S. Packing Problems and Project Scheduling Models: An Integrating Perspective. *Journal of the Operational Research Society*, 51 (2000), 1083-1092.