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THE PROCEDURE PROPOSAL FOR ORDER PICK AREA DESIGN

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The problem of order pick area (OPA) defining during warehouse designing is a very complex task that requires a full set of analysis and trade offs of different factors. Configuration of OPA is the function of numerous criteria, which differ by their significance and impact on decision-making. In this paper, hierarchy iterative procedure for technological configuration of picking area is proposed, whose appliance enables cost minimization respecting the required service level. The procedure includes generating alternative concepts, determinating size of OPA and evaluating relevant costs of certain concepts using partial analytical methods.

Keywords: *design procedure, order pick area, warehouse*

Prijedlog procedure za projektiranje komisione zone

Izvorni znanstveni članak

Problem definiranja komisione zone pri projektiranju skladišta je vrlo složen zadatak koji zahtijeva opsežnu analizu i štovanje niza različitih faktora. Konfiguracija komisione zone je u funkciji niza kriterija koji se razlikuju po značaju i utjecaju pri donošenju odluke. U ovom članku predložena je hijerarhijska iterativna procedura za tehnološko uobličavanje komisione zone, čija primjena omogućava minimizaciju troškova uz štovanje zahtjevane razine servisa. Procedura obuhvaća generiranje alternativnih koncepcija komisione zone, određivanje njene veličine i procjenu relevantnih troškova primjenom parcijalnih analitičkih metoda.

Ključne reči: *komisiona zona, procedura projektiranja, skladište*

1 Introduction

Warehouses are the essential parts of logistic processes and supply chains. There are many reasons which support existence of a warehouse and they are very well described in available literature [1, 2]. In supply chains there are various types of warehouses, where *distribution warehouse* is the specific one. According to Berg [3], a distribution warehouse (DC) is a warehouse in which products from different suppliers are collected (and sometimes assembled, repacked, etc.) for delivery, usually to a greater number of customers. The key objectives of such warehouses are to achieve a high utilization of their storage spaces and, at the same time, be able to quickly fulfill customers' orders with the minimum amount of effort and costs. These objectives are often conflicting - while efficient space utilization involves high-density storage, an efficient order picking requires ready access to the full portfolio of products, resulting in a low-density storage. For that reason, many warehouses use a concept of warehouse solution-structure based on specialization of warehouse areas for their primary activities [2, 4 ÷ 21]. So, warehouse area is primarily designed for storing function (preserving goods – in ***reserve area*** (RA)) with the aim of more efficient utilization of storage space. On the other hand, physically separated ***order pick area*** (OPA) (sometimes named forward area) is shaped as specialized one, which provides preconditions for more efficient order picking.

However, benefits of warehouse configuration with separated RA and OPA cannot be completely achieved from the spatial, technological and organizational aspects without tradeoffs of these areas. This relation enables preconditions for warehouse performances optimization related to flow, response time and capacity, minimized additional investment and operational costs, whereas each of the listed optimization aspects includes a set of sub-problems. In order to avoid partial optimization, by which optimal solutions would be achieved, these problems should be treated simultaneously and interdependently.

Numerous design and cost parameters, combined with an endless variety of equipment types, make it difficult to specify an OPA. This problem, despite its importance, is not adequately present in the available literature. Also, according to the research of the authors, it can be stated that integral approach to configuration of OPA is not present in the literature. Due to the problem complexity, papers are mostly limited to the specific aspects of the problem, which is presented in further text in details.

The following papers stand out: (i) papers concerning warehouse zone separation into OPA and RA problems [4 ÷ 7], (ii) papers concerning OPA optimal size determination problems [10, 11], which often include the goods allocation in OPA, and (iii) papers concerning specific aspects of allocation problems [12 ÷ 16].

Ballou's paper in 1967 [4] is one of the first papers concerning optimal separation of warehouse area into OPA and RA (while the optimization criterion was the cost of material handling in those two areas). Gudehus [5], dealt with problem of separating OPA and RA by analyzing different aspects which followed this decision. Bozer [6] dealt with the pallet rack separation into an upper zone for RA and a lower zone for OPA (so-called vertical separation). Under specific assumptions related to technology and warehousing strategy and troughput, he has shawn when the separation of pallet rack is justified. Bhaskaran and Malmborg [7] analyze economic aspect of the problem of sizes of RA and OPA.

Hackman and Rosenblatt [8] were the first to propose a mathematical model for space allocation of products in an OPA. They describe a heuristic that attempts to minimize the total costs for picking and replenishing. Applicability of the proposed greedy heuristic by Hackman and Rosenblatt on practical problems is checked and confirmed by Gu et al. [9]. Frazelle et al.

[10] extend the problem and the solution method of Hackman and Rosenblatt [8] by treating the size of the forward area (OPA) as a decision variable and define Forward Reserve Problem (FRP): "A critical design decision is the amount of space to allocate in forward area for each item. The picking cost in the reserve area is much higher than the picking costs of forward area, and so the overall picking costs can be reduced by assigning items to the forward area. When more items are assigned to the forward area, it grows in size. As the size of the forward area increases, the picking productivity decreases, leading to an increase in cost to pick in the forward area. …One can reduce the size of the forward area, with no increase in the number of items, but this will necessarily increase the number of internal replenishments. Typically, the cost of an internal replenishment is several times of the cost of a pick." Heragu et al. [11], similarly to the mathematical model developed in [10] developed a higher-level model that jointly determines the functional areas size and the product allocation in a way that minimizes the total material handling cost.

Van den Berg et al. [12], Djurdjevic [13], Bartholdi and Hackman [14], Gagliardi et al. [15] and Anken et al. [16] have addressed the problem of which products should be placed in the OPA and in which quantities in different warehouse configurations.

Review and analyses of available literature point to significant area for further research, from the point of adjusting present knowledge to practical design requirements and warehouse exploitation, as well as from the point of planning new support models development for technological configuration of OPA, since many problems which appear in the process of solution design are not adequately treated and analyzed. Because of this, a procedure for solving choice problem and OPA configuration in the context of warehouse designing is proposed here. Besides this, within the procedure, partial models for decision-making support for specific decisions are proposed. Therefore, the main goals of this paper are: (i) to identify specific decisions (during the warehouse design process) related to the design of OPA and (ii) to propose the required methodology procedure which will enable support for application and design of corresponding OPA.

The paper is organized as follows: section two is devoted to critical decisions of OPA design, section three is related to the procedure of OPA design and finally it is wrapped up with a conclusion.

2 Critical decisions of OPA design

The OPA is one of the several warehouse areas, tightly connected with others, so that it cannot be independently observed. Therefore in this paper the problem of design of OPA is observed through the design of the warehouse.

By analyzing the project practical experiences, different approaches applied for this type of design are observed which clearly point out that the methodology which is uniquely accepted, does not exist [22]. Considering that, general properties of design process are described in the following section, in order to perceive the genesis of the solution development problem and OPA configuration in the warehouse design process.

2.1 Warehouse design process

Warehouse design is a complex process directed to the creation of a warehouse solution which will optimally fulfil the required design task (DT). As a rule, it is a multiphase iterative process [22] in which different kinds and levels of decisions are made in each phase [17]: strategic, tactical and operative. Decision- making in particular phases of design is interlinked and a degree of reiteration is necessary.

Typically, the design starts with gathering and analyzing relevant information (information related to goods, orders, system requirements and limitations, financial and technical nature is especially important, see details in [18, 23]). Based on this, it is possible to define the main requests, objectives and constraints. Outcome results of the starting phase define the design task which will be outfitted in further phases. In addition, in the next phase the functional warehouse departments and process will be defined by describing strategic decisions. Here the bases of the system are described by making a decision about the overall structure of the system. Selection of the type of technology for each of the warehouse functional departments and processes is also carried out. With this approach the architecture of the whole system i.e. its *conceptual technological design* is realized.

The effect of these conceptual decisions is seen in significant reduction of degrees of freedom in design, so that the next phases (*detailed design*) are concentrated on the specification and optimization of the (sub)-systems by tactical and operational decisions (dimensioning components of systems, layout of systems and selection of planning and control policies).

The whole process is iterative and various technological concepts (*TC*) could appear as potential suitable solutions. Evaluation and selection of alternative *TC*, concerning the established goals will lead toward reaching the desired solution.

In order to evaluate a particular warehouse design and estimate the quality of design decisions, the performance criterion needs to be defined. Evaluation of performance provides feedback on the quality of proposed design decisions. According to the literature [17], within the field of warehousing the following criteria could be distinguished: investment and operational costs, volume and mix flexibility, throughput, storage capacity, response time and order fulfilment quality (accuracy). Relative importance of a particular criterion varies with environment conditions, types of warehouses and the various design levels.

2.2 The design decisions for the OPA

In the process of DC design, choice of the OPA (type) and its configuration are very important decisions with the consequences related to many warehousing aspects (resources, performances, costs, etc.). Therefore, Gudehus [26] recommends the warehouse design and all other warehouse subsystems should be subordinated to this.

There are several typical alternatives for spatial appearance of OPA related to RA (Figure 1): (V1) where OPA is integrated with the whole RA; (V2) where OPA is located in lower levels of RA – known as vertical separation, and (V3) where OPA is dislocated from RA (detailed in [18]).

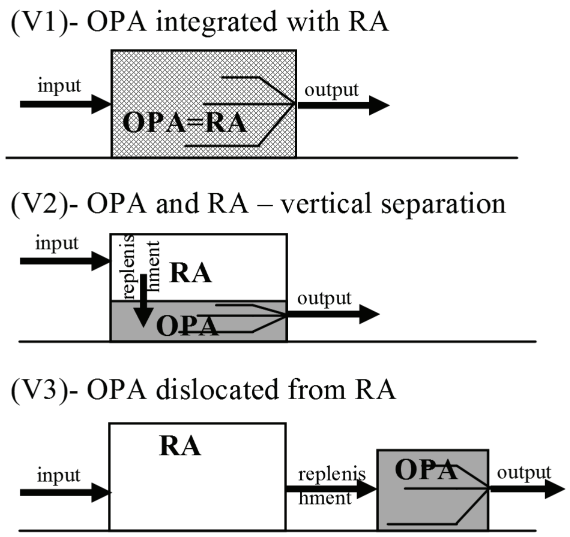

Figure 1 Spatial alternative configurations of the OPA and RA options

These alternatives differ not only in spatial configuration, but also in potentially applicable warehouse process technologies [21], warehouse resources requirements and reaching required performances. Consequently, many potential OPA concepts (types) can be formed, where the feasible ones should be chosen, in accordance with the characteristics and constraints of specific DT.

In order to reach the desired system performances (storage capacity, productivity, response time, etc.) it is necessary to define technical-technological parameters through which the OPA alternative is closely defined. Determination of the OPA storage capacity size is of special significance, since the function of replenishment of OPA from RA becomes significant, in order to provide the required inventory level in OPA. By analyzing the warehouse process, it is logical that OPA with higher storage capacity generates higher costs (the price of the object/OPA increases), its equipment and travelled distance, while smaller OPA with lower storage capacity generates lower picking costs – order-picker travels smaller distances for meeting order, and the costs of space and equipment are lower. However, when the OPA storage capacity decreases, the costs of replenishment increase, since inventories in OPA must be replenished more frequently [19]. Decision on portfolio and quantity of specific products in OPA is directly connected with this decision.

Based on the stated, the following critical design decisions in designing OPA can be distinguished:

1. Determine type of the OPA
2. Determine the technologies in the OPA
3. Determine the size of the OPA
4. Determine the set of product to be stored in the OPA
5. Determine the quantity of each product to be stored in the OPA.

Based on the all above mentioned it could be recognized that the problem related to defining the OPA during design of warehouse is a very complex task that requires a full set of analysis and trade off of different factors. For entire solution of these complex tasks (which appear in different levels of hierarchy of decision making and in different phases in design process) it is necessary for a suitable methodological procedure to be applied, which is missing, as it is stated in the literature review. The next chapter deals with the proposed procedures in details.

3 Proposed procedure for the OPA design

"A design procedure determines the various decision problems in the design project, in which sequence they are solved, and how they are related. In most of the engineering design projects, this design procedure is not a linear procedure from start to finish through the various phases or design problems. The current design of the artifact may violate some constraints or may have unacceptable or undesirable performance characteristics causing the design procedure to return to an earlier step in the procedure. The engineering design process is essentially an iterative process." [25]

Respecting all analyzed in previous section, as well as the mentioned quatation, a suitable approach to solve this group of problems is proposed by methodology procedures for the OPA design (Fig. 2). Hierarchy decomposition with two decision levels is chosen for the observed problem.

On the first decision-making level, based on design task DT derived from design requests, objectives and constraints determine the acceptable OPA alternative TC.

On the second decision-making level, configuration of the chosen OPA alternative concept is approached, by determining its size. Solution of the «Assignment-Allocation» (AA) task is closely related to this, that is, defining the type and quantity of goods and the period the products occur in OPA. Within this level for specific design decision creation, suitable analytical models for AA and relevant cost estimation are applied. There is a strong interaction between them, which is shown in Figure 2. Due to this connection and with the aim of achieving required performances within the alternative OPA concepts, iterative procedure is applied on this level.

Decision-making procedure for all alternative concepts is required for determining an optimal OPA solution. The optimal OPA solution is determined based on the chosen criteria from the set of optimal solutions by alternatives.

3.1 Procedure on Level 1

The initial step of the procedure is devoted to perceive and analyze the warehouse design requests, objectives and constraints in order to define DT. It is not meaningful to define DT in all its complexity (including all components) in the phase of the concept while developing the alternative OPA and specific design decision-making, but to define the task only through basic influence factors and their important characteristics. Considering the fact that picking processes are analyzed, the DT are typically posed as the ability to handle a certain order pattern, whose partition may result in primary influence factors for defining the DT: number of different items which are stored (picked), proper inventory level of these products, handling units in warehouse and picking processes, required picking process productivity (according to proper ordering type - data of the sizes of the orders in terms of number of lines with data about number of products, total weight, total cubic volume, etc.). They can have different values separately and appear in different combinations, so it is theoretically possible to define a number of different DTs. It is of importance to be mentioned that within this paper the analysis will not include all potential combinations of the mentioned factors, but only the characteristic ones for DC. Also, the special analysis subject is limited only to one alternative transformation of load unit manifestation, typical for DC – items received and stored as pallet load of cases of the same item, and picked as boxes and dispatched as pallet load of mixed items.

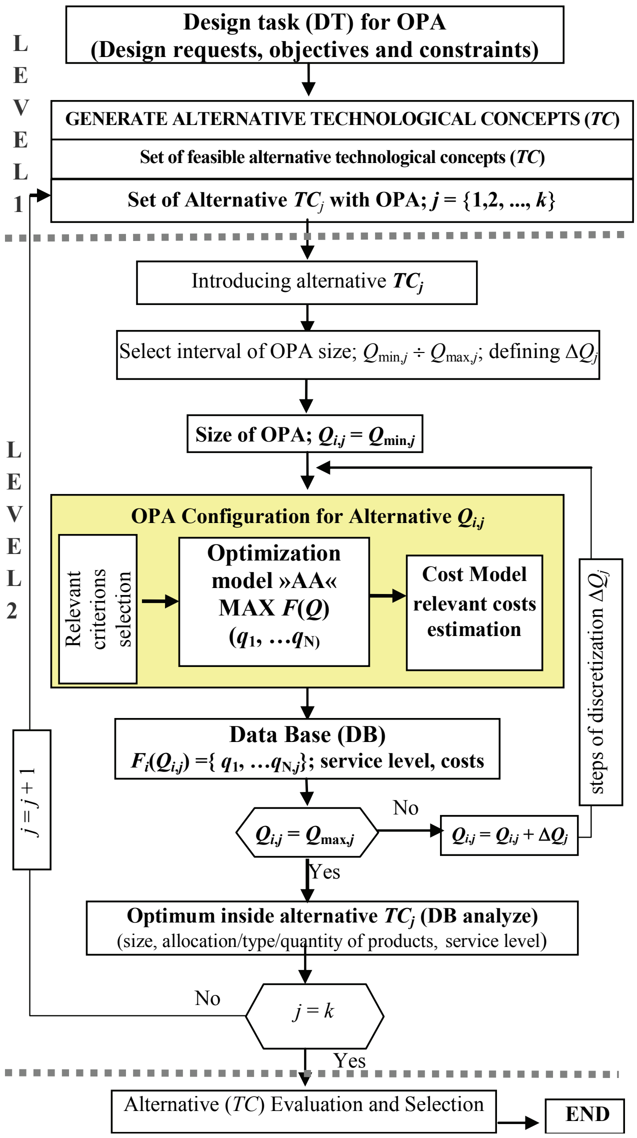

Figure 2 The procedures for OPA design

As the following step at this level of the proposed procedure, and in accordance with the defined DT, acceptable alternative OPA concepts are determined by specific design decision-making regarding the selection of the type of space and the selection of technology in that area. The mentioned decisions are at a high level of correlation and dependence, and only their specific combinations generate potentially feasible alternatives.

By the choice of feasible alternatives (which satisfy DT requirements), there are many interdependent factors (throughput, assortment of products, inventories...). Therefore, it is convenient to apply the iterative method in making choice: in the first iteration, starting from the first factor (throughput), all alternatives which do not satisfy these requirements are rejected; for alternatives which do satisfy the previous requirement, the iterations are repeated by including the following factor, and this procedure is repeated until all determined factors are analyzed. At the end of the procedure, a set of feasible alternatives is reached. Problem of rejection of criteria of certain *TC* can appear in iteration, and for feasibility estimation some derived solution can be applied [26], recommendation of equipment manufacturers, benchmarking, etc. The range of possible technologies within OPA for this type of DT is very wide, from manual to high-levelled mechanized/automated systems. For pallet storage/carton picking, the typical eligible media include AS/RS with I/O point picking, floor stacking with at least one pallet of each product at floor level, pallet rack (1-deep) with person-aboard pick vehicle, lower level(s) of pallet rack (1-deep) with pallet jack, and lower level(s) of pallet rack with a conveyor and replenishment from the back side [23]. There are also a variety of alternative configurations for RA including block stacking, conventional pallet rack accessed by counterbalanced lift trucks, and narrow-aisle systems accessed with reach or turret truck, or AS/RS. Recommendation related to technology choice in OPA can be met (presented in grey in Tab. 1), as well as in RA based on some influence factors [27, 28].

Table 1 Typical Pick Equipment [28]

Picking type	Slow mover	Fast mover
Broken case	▪ Static shelving ▪ Decked Rack ▪ Vertical Carousels ▪ Drawers	▪ Carton Flow Rack ▪ Horizontal Carousels ▪ Mini-Load AS/RS ▪ Draw AS/RS
Case	▪ Single-Deep pallet Rack ▪ Decked Rack ▪ Hi-Bay Shelving	▪ Pallet Flow ▪ (floor pick) ▪ Pallet flow ▪ (pick to belt) ▪ Automated Case Flow
Pallet	▪ Bulk Floor Storage ▪ Double-Deep Rack ▪ Push-Back Rack	▪ AS/RS ▪ Drive in Rack ▪ Deep Pallet Flow

Each of possible alternatives gives different possibilities of spatial organization, which is respected in potential *TC*s designing. Also, relevant costs must be respected in feasible alternatives decision-making [5, 18]. These costs (space, equipment, working force, depend on many other - sometimes local - factors including: wage rate, cost of space, cost of capital, the planning time horizon, and so on) may exclude some *TC*s which satisfy other factors in iteration steps.

Previously described procedure defines a set of feasible alternative *TC*s. In the proposed procedure, the alternatives which assume presence of OPA enter the following steps (alternatives V2 and V3).

3.2 Procedure on Level 2

In accordance with the set goal, on the second level each of feasible alternatives TC_j (j=1,…k) gained in the first step is brought to appropriate form. That is accomplished by iterative procedure, as shown in Figure 2.

In the first step, for previously defined alternative TC_j and for initial size - storage capacity OPA ($Q_{\min,j}$), type of items (out of set N) and item quantity stored in OPA are determined by the optimization model AA appliance [8,10, 13, 14, 22]. For this decision set appropriate effects are determined by implementing relevant costs (basic working cost in OPA – order-picking cost and replenishment costs) [8, 10, 13, 14, 22] and memorized in data base (DB). For the same TC, the procedure is repeated for the following size of storage capacity OPA (increased for ΔQ_j) – iterations number corresponds to the number of discrete states of OPA sizes till $Q_{\max,j}$ is reached; after that the procedure ends for alternative TC_j. The most suitable shape – combination (size of OPA, allocation/type/ quantity of products, service level etc.) within alternative TC_j is determined by analyzing results from DB. The procedure is conducted for all alternatives TC_j (until satisfying requirement $j=k$).

The last phase of the proposed procedure includes evaluation of alternative TC optimal solutions, based on the previously defined criteria. The output is the OPA solution proposition which is used in further phases of DC design.

3.3 Demonstration of the proposed procedure application

In order to demonstrate the proposed procedure, description of its application on characteristic OPA design task in DC follows up. It is assumed that alternative V2 is chosen in DC. This alternative provides forming OPA and RA in the same pallet rack and its vertical separation (Fig. 3). Basic demands and methods of their realizations within this TC are presented in Fig. 4. This TC is developed under assumptions that the picking process is done only in OPA and that the quantities of the picked items in one picking are less than the content of the whole pallet (otherwise, separation of these zones would not be meaningful). This TC provides such organization of work that item replenishment (pallet unit with items) in OPA, which can be the contents of orders in the following picking periods, is done before that period (this period can be defined as one working shift, day, several days, week, etc.). Determination of this period is a special optimization problem and is assumed to be solved. In case of eventual shortage of items in OPA in the picking period, concurent replenishment is done (by moving down the pallet with required items) from RA.

In accordance with the presented procedure, the chosen TC enters further procedure. It consists of several steps, which will be presented in detail.

Interval of OPA size selection: $Q_{\min,j} \div Q_{\max,j}$

According to requirements and constraints TC_j for OPA size-$Q_{\min,j}$ number of pallet positions corresponding to the number of different items to be picked within picking period is adopted (min. one pallet position per each product). The maximum number of pallet positions $Q_{\max,j}$ corresponds to the total demand for products in the picking period (expressed in pallet units). Increment of capacity change ΔQ_j is adjusted to technical-technological characteristics of the warehouse equipment and the required space for OPA and defines the number of required iterations.

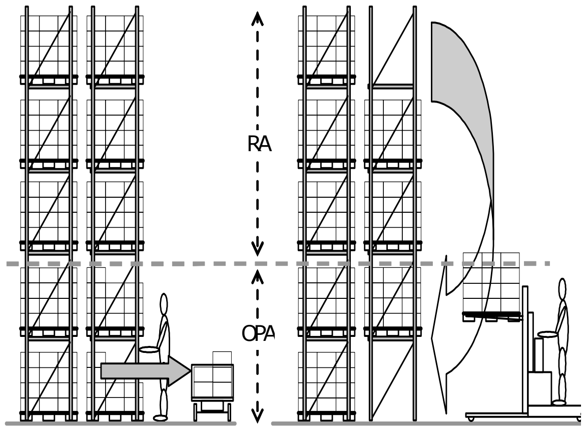

Figure 3 Simplified presentation of *TC*

Resource engaged / Demand	Handling equipment		Pallet rack		Workforce	
	fork-lift	order picker truck	RA	OPA	fork-lift driver	order-picker
Pallet input	*				*	
Pallet storing			*			
Replenishment OPA from RA	*		*	*	*	
Storing pallet for picking				*		
Order picking from OPA		*				*

Figure 4 Presentation of *TC* by corresponding matrix of technological requirements and technological elements

OPA Configuration for Alternative Q_i

For alternative OPA capacity (Q_i) optimization task **AA** is solved in the configuration procedure. In the process of solving this task, the solution which leads to the maximization of accomplishing picking tasks $F(Q)$ is a goal, and that is acquired by minimization of the number of required concurent replenishments of OPA from RA in the picking period (that is the chosen criterion of optimization). It is important to point out that for the analized TC_j task AA is reduced only to the allocation problem, since all items are picked only from OPA, and therefore must be present in it in the picking period. In that situation major assumption is that for the required products for a picking period of time adequate data are known. For solving this kind of problem, allocation optimization model is used, which is solved applying dynamic programming [13]. For any sets of decision (such as area capacity, quantity of products that will go into this area (q_1,...,q_N), - which result in minimum number of concurent replenishments) corresponding effects will be estimated by the use of a cost model. The cost model enables estimation of picking and replenishment costs, as basic costs of processes in OPA.

Picking costs in OPA are the function of the size of OPA, assuming that the order picker passes all locations in OPA when it fulfills order requirements. This is a usual mode in OPA in DC, due to the order characteristics (typically with the number of order-lines). Costs of concurrent replenishments are directly proportional to their number, where each concurrent replenishment may result in additional costs due to the disturbance/slowdown of the order pickers' work.

Gained results are memorized in appropriate data base (DB). The procedure is repeated untill the requirement $Q_i=Q_{\max}$ is satisfied. In order to reach the optimum, results from DB are analyzed and may be represented by chart (Fig. 5).

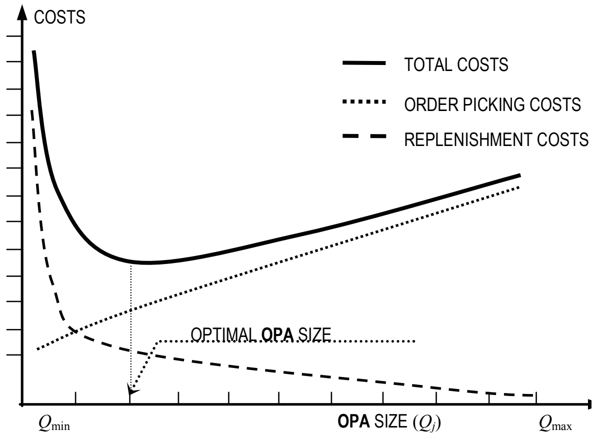

Figure 5 Determining of optimal opa size as a function of costs

Optimal solution of OPA size is gained based on a minimum of function of total costs. The size of OPA gained this way is a preliminary solution, and for the final solution, it is required to include other influence design factors in practical application. It is necessary to point out that the model application within the proposed procedure implicits that the assumptions under which the model is developed are still valid. This refers, primerly, to *TC* and demand characteristics as main factors for the solution development.

4 Conclusions

In this paper the problem design of OPA is considered. For entire solution of these complex tasks the methodological procedure was suggested and explained. It enables an overall practical solution of the problem. The proposed procedure allows identification, design and assessment of superior – suitable (feasible) alternative *TC* for OPA representing the initial basis for the process of development and definition of DC solutions.

Hierarchy decomposition in two decision-making levels is proposed. On the first level, based on DT, feasible alternative concepts of OPA are generated. On the second decision-making level, all chosen alternative OPA concepts are configurated by including appropriate analytical model for **AA** and for estimation of cost parameters in iterative procedure (by varying OPA capacity in each iteration). Optimal solution for OPA is determined based on the chosen criteria out of a set of optimal solutions for the alternatives

The proposed procedure is described in charachteristic OPA type in DC. For the chosen OPA type, appropriate models from literature are proposed for decision-making. For the choice and application of specific models from literature within the proposed procedure, it is required to start from *TC* and demand characteristics as main limiting factors, because otherwise it could happen that inappropriate models are used for certain situations.

Diversity of goods flow and transformations in manifestation of goods which could be potentially expected in the warehouse, are affected by the increase of complexity of its structure, so that within the warehouse design solution the specification of a larger number of OPA and RA may be required. This paper limits the research area to the problem of one OPA and the related RA, where principles derived in the paper could be applied to more OPAs in one warehouse with appropriate modifications. This procedure offers support in design of real systems by providing a methodology which allows avoiding errors in certain stages of design. In order to be applied in practice, certain steps of the proposed procedure shall be transformed in DSS (Decision Support System). This task should be interesting for future research.

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