HEURISTIC APPROACH TO INVENTORY CENTRALIZATION

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Abstract: *For production or maintenance system inventories are necessity as well as additional cost incurred by capital that is invested in those inventories as well as warehousing (equipments, objects, workforce). By inventory centralization it is possible to achieve system wide reduction of inventory level trough risk pooling effect, and therefore costs reduction. In the same time, inventory centralization increases transportation distances and service times which leads to costs increase. In this paper we describe heuristic approach to inventory centralization of spare parts in multi-echelon storage for an arbitrary maintenance system. Objective function of the proposed model has three main segments: inventory costs, transportation costs, and workforce costs. The heuristic approach is based on the model developed for one utility company in Republic of Serbia.*

Keywords*: Inventory centralization, heuristics, spare parts, warehouse locations.*

1. INTRODUCTION

Inventory centralization to fewer warehouses incurs system wide reduction of inventory level, while increasing transportation distances and therefore service times which is very important quality measure in maintenance industry of technical systems. By maintenance industry we refer to maintenance of large technical systems (country wide) that requires network of warehouses with spare parts inventories used for preventive and corrective maintenance where long downtimes are typically very expensive. Warehouses are used to hold inventories of spare parts and therefore are usually a part of maintenance centers. These technical systems can be large public and cargo transportation systems, utility companies (generation and transmission or distribution of electricity, gas, water, or heating power to general public), etc. In the problem of inventory centralization two sub-problems are closely depended, determining the level of centralization and choosing the locations of warehouses in which stock will be held. The main goal of solving these problems is to minimize total costs (e.g. inventory costs, warehouse costs, transportation costs, manpower costs) while ensuring adequate service level which is represented by the level of inventory stock-outs and service response times especially in corrective maintenance (directly correlated to length of system downtime). There are many research papers in the available literature related to inventory centralization and maintenance industry of large technical systems. In the following we outline few of the most relevant to our topic. Centralization of warehouse locations can lead to cost savings through the reduction of the total level of the stock, but on the other side centralization has a negative effect on the necessary transport of goods, as noted by Das and Tyagi (1997). That is, to optimize warehouse operations in terms of inventory centralization, it is essential to respect the impact on transport

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costs. Basten and Houtum (2014) observed models for inventory management of spare parts in different systems. They stated that the location of warehouses and maintenance centers are very important segments of optimization. Perrier et al. (2013) observed the models and algorithms for warehouse locations and service zones for utility company with emphasis on corrective maintenance, where they state that transportation needs in the maintenance has high impact. Berg (2013) looks at the allocation of materials in multi-echelon storage system at the Dutch utility company, considering primarily the methodology of allocation of parts for emergency response (as most important) from the rest of the materials and parts, as well as the allocation of those goods in the warehouses of different levels.

In this paper we describe methodology and heuristic approach to inventory centralization of spare parts for an arbitrary maintenance system. The heuristic approach is based on the model developed for one utility company in Republic of Serbia. The remaining part of this paper is organized as follows. The problem and methodology description is given in Section 2. The heuristic approach is described in Section 3. Section 4 presents test instances and computational results. Finally, some concluding remarks are given in Section 5.

2. PROBLEM DESCRIPTION

In this paper we analyze the system with the four hierarchical levels. It is assumed that the central warehouses (1st tier) and 2nd tier warehouses have large storage capacities (also, its capacity could be potentially increased if necessary), while 3rd and 4th tier warehouses are auxiliary and have very limited opportunities for expansion. Additionally, not all locations from the first two hierarchical levels are adequate for centralization mainly due to the lack of available storage capacity for different spare parts, expansion restrictions and legislative reasons. Also, it is assumed, accordingly to previous experience, that some of warehouse locations are well developed, have strategic importance and that they are crucial for company's operations. Therefore, those warehouses must be included in the solution.

The territory covered by the service network is divided into service zones where each zone is defined by its spatial centroid and expected monthly consumption (spare parts demand). Spare parts are classified in clusters, with known average demand, and its standard deviation. Also, for each cluster - group of spare parts is also known expected number of maintenance runs during the one observed period (one month), which is based on the maintenance history data and maintenance plans on the one year level. The clustering of spare parts (groups of components and parts) is based on the type, dimensions and technical characteristics. Inventories can be centralized on the level of cluster. In other words it means that it is possible to centralize spare parts from different service zones in the same warehouse, but only considering all parts belonging to the certain cluster. It should be noted that groups of spare parts with high maintenance intensity is preferable to be close to maintenance location and therefore less likely to be centralized, due to high transportation costs incurred. Also, when centralizing inventories from one zone to some location outside that zone service response time should be always respected. In the proposed heuristics mentioned requirement is included as a constraint counting travel time to the service zone. In the following chapter we describe the heuristic approach to solving the inventory centralization problem.

3. HEURISIC APPROACH

Inventory centralization optimization is based on the idea of determining the effects of risk pooling where centralized inventory results in lower safety stock and average inventory in the system. Centralization of a safety stocks at one place results in the same level of the stock-out risk while having lower safety stock quantity. In our heuristic approach, without loss of generality, we presume that the demand for spare parts can be represented by Normal

Distribution $N\sim(\mu,\sigma)$ where μ stands for mean of demand for spare parts and σ stands for standard deviation of that demand in the observed period (replenishment time or lead time). For two warehouses with identical demands (same mean and standard deviation) total stock can be represented by equation $2\cdot(\mu+k\cdot\sigma)$, while in the case of centralization total stock can be represented as $2\cdot\mu+\sqrt{2}\cdot k\cdot\sigma$ (square root law). In the case of inventory centralization of three warehouses with identical demands total stock can be represented by equation $3\cdot\mu+\sqrt{3}\cdot k\cdot\sigma$, etc. In our model we exploit square root law equation to approximate total stocks in centralized locations (locations in which multiple zones hold its spare parts). Coefficient k is used to determine the size of safety stock, where higher value means higher probability of having enough stock to satisfy the demand, e.g. in case of k=3 system would have 99.7% probability of no stock-outs. This value for k, referring to high service level, is used in the model with the idea of avoiding stock-outs and system downtimes which are typically very expensive. It is obvious by looking at square root law equation that the total stock level in system is reduced by higher level of centralization which leads to lower costs of bound capital (opportunity costs) and warehousing, while at the same time transportation needs to transit longer distances which in turn increases total costs. Therefore, objective function of the proposed model has three main segments as given by Eq. (1): inventory costs; transportation costs; workforce costs.

$$\min \rightarrow T_{inv} + T_{tran} + T_{workf} \tag{1}$$

Inventory costs (given by Eq. (2)) are defined by lost opportunity costs (given as percentage of total value of stock in system) and by cost of handling and storage of inventories in objects (where costs depend on number of storage units) and open storage space (where costs depend on occupied square meters of space).

$$T_{inv} = \sum_{i\in I}\sum_{j\in J}\sum_{a\in A} x_i^{ja}\cdot Z_i^{ja}\cdot C^c + \sum_{i\in I}\sum_{j\in J}\sum_{b\in B} x_i^{jb}\cdot Z_i^{jb}\cdot C^{unit} + \sum_{i\in I}\sum_{j\in J}\sum_{h\in H} x_i^{jh}\cdot Z_i^{jh}\cdot C^{m2} \tag{2}$$

i - warehouse location ($i\in I$)
j - service zones ($j\in J$)
a - spare parts group ($a\in A=B\cup H$)
b - spare parts group which is primarily stored in warehouse building ($b\in B$)
h - spare parts group which is primarily stored at open space warehouse , ($h\in H$)
x_i^{ja}, x_i^{jb}, x_i^{jh} - binary variable that is equal to 1 if warehouse i serves zone j with spare parts group a, b and h respectively
Z_i^{ja}, Z_i^{jb}, Z_i^{jh} - average inventory stock in warehouse i for zone j of spare parts group a, b and h respectively (these values are calculated by square root law equation for those warehouses that have inventory centralization, i.e., store spare parts groups from different service zones)
C^c - percentage of stock value used for calculation of lost opportunity costs
C^{unit} - unit cost of storing one unit in warehouse buildings
C^{m2} - unit cost of occupied square meters open space warehouse

Transportation cost (given by Eq. (3)) depends on the expected number of transportation runs initiated by maintenance demand, and distance of a service zone from warehouse location.

$$T_{tran} = \sum_{i\in I}\sum_{j\in J}\sum_{a\in A} x_i^{ja}\cdot F^{ja}\cdot D_i^j\cdot C^t \tag{3}$$

F^{ja} - expected number of transportation runs in service zone j which include spare parts group a
D_i^j - travel distance from warehouse location i to the centroid of service zone j
C^t - unit transportation costs

Workforce costs are defined by Eq. (4) and (5). Those costs depend on the intensity of operations. It is assumed that the intensity of operations depends mostly on the number of maintenance orders.

$$T_{workf} = \sum_{i \in I} r_i \cdot C^{workf} \tag{4}$$

$$r_i = \frac{\sum_{j \in J} \sum_{a \in A} x_i^{ja} \cdot \frac{Y^{ja}}{D}}{N} \qquad \forall i \in I \tag{5}$$

r_i - required number of workers in warehouse *i* (integer value round to first ceiling value)
C^{workf} - monthly costs of one worker
Y^{ja} - number of maintenance orders per month for spare parts group *a* in service zone *j*
D - number of working days in one month
N - nominal number of maintenance orders can be done by one warehouse worker

Algorithm of the proposed heuristic approach is presented in Fig. 1, and comprises four local search improvement neighborhoods. It is greedy heuristics based on the best improvement concept. When there is no improvement in one neighborhood, improvement phase continues to the next one until the final neighborhood of swapping pairs of warehouses.

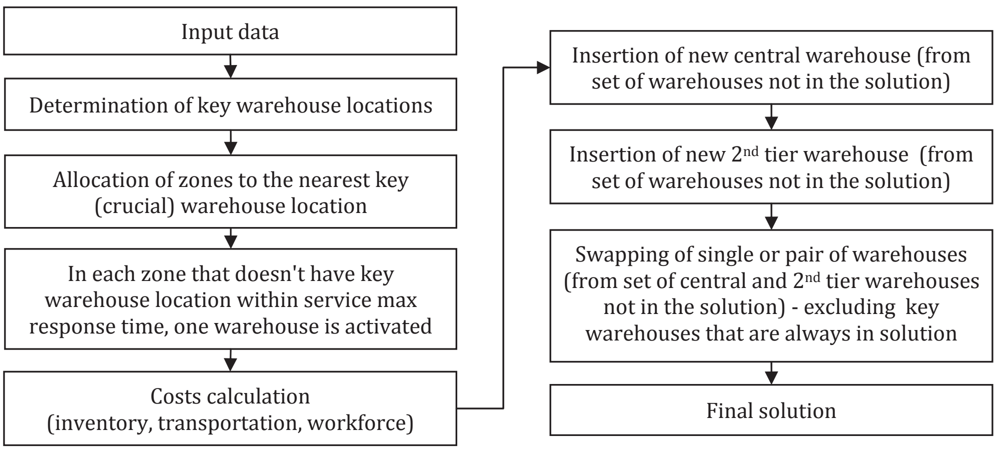

Figure 1. Heuristic approach algorithm (left - construction phase, right - improvement phase)

4. COMPUTATIONAL RESULTS

To test proposed heuristics we used general input parameters given in Table 1.

Table 1. General input parameters for the model

DATA	VALUE	
Transportation cost	0.25	per km
Open storage cost	3.30	per m^2 per month
Cost of storage in closed objects (warehouses)	1.25	per storage unit per month
Workforce cost	580.00	per worker per month
Replenishment period		quarterly
C^c - percentage of stock value	12	%
Service max response time	2.5	h
N - norm for one warehouse worker	150	output (storage units) daily

System we considered consists of 120 service zones and 57 warehouse locations which included 7 predefined locations that must be included in the solution. The best solution found (Fig. 3) includes 28 centralized locations, while multiple run of proposed heuristics for predefined range of centralized inventory locations (24 to 33 locations) showed its impact to the total system costs (Fig.2). Heuristic model was implemented in Python 2.7 programming language on PC Intel(R) Core(TM) i3 CPU M380@2.53GHz with 6 GB RAM memory.

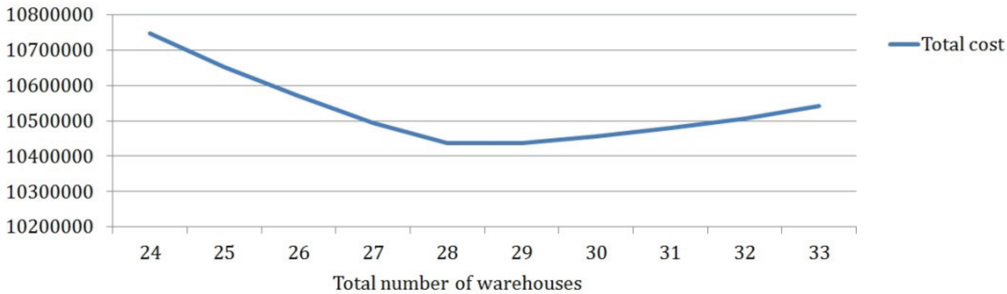

Figure 2. Total costs for different level of centralization (number of warehouses in solution)

Table 2. Computational results for the best heuristic's solution (28 centralized locations)

Locations from Fig. 3	Number of allocated zones	Total annual costs	No. of warehouse workers	Warehouse capacity in storage units	Warehouse capacity in m² of open storage	Annual travel distance of vehicles in km
1	7	1 200 131	4	4 876	5 133	1 764 291
2	6	687 067	3	7 085	2 141	1 063 169
3	2	471 782	2	5 163	2 464	472 985
4	4	583 687	2	6 203	2 056	989 194
5	2	429 353	2	3 687	2 374	500 255
6	5	510 793	2	5 193	1 995	710 655
7	2	358 731	2	4 750	1 644	373 159
8	2	369 804	2	3 752	1 859	392 430
9	3	391 384	2	4 512	1 480	525 202
10	1	272 479	1	2 780	1 835	193 903
11	1	271 910	1	3 303	1 666	136 659
12	9	516 870	2	4 692	1 191	935 163
13	4	505 809	2	4 769	1 127	836 907
14	2	284 408	1	3 117	1 364	244 432
15	9	536 259	1	1 713	1 561	1 413 514
16	11	463 795	1	2 287	1 159	1 080 435
17	4	246 465	1	3 316	895	296 288
18	5	340 201	1	3 513	783	609 490
19	5	240 733	1	2 526	771	285 053
20	6	199 367	1	830	902	366 833
21	3	367 616	1	1 394	725	971 486
22	3	195 979	1	2 074	548	182 456
23	3	222 543	1	1 307	699	427 310
24	3	209 100	1	1 070	519	438 234
25	4	159 661	1	420	592	314 980
26	4	143 898	1	633	338	309 102
27	8	112 693	1	677	315	178 115
28	2	144 961	1	607	261	319 305
Centralization (sum for 28 locations)		*10 437 479*	*42*	*86 248*	*38 398*	*16 331 002*
Without centralization		*12 273 065*	*122*	*112 687*	*43 650*	*9 089 528*

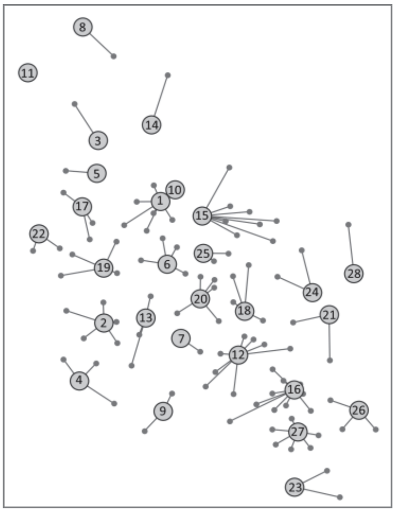

Figure 3. Best solution obtained from heuristic with total of 28 warehouses

5. CONCLUSION

In this paper we outlined the heuristic approach to inventory centralization of spare parts which was based on the model developed for one utility company. Results show that inventory centralization is justified where expected total costs can be reduced by significant amount (in our approximated model that reduction is near 15 %) by reducing total stocks, workforce and warehousing. On the other hand, transportation costs are significantly increased by 80 % (increased travel distances) which can have negative impact on service response times and on duration of system downtimes. Further research should explore the effects of increased maintenance transportation travel times on the duration of system downtimes, as well as to include in the analysis new potential locations of warehouses. Also, our idea is to develop optimal nonlinear formulation for this type of location inventory model and to analyze other possible solution approaches.

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