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HOW TO SUPPLY ASSEMBLY LINES

Great efforts are currently dedicated to cost engineering in industry. The lean production approach is a good way to lower production costs. Material flows and treatment should be planned and controlled neither too early nor too late, because early production leads to an increase of stocks of materials and late production to a backlog of orders. This task is especially important in serial production, e.g. in the automotive industry. A buffer stock could be connected with assembly lines in many ways, such as handcarts, fork lift trucks or special cableways. A modern method of material supply in an assembly workshop is the usage of tow trains consisting of a tow truck and several carts. The number of carts in a train can change but it cannot be high because of turnings and crossings. The task is to find and optimize transport routes. This task is considered to be NP-hard. The paper describes several approaches to solving the task.

Keywords: *Material supplies, heuristic optimization, assembly lines, milk run VRP problem.*

1. Task specification

There are two main possibilities for building tow trains in a central store:

- Using static milk run
- Using dynamic milk runs

The first case expects that transport routes are constantly designed. Assembly lines are operated with trains which run on fixed routes, sometimes in fixed periods. Optimization tasks are focused on finding good coverage of an assembly workshop with transport routes, and estimating the optimal number of trains and their lengths. Another task is to find a good solution for the bin packing problem of a cart. The optimization of such a system has been made by Ulrych and Raska [1].

A more interesting way of supplying assembly lines is the creation of routes and lengths of tow trains according to the momentary situation. There are demands from some assembly points for a new delivery of a material batch. The delivery must be in time. The criterion of optimization is a minimum sum of the length of all routes. The task is open, which means that during processing of an optimal schedule of tow trains new demands can appear. Trains on routes must carry out their orders but the rest of the demands are added to with new demands and newly optimized.

An example of such an assembly system is shown in Fig. 1. There is a central store, several assembly lines with work places and supply points. Tow trains can go in lanes. Lanes are mostly one-way. Trains cannot be overtaken and must wait when another train provides a supply point.

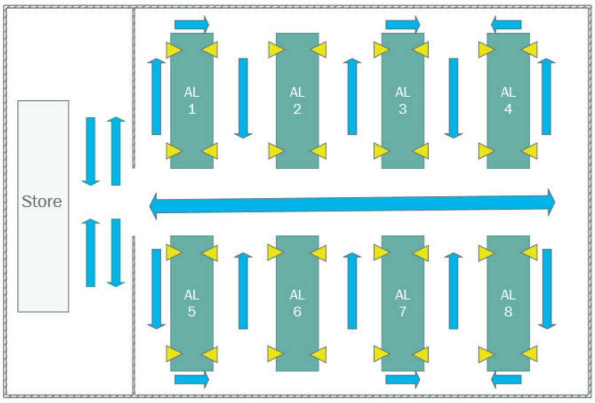

Fig. 1 Model of an assembly line (AL) supply system

This model can be represented in the form of a graph (Fig. 2). In this example, U00 represents the store, vertices Uxx supply points on assembly lines. Edges are evaluated by distances between them. Transport demands of U01, U05, U17, U18, U11, U13 and U14 can be covered by two cycles (red and blue) which represent routes of two supply trains.

If the length of a tow train is n carts then the task of optimizing the sum of lengths of routes can be represented by covering the graph with cycles going through maximal n vertices of the graph.

Groups of n demands ($1 < n < 20$) are randomly generated from vertices needing service by trains. Every group can be considered as a subgraph. The task is to cover the subgraph with cycles of a maximum of 5 vertices (start in the central store and

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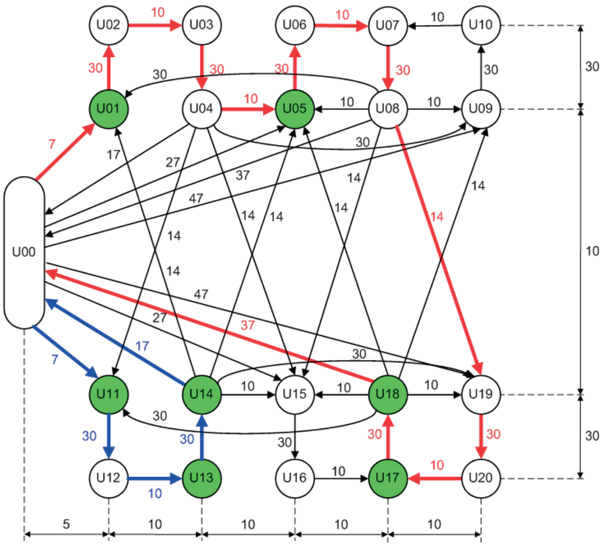

Fig. 2 Graph representation of assembly lines and supply routes

4 supply points in assembly lines) so that the total length of these cycles representing the routes of individual trains will be the shortest of them.

2. Related literature

Several approaches for solving this or similar tasks can be found in published papers.

Andras Kovacs [2] tries to minimize the order cycle time and the average picking effort. A probability model is used. Kovacs stated that "We showed that the milkrun system leads to a correlation among the request probabilities of items that can be exploited in a mathematical programming model".

Some authors use artificial intelligence. Ediz Atmaca and Ayla Ozturk [3] use a simulated annealing solution. Zahalka [4], Tripathi [5], Montemani A.V. [6], Naqvi [7] and Lucka [8] use methods of an ant colony. Adamidis and others [9] use an evolutionary algorithm.

The vehicle routing problem is also described and solved by using a branch-and-price algorithm in [10]. Genetic algorithms are also used in [11]. Collection and Delivery problem is solved by Brian Coltin (minimizing energy and time, minimizing distances of a robot delivery) [12]. The task of supply of assembly lines was studied using a mathematical approach by Cardenas-Barron [13].

A very good overview of the related literature, a mathematical model and a heuristic approach is made by Satoglu and Sahim [14]. A case study of an assembly system is made by Emde and Boysen [15].

Selected Heuristic Methods Used in Industrial Engineering were published in DAAAM conference in Vienna 2013 [16].

3. Summary of related literature

Because the task of creating optimal routes for tow trains supplying assembly lines is NP-hard, the heuristic approach is considered to be a good solution for this task. A lot of authors use some genetic algorithms, ant colony systems or simulated annealing.

The weaknesses of these approaches can be found in the following areas:

- Complicated algorithms with long time solutions;
- Difficulties with determining or measuring real and valid input parameters that can change in time;
- Breakdowns and disturbances in a real production process which are unpredictable.

Solutions can be of long duration, sometimes hours and not seconds, changing parameters are not estimated with the necessary accuracy, unpredictable disturbances in workshops and simplifications in the abstraction arc from a real system to a mathematical model lead to no valid system.

4. A practical approach

It is interesting to observe a crane driver. If there are not many transport demands a crane driver has long idle times and the probability of some transport queues is low. If a lot of transport demands exist, the driver tries to solve the nearest demand. Sometimes he takes priorities into account. The simulation of this approach proved that the more demands there are, it is best for the driver to first prioritize and after that solve the nearest demand. The optimization could be done for queues of length under 10 by computing all permutations on a normal PC in times less than one second.

5. Hypotheses

Selection of the nearest demand

There is a simple deterministic solution – repeated selection of the nearest demand, then of the demand nearest to the goal of the last selected demand up to the maximum length of the train. The next trains are selected in the same way. This strategy could be good for a stacker in a FMS (Flexible manufacturing System) or in a store but not very appropriate for tow trains.

Simple crane or stacker in a FMS

For a small number of demands all permutations can be computed in a short time and for a great number of demands the strategy to select a nearest demand is also a good solution. The area between small and great number of demands could be covered by a selection from random generated permutations of demands.

Tow trains in assembly line systems

Let's say that the length of a train is maximal n. For less or equal demands than n all permutations can be computed (the practical length is under 7 carts). For more than n demands it is possible to randomly select several n-tuples of demands. Each n-tuple is optimized by computing all permutations. The random selection of n-tuples could be repeated many times. The number of repetitions is limited only by computer time (for example under 3 seconds).

6. Approval of hypotheses

Solution by brute force

The optimization problem is considered to be NP-hard. It is possible to solve it by brute force trying all permutations of high order up to 12 demands. To verify it, a test program has been developed. Results are shown in Table 1.

Times for solutions with brute force — Table 1

n	factorial	Sec	min
2	2	0.000	0.000
3	6	0.000	0.000
4	24	0.000	0.000
5	120	0.000	0.000
6	720	0.000	0.000
7	5 040	0.000	0.000
8	40 320	0.003	0.000
9	362 880	0.029	0.000
10	3 628 800	0.277	0.005
11	39 916 800	3.020	0.050
12	479 001 600	36.082	0.601
13	6 227 020 800	489.931	8.166
14	87 178 291 200	7 000.000	116.667

Stacker

Simulation programs have been developed to validate the hypotheses.

It is possible to consider that demands for a stacker in a FMS have regular distribution of demands, which means that horizontal positions of all start and end points of demands could appear with the same probability. The task is to minimize the sum of the length of unloaded moves. With no optimization (FIFO – First In First Out), the ratio between unloaded and loaded moves is 100%.

Four strategies of optimization have been tested (Fig. 3):

- No optimization (FIFO).
- Selection of the nearest demand (Proximate).
- Repeated selection of random permutation (Random permutation).
- Brute force (all possible permutation up to 10 demands, then the computing time rises too much).

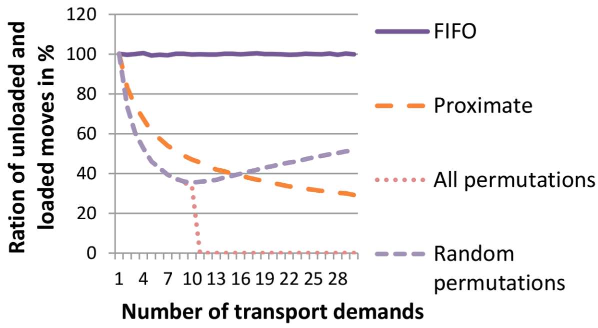

Fig. 3 Optimization of a stacker in a FMS

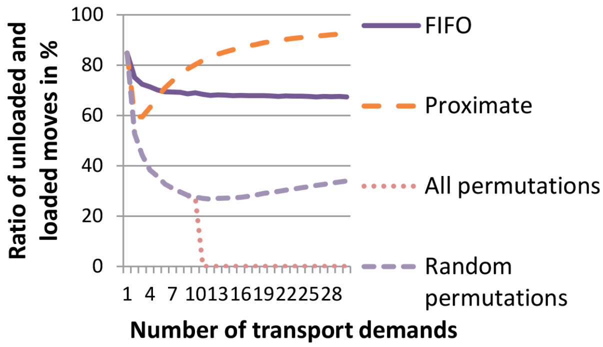

Fig. 4 Optimization of a stacker in a store

Stackers are often used in stores (Fig. 4). Moves of a stacker in a store are asymmetric which means that it either starts at one end (input place of a rack) and ends anywhere in a rack, or starts anywhere in a rack and ends at the same end (output place) where the input place is. This case was also simulated and optimized.

The simulations verified the hypotheses.

Tow trains in assembly line systems

The maximum length of a train was considered to be 4 carts and 1 tow truck. The optimum in a 4-tuple was found by testing all 24 possibilities. The task was to divide all transport demands into 4-tuples. Two strategies were used:

- selection of the proximate demand (deterministic),
- repeated random selection of 4-tuples, evaluation of lengths of routes for all tuples, the selection of the best selection (minimum length).

The worst selection was chosen for comparison.

This simulation verified that this method can decrease lengths of routes to about 70% of an unoptimized strategy (Fig. 5).

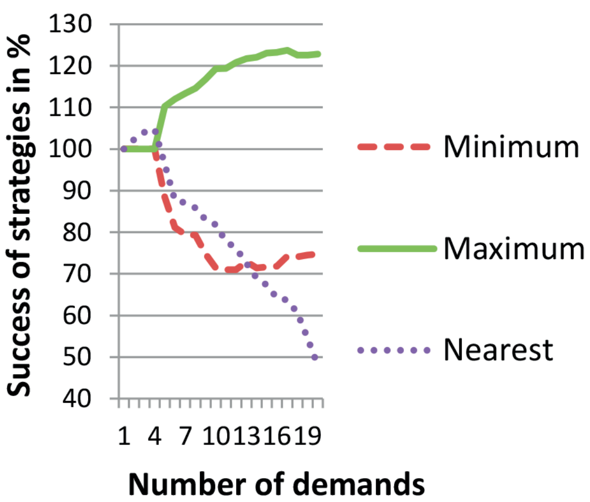

Fig. 5 Success of strategies
(nearest demand, min and max random selection)

7. Conclusion

The research carried out on an "ad hoc" proposed model proved the hypothesis that a dynamic optimization of train creation and specification of supply routes of trains can be made in real time using relatively simple methods which are not critically dependent on the accuracy of input data with good optimization results. Means of transportation and manpower can be saved in this way, and peaks of transport demands can be solved more quickly.

The model presented here has been developed theoretically, but inspired by an actual production system model of an assembly line. Subsequent research will be based on the one hand on optimization of larger production systems with the hypothesis of division of the optimized system into two or more parts, and on the other hand on specification of accurate data of an actual production system and experiments leading to optimization of its supply demands.

The optimization of a stacker in a FMS or in a store has been presented for comparison but this strategy was used in several production systems many years ago.

Repeated random selections could be a good solution when optimization tasks are considered for NP-complete. As has been shown above, some "ad hoc" deterministic strategies can also be used and compared with random selections.

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