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Hierarchical Warehouse Design Approach for Distribution Centres

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ABSTRACT:*Warehouses are essential components of supply chains withregard to customer service and cost levels. As a result of a comprehensive literature review, this paper asserts the need for systematic warehouse design methodology that considers the different and interrelated decision points. The purpose of the study is to develop a systematic methodology for warehouse design problems in order to make a more efficient and cost effective warehouse design. This purpose is realized through a comprehensive systematic literature review that addresses warehouse design problems and solution approaches, and detailed interviews with both logistics service providers and key fast moving consumer goods and retail industry companies in Turkey. Thedescribed methodology that provides an end-to-end, holistic approach for warehouse design problems by proposing a systematic flow for each design parameter and taking into consideration their interrelations. The methodology enables to conduct more effective and efficient warehouse design. The proposed methodology is easy to use and helpful since it provides a systematic and intelligible way of completing an end-to-end warehouse design project. The methodology covers all the necessary steps of warehouse design and provides a better, more efficient and cost effective way of managing warehouse design project. This methodology provides a holistic and systematic approach for warehouse design. Therefore, the methodology can be treated as a roadmap / guideline for both academicians and practitioners.*

KEYWORDS:*Warehouse design, Facility planning, Conceptual framework*

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I. INTRODUCTION

Warehouses are essential components of the supply chain (Gu*et al.,* 2007), playing an important role in the success or failure of a business from both a customer service level perspective and a cost perspective (Baker and Canessa, 2009). Warehouses have several major roles, such as enabling a buffer for material flow along the supply chain when altered by seasonality, batching, or transportation and providing a location for value-added services such as kitting, labelling, and stamping. When market competition is added to this situation, warehouses, as important players in supply networks, need to show continuous improvement in design and operations in order to achieve ever-higher performance (Gu*et al.,* 2007). A recent literature review study on warehouse performance evaluation conducted by Staudt *et al.* (2015) revealed all key performance indicators with clear definitions.

Because of the increase in labour costs, allocating more people for any warehouse performance problem is not a viable solution (Gray*et al.,* 1992). Therefore, these improvement efforts typically result in the adoption of new management philosophies, such as tighter inventory control and shorter response times, andimplementation of new technology, like bar coding, radio frequency communications, warehouse management systems (WMS), automatic storage and retrieval systems (AS/RS), and automated vehicle storage/retrieval systems (Gray*et al.,* 1992; Gu*et al.,* 2007; Marchet *et al.,* 2013). Because these solutions have a very significant cost impact, warehouses need to function cost effectively (Baker and Canessa, 2009). These cost drivers are in fact determined during the design phase (Rouwenhorst *et al.,* 2000).

Warehouse design involves making decisions about different design parameters in order to satisfy cost and performance objectives. This paper proposes a warehouse design methodology for ensuring that all required parameters and factors are accounted for and that the best-fit design alternative is developed according to economic and technical expectations and performance targets by considering different design elements and their dependencies. Thus, the following questions should be answered regarding the warehouse design:

- Is this design correct? (i.e. Are any parameters missing or forgotten?Is the design consistent through the different parameters?)

- Is this the "correct" design? (i.e. Are warehouse performance targets achieved by this design or not?)
  In the literature, one of the structured design approaches is proposed as Rouwenhorst *et al.* (2000) stated by which multiple interrelated decisions are made at the strategic, tactical, and operational levels. For each level, problems are defined using three axes: processes (receiving, storage, picking, shipping, etc.), resources (storage unit, storage system, picking equipment, WMS, etc.), and organization (process flow, storage policy, order picking policy, etc.) (Rouwenhorst *et al.,* 2000). For instance, selection of a storage strategy is a strategic decision that affects the warehouse design (Gu*et al.,* 2007). Overall warehouse design is a different problem from warehousing systems design,which is another critical strategic-level subject related to sizing problems. Conceptual models and systematic approaches can be found within the literature regarding the sizing topic (Keserla and Peters, 1994; Roll*et al.,* 1989).
  As clearly seen in the literature, the systematic layout planning (SLP) developed by Muther (1987) is one of the most used methodology for especially facility layouts. On the basis of the definition of overall warehouse design stated above, this paper asserts that SLP approach is not appropriate for warehouse design, although it is widely used in practice. The reasons for this assertion are as follows:
- SLP provides a good view of analysis (flows, products, time, etc.).However, while flows are important for warehousing, the number of materials, loads, units, storage types, and sizes of the storage types over time are also crucial. Analysis of these other factors is not explicitly addressed by the SLP framework.
- SLP is helpful for layout planning of the warehouse, but layout is only one of the key components of overall warehouse design, as stated by Gu *et al.* (2010).
- SLP design does not use a system choice perspective, including combined selection of storage equipment, a material handling system for transport from/to the storage areas, and order picking and storage methods. These decisions are not able to be taken in isolation since they are part of a complete system choice. For instance, one may have to choose between an operation with wide aisle pallet racks using low-level order pick trucks with reach trucks for pallet storage and retrieval versus a pallet storage system with narrow aisle pallet racks and semi-high bay combi trucks.
- SLPlacks the ability to address the procedure steps regarding order picking system design, according to Dallari *et al.* (2009).

The third point is one of the core aspectsof warehouse design which is not addressed by SLP;therefore, this method is not a best-fit solution for warehouse design projects. Moreover, all these decision points are interrelated and dependent on each other, which meanthat iteration is required to achieve the most appropriate design solution. This aspect is also not covered by SLP.

On the other hand, there is another framework for warehouse design problems thatinvolves five major decisions as stated by Gu *et al.* (2010).1) Determining the overall structure requires a conceptual design that determines the material flow pattern within the warehouse, specification of the functional departments, and the flow relationships between them. 2) Sizing decisions determine the size (capacity) and dimensions (translation of capacity into floor space). 3) Department layout involves detailsabout such things as aisle configuration in the retrieval area and configuration of AS/RS. 4) Equipment selection determines the automation level of the warehouse in terms of storage, transportation, order picking, and sorting. 5) Operation strategy determines how the warehouse will be operated in terms of whether randomized storage or dedicated storage will be used and whether or not to use zone picking (Gu*et al.,* 2007, 2010). Besides, a step-wise approach, a kind of decision support system developed by Duve and Mantel (1996) for warehouse design. Goetschalckx *et al.* (2001) provided a framework for systematic warehouse design in terms of developing a mixed integer mathematical model.

Ina conceptual warehouse design,the strategic level includes data acquisition regarding the warehouse and functional and technical high-level descriptions of the warehouse. The tactical level involves equipment selection and internal layout determination on the basis of technical details determined at the strategic level. The operational level includes planning and control policies for daily warehouse processes.Because order picking is one of the most important operations in terms of time and cost effectiveness, several studies that focus only order picking system design in the literature (Brynzer *et al.,* 1994; Yoon and Sharp, 1996; de Koster*et al.,* 2007). Moreover, Thomas and Meller (2015) recently developed design guidelines for case-picking warehouse by using statistical based methodology and analytical models.Recently, the optimum design of warehousing systems for a specific sizing has been asserted to be independent from storage policies (Zaerpour*et al.,* 2013).

Two different approaches are used for warehouse design. The first is a top-down approach with limited details, which can be described roughly as design at first glance and subsequent branching into the details. The second approach is the reverse of the first,namely a bottom-up approach (Rouwenhorst *et al.,* 2000). This paper proposes top-down approach as well.

For the purposes of this paper, 243 studies were reviewed, and 170 of these were classified according to the method(s) used for warehouse design. It is obvious from the results of this review that many studies have been done regarding the operational level. Fewer studies have been conducted regarding the tactical level, and significantly fewer strategic-level studies have been done in comparison to tactical level research papers. Therefore, this paper asserts that there is a need to focus on warehouse problems at the strategic level. Furthermore, only a few studies have been conducted on warehouse design methodology (Karakis*et al.*, 2011). The key studies including the literature review papers regarding warehouse design is given in Table 1.

Table 1. A summary of the literature on overall warehouse design.

Citation	Focus	Method	Details
Muther (1987)	Facility layout planning	Systematic Layout Planning (SLP)	
Gray *et al.* (1992)	Overall warehouse design	Analytical Model	Mathematical Model & Simulation
Duve and Mantel (1996)	Overall warehousedesign	Conceptual Model	Step-wise approach
Goetschalckx *et al.* (2001)	Overall warehousedesign	Analytical Model	Mixed Integer Programming
Brynzer *et al.* (1994)	Order picking system design	Analytical Model	Zero-based Analysis Method
Yoon and Sharp (1996)	Order picking system design	Conceptual Model	
Thomas and Meller (2015)	Order picking system design	Analytical Model	Statistical Based Methodology, Mathematical Models
Ashayeri and Gelders (1985); Rouwenhorst *et al.* (2000); Baker and Canessa (2009);	Warehouse design methodologies	Literature Review	
de Koster *et al.* (2007)	Order picking system design	Literature Review	
Gu *et al.* (2007)	Warehouse Operations	Literature Review	
Gu *et al.* (2010); Staudt *et al.* (2015)	Warehouse Performance Evaluation	Literature Review	

The warehouse design issue is crucial since it is the base for further execution of operations and, if neglected, it may necessitate costly design modification efforts later. Because no overall design methodology has been defined in the literature as well as in practices in the industry, this paper proposes a systematic approach to the warehouse design process.From a review of the literature, it is obvious that although there is a general consensus on the overall structure of the approaches to warehouse design, there is less consensus on the tools to be used for warehouse design (Baker and Canessa, 2009).

With regard to methodologies, analytical models are widely used, appearing in 77 studies for warehouse design and validated with heuristics and simulation models. Heuristics and metaheuristics are the second most common method used (51 studies). Conceptual models, including literature reviews, are mentioned in 25 studies, mainly related to strategic-level topics. Seventeen studies use simulation models as a primary tool (Karakis*et al.*, 2011). According to Ashayeri and Gelders (1985), the combination of analytical models and simulation is the most practical approach for topics related to warehouse design optimization. Moreover, Ashayeri and Gelders (1985) state that very few papers deal with the general warehouse design problem. This view is supported by Rouwenhorst *et al.* (2000), who emphasize the need for research oriented towards a synthesis of currently isolated models and techniques as a basis for decision support in designing complete warehousing systems. Recent research papers agree as well; Baker and Canessa (2009) describe the lack of a comprehensive and science-based methodology for the overall design of warehousing systems and the absence of a procedure for systematically analysing the requirementsfor and design of a warehouse. Baker and Canessa (2009) also assert that there appears to be only some consensus on the overall design approach across the warehouse design companies within the UK.

Simple, validated models that actually give useful results for guiding overall structural design is identified as one of the key research needsin a recent literature review paper by Gu, Goetschalckx, and McGinnis (2010).

As a result of the comprehensive literature review, it is asserted that the systematic warehouse design approach is poorly represented. In light of this gap in the literature, this paper aims to develop a systematic and hierarchical warehouse design approach, especially for distribution centres (Karakis*et al.*,2011). The methodology proposed provides an end-to-end, holistic approach for warehouse design problems, suggesting a systematic flow for each design parameter by taking into consideration interrelations with other parameters. Both academicians and practitioners can use the proposed methodology as a guideline for warehouse design projects.

II. PURPOSE

The purpose of the study was to develop a hierarchical methodology for warehouse design problems in order to make a more efficient and cost effective warehouse design. This purpose is realized by developing a conceptual methodology through a comprehensive systematic literature review and detailed interviews with both logistics service providers and key fast moving consumer goods (FMCG) and retail industry companies in Turkey (Karakis*et al.*, 2011, 2012). As stated before, despite the fact that there are several studies regarding the problems of warehouse design as seen in the appendix with the details, there is a lack of research on systematic approaches or methodology for addressing these problems (Karakis*et al.*, 2011, 2012; Rouwenhorst *et al.*, 2000).

Elements, issues, and parameters related to warehouse design are dependent on the type of warehouse. Thus, the type of warehouse for which the methodology will be valid was first determined. Distribution centresfor the FMCG industry were selected for several reasons:

- The importance of balancing speed and volume compared to other warehouse types (e.g. raw materials warehouses)
- The possibility and probability of storage of different types of products within the same warehouse location, implying usage of different types of equipment and rack systems
- The existence of specific processes and applications (e.g. cross docking, value-added services, etc.)

III. METHODOLOGY

A comprehensive literature review of journal articles was conducted using library facilities. A range of electronic databases were searched, including Emerald Insight, EBSCO Host, Science Direct, Springer Link, and Taylor & Francis Journals. These databases were searched using relevant keywords, especially “warehouse” combined with “design” of those details regarding the classification of the existing topics investigated and the methods used in the existing studies in the literature are stated in Karakis *et al.* (2011). Moreover, detailed interviews were conducted with executives oftwo global and four local leading logistics service provider companies as well as one local logistics consulting company in Turkey. These logistics service provider companies are the top companies in the Turkish market in terms of client base, especially among FMCG companies, and in terms of projects and service variability and use of leading practices in warehousing function. In addition, executives of three leading global FMCG companies and two local retail companies were interviewed (Karakis*et al.*, 2011). The interviews were performed with sales, business development, and warehousing executives of logistics companies and distribution centre managers and supply chain managers of the industrial companies. The interviews covered current approaches and tools used for warehouse design projects, main critical decision points, improvement areas for the warehouse design process, and so forth. The studies conducted by Muther (1987), Gu *et al.* (2007, 2010), Rouwenhorst *et al.* (2000), and Baker and Canessa (2009), and Baker (2010) were theoretical background of this study and taken as starting points. Moreover, the need of such an overall design methodology is treated as the main future research area by Baker and Canessa (2009). Thus, the systematic methodology stated in this paper is also aimed to address the gaps identified by Baker and Canessa (2009).

All the information gathered from the different resources was used for the development of the hierarchical warehouse design approach, illustrated in Figure 1.

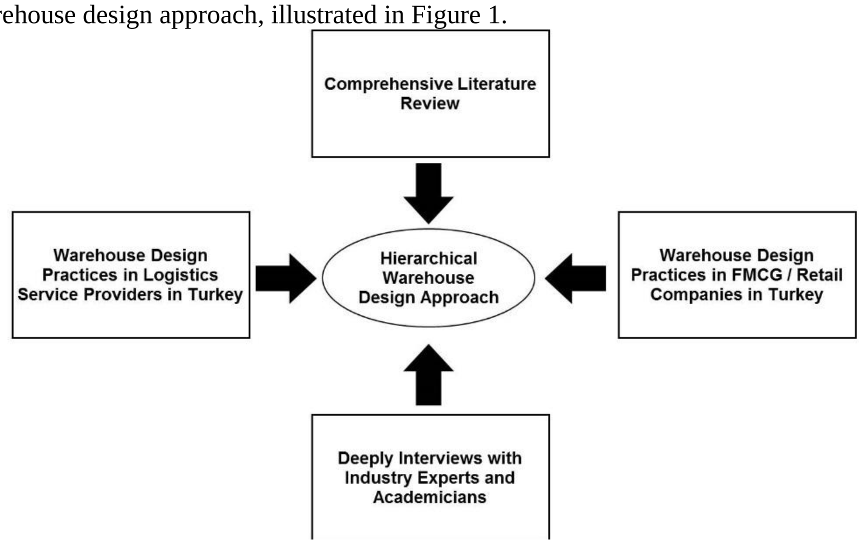


Figure 1. Approach for development of warehouse design methodology.

3.1 Hierarchical Warehouse Design Approach

Effective and efficient warehouse management requires sustainable cost and service performance. The factors that affect cost and service level performance are determined during the warehouse design phase. Both fixed costs like rent and depreciation, which average 30–50% of total warehousing costs, and variable costs like personnel, heating, cooling, and lighting are all determined during the design phase. The economic life of a warehouse is 25–30 years, and equipment life averages 5–10 years.Therefore, a warehouse that is not flexibly designed according to expected performance criteria can negatively affect company performance for many years (Baker, 2010).

As stated above, the warehouse design process takes a large number of interrelated decisions into consideration (Rouwenhorst *et al.*, 2000). Therefore, this paper asserts that warehouse design should be evaluated according to three hierarchical levels: strategic, tactical, and operational. The approach in this paper assumes that the outcomes of each level are used as inputs for the next level and that the various steps or tasks are interrelated.

3.1.1 Strategic Level

The reasons for warehouse design includethe building of a new warehouse, migration to a larger/smaller warehouse, and modification of an existing warehouse. The first step in thestrategic level is to determine the strategic goals in order to be able to definethe warehouse design problem in more detail. These goals are determined according to the following points:

- Warehouse type and purpose
- The industry the warehouse will serve
- The number of product groups in the warehouse (one or multiple)
- The number of floors in the warehouse (one, two, etc.)
- Goals related to desired sustainability of the warehouse
- The number of customers that the warehouse will serve (one or multiple)

The second step is to make a decision regarding the warehouse location. At this stage, such aspects as territory limitations due to topography and legal regulations should be examined. This step will be visited again after dimensioning of the warehouse is completed in order to determine a suitable location for the warehouse. The third step includes a comprehensive data analysis in order to determine the general design principles of the warehouse. Data analysis should have two phases, including a current state analysis (material flow, quantities, and movements) and a future state design (future goals, new products). This is the most time consuming step. Two basic data collection tasks are always applicable: storage analysis and movement analysis (Baker, 2010).

A key decision point in warehouse design involves the need to balance speed and volume. Because speed and volume requirements are often conflicting, the optimization of this balance is crucial.Besides storage and movement analysis, volumetric analysis should be conducted as well. The results of this analysis are particularly critical for warehouse management systems. For this analysis, products that have large physical volume with fast movements should be the focus (Baker, 2010). According to the outcomes of these analyses, material flow diagrams are developed for each different type of product through different lines. After this, a Pareto analysis can be conducted to provide input for a warehouse sizing study in terms of determining warehouse units, volume, and dimensions.

The next step is to decide whether the warehouse will be conventional or automated. There are advantages and disadvantages to automated warehouses (Baker and Halim, 2007). Recent research has indicated that scale (pallets stored) and throughput (pallet movements per hour) are key factors in the choice of automation by retailers, manufacturers, and logistics service providers (Baker, 2010). A study by Dallari *et al.* (2006) shows that automated warehouses tend to be selected when storage location values are higher than 5,000–7,000 pallets and the pallets moved per hour are greater than 50–60. Since this is one of the key strategic decisions, it is advised that not only the current situation but also the future state of the warehouse be taken into account before taking the final decision. At this stage, hybrid solutions (e.g. a partly automated warehouse) can be evaluated if the movements and storage volumes differ among the various product groups.

The next step is to determine the warehouse flow type (e.g. S type, I type, or U type), depending on the inputs from the previous steps. Moreover, this step also involves identification ofgeneral process flow principlesthat affect the tactical and operational level steps. During this step, receiving, bulk stock, dispatch, and picking should be considered as the main flows (Baker, 2010). The purpose of this step is to determine the high-level area requirements.

As the final step of the strategic level, the high-level warehouse layout should be developed by taking into consideration basic processes as well as some special processes relevant to distribution centres, like value-added services and special storage conditions. At the end of this step, the main deliverable is the high-level layout with a rough estimation of the total storage area; the estimatewill be matured on the basis of the decisions made during the following levels.

3.1.2 Tactical Level

The first step of the tactical level is to determine storage policies, including selection of a storage method and an order picking method. Dedicated storage, random storage, class-based storage, and product-group-based storage are the main methods that should be evaluated and decided on during this step (Rouwenhorst *et al.,* 2000). For determination of the storage location, cube-per-order index (COI) rule can also be considered (de Koster*et al.,* 2007).

In the second step, aisle configuration should be determined based on storage policies. The third step includes racking system selections and equipment selections. After these outcomes are fully determined, warehouse aisles should be reviewed and aligned with the racking systems and equipment selected. At this stage, warehouse sizing will be translated into floor space in order to assess construction and operating costs (Gu*et al.,* 2010). Lastly, the detailed warehouse layout should be decided upon, with determination of the warehouse dimensions as the last step in the tactical level.

3.1.3 Operational Level

The operational level starts with the detailed design of the warehouse processes, with the outcomes of the high-level design of the processes conducted during the strategic level treated as inputs.

For receiving, the number of docks and doors of the warehouse should be determined, and putaway and order picking processes should be designed in greater detail during this step. With regard to putaway and storage, department or rack dispersion will be determined. The order picking process is the most important process from a work force perspective since this process requires around 60% of all work force used within the warehouse (de Koster*et al.,* 1999). During picking process design, suitable picking methods (batching, single order picking, zone picking, etc.) should be determined for each product group. A cross docking process should be designed, if necessary. This special process is crucial for FMCG and retail industry companies that have many distribution centres. One process that should receive special attention is batching, which is the grouping of orders during the picking process (Gu*et al.,* 2007). The key tasks are to determine whether batching will be used and, if so,to define the most suitable batch method and batch quantities. Value-added services, such as sorting, storing, routing and sequencing, and shipping, are other processes that should be designed with an eye towardsthe future requirements of the warehouse. All these processes will be designed at the task level on the basis of principles set during the strategic design level. After all processes are designedfor execution in daily operational life, the number of staff needed for carrying out these operations within the warehouse is calculated.

3.1.4 Evaluation and Implementation

The purpose of this stage is to evaluate the possible different design alternatives and figure out the implementation details resulting from all of the steps stated above. Sample evaluation techniques and key indicators are listed below (Baker, 2010):

- Determining the costs for equipment and staffing as well as the budgets for the design alternative(s)
- Evaluation of alternative(s)

o Financial evaluation (calculation of total cost of ownership with consideration of investment costs and operational costs, net present value (NPV) analysis, return on investment (ROI) calculation, etc.)

o Technical evaluation (customer service level, throughput rate, environmental analysis, risk analysis, simulation, etc.)

At this stage, the following key performance indicators are proposed, with the breakdown for each thread shown in Table 2.

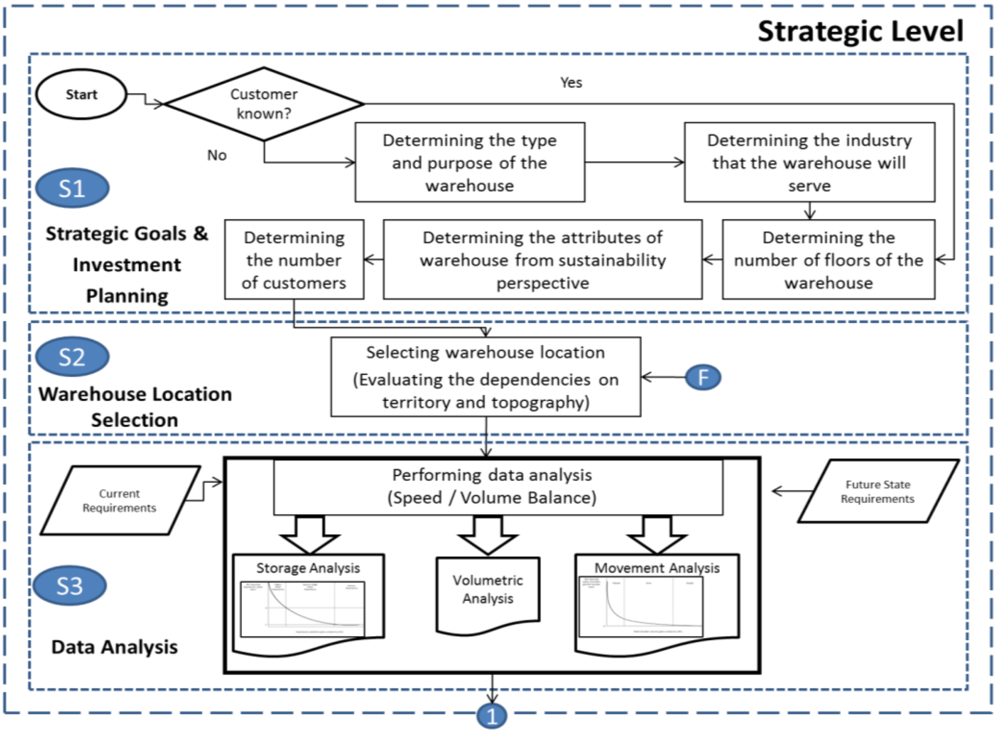
Table 2. Performance indicators for hierarchical warehouse design.

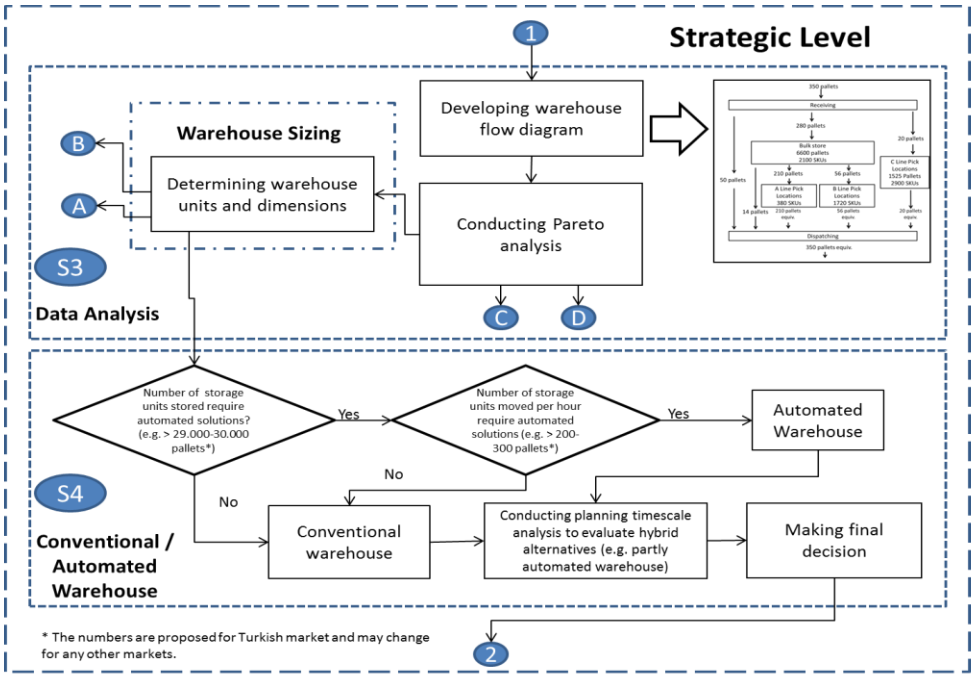
Thread	Performance Indicator	Unit	Formula
S1 – Strategic Goals & Investment Planning	Return on Investment (ROI)	USD	Net Profit/Investment Cost
S1 – Strategic Goals & Investment Planning	Energy Consumption per m^2	kWh/m^2	Total Energy Consumption/m^2
S1 – Strategic Goals & Investment Planning	Ratio of Energy Consumed from Renewable Energy Resources	%	Energy Consumption from Renewable Energy Resources/Total Energy Consumption
S4 – Conventional/Automated Warehouse	Cost per Storage Unit	USD/Pallet	Total Costs/Total Number of Storage Units
S4 – Conventional/Automated Warehouse	Ratio of Operational Costs to Total Costs	%	(Operational Costs/ Total Costs) × 100
S4 – Conventional/Automated Warehouse	Cost per m^2	USD/m^2	Total Costs/Net m^2
S4 – Conventional/Automated Warehouse	Order Picking Time	Min.	Total Time Between Start and Finish of Picking an Order

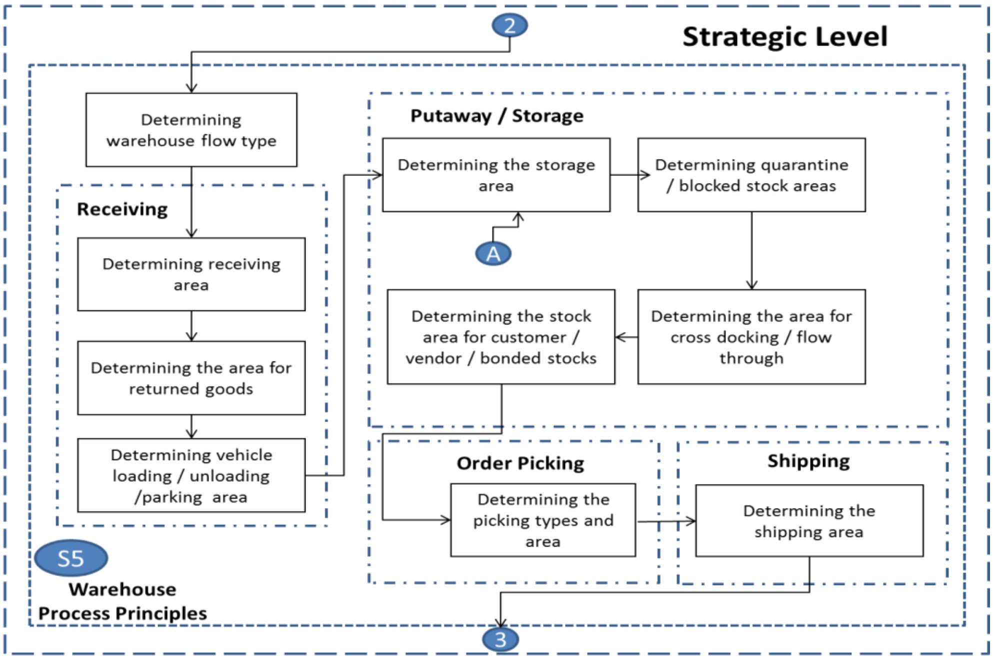
S4 – Conventional/Automated Warehouse	Product Shipping Speed	Pallets/Hour	Shipped Goods/Daily Working Time
S4 – Conventional/Automated Warehouse	Inventory Turnover	-	Total Annual Sales/Annual Inventory Value
S4 – Conventional/Automated Warehouse	Inventory Days	Days	Inventory Turnover/ Numbers of Working Days
S4 – Conventional/Automated Warehouse	Transaction Accuracy Ratio	%	Number of Accurate Transactions/Number of Total Transactions
T1 – Storage Policies	Rack Occupation Ratio	%	Number of SKUs Within the Rack/Number of Total SKUs
T1 – Storage Policies	Storage Location Accuracy Ratio	%	Number of SKUs with Accurate Location/Number of Total Stored SKUs
T3 – Rack Systems and Equipment	Equipment Utilization Ratio	%	(Net Working Hours + Net Broken Hours)/Total Working Hours))× 100
O1 – Warehouse Processes Detailed Design	Inventory Accuracy Ratio	%	Number of SKUs with Accurate Inventory Quantity/Number of Total SKUs
O1 – Warehouse Processes Detailed Design	Cost per Item	USD/Unit	Total Costs/Total Items
O1 – Warehouse Processes Detailed Design	Cost per Order Line	USD/Unit	Total Costs/Total Order Lines
O1 – Warehouse Processes Detailed Design	On-Time Receiving	%	Number of Vehicles with On-Time Receiving/Number of Total Vehicles for Receiving
O1 – Warehouse Processes Detailed Design	On-Time Shipping	%	Number of Vehicles with On-Time Shipping/Number of Total Vehicles for Shipping
O1 – Warehouse Processes Detailed Design	Ratio of Accurate Order Fulfilment	%	1 –(((Number of Incorrect Products Shipping +Number of Incorrect Quantities Shipping+Number of Incorrect Destinations Shipping+Number of Damaged Shipping)/Number of Total Shipping) × 100)
O1 – Warehouse Processes Detailed Design	Order Picking Accuracy	%	Accurate Picked Orders/Number of Total Orders
O1 – Warehouse Processes Detailed Design	Damage Ratio	%	(Number of Damaged Items/(Number of Received Items+Number of Shipped Items+Number of Transferred Items))× 100
O1 – Warehouse Processes Detailed Design	Transaction Accuracy Ratio	%	Number of Accurate Transactions/Number of Total Transactions
O1 – Warehouse Processes Detailed Design	Number of Items per Warehouse Staff	Unit	(Number of Items Received+Number of Items Shipped)/Number of Warehouse Personnel
O1 – Warehouse Processes Detailed Design	Number of Occupational Accidents	Unit	Accidents Due to Staff+Accidents Due to Equipment+Accidents Due to Operation

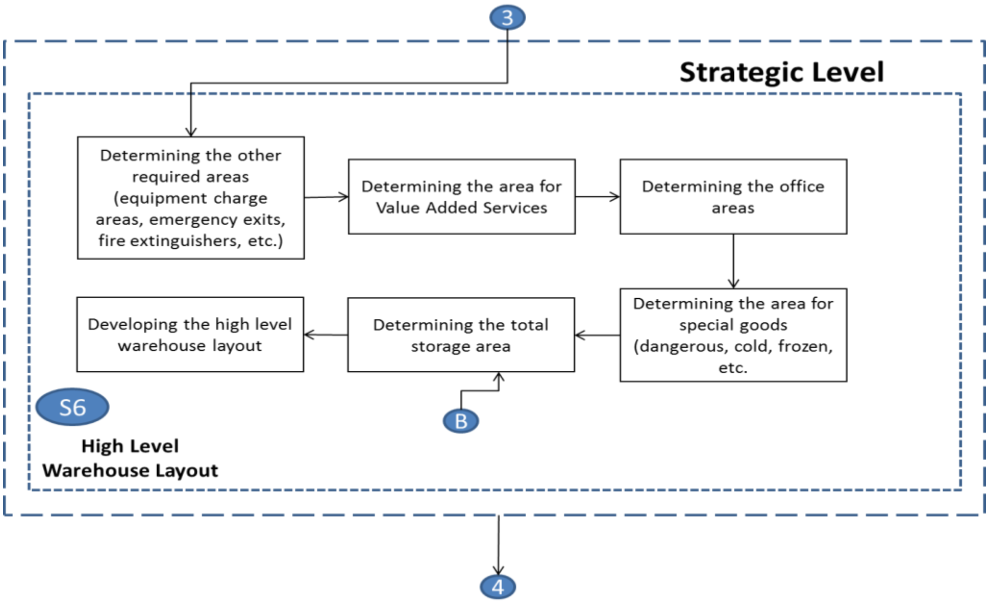
After all of these steps are completed at the three different hierarchical levels, the warehouse design should be evaluated and realized in terms of building the warehouse, implementation of equipment and warehouse management systems, and recruitment of the required staff. After all steps are completed, the warehouse will start to operate according tothe design. It is advisable to monitor the performance of the warehouse to enable continuous improvement.

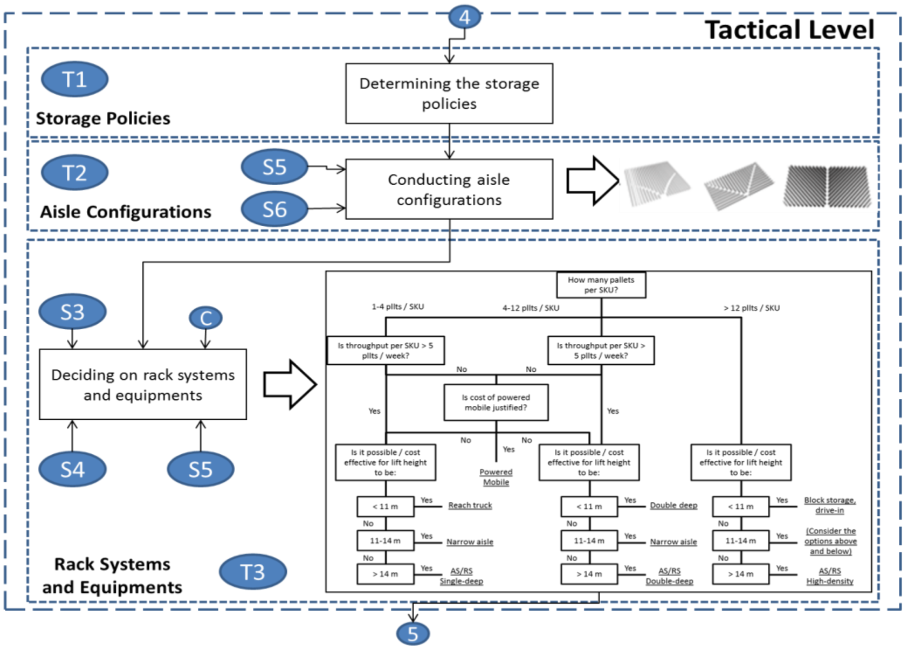
Figure 2 shows the hierarchical warehouse design approach for distribution centres that covers the design topics and related activities described above.

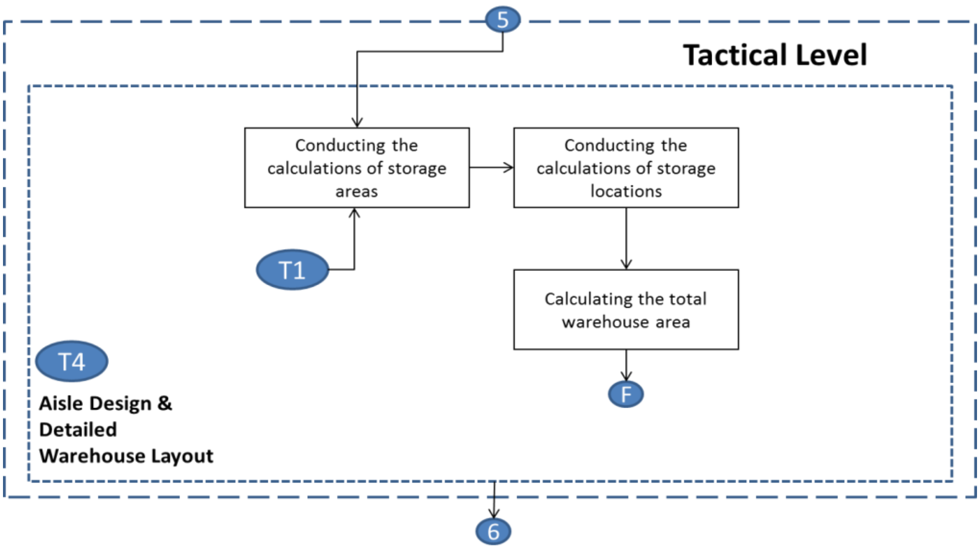

Strategic Level
Start
Customer known?
Yes
No
Determining the type and purpose of the warehouse
Determining the industry that the warehouse will serve
S1
Strategic Goals & Investment Planning
Determining the number of customers
Determining the attributes of warehouse from sustainability perspective
Determining the number of floors of the warehouse
S2
Warehouse Location Selection
Selecting warehouse location (Evaluating the dependencies on territory and topography)
F
Current Requirements
Performing data analysis (Speed / Volume Balance)
Future State Requirements
Storage Analysis
Volumetric Analysis
Movement Analysis
S3
Data Analysis
1

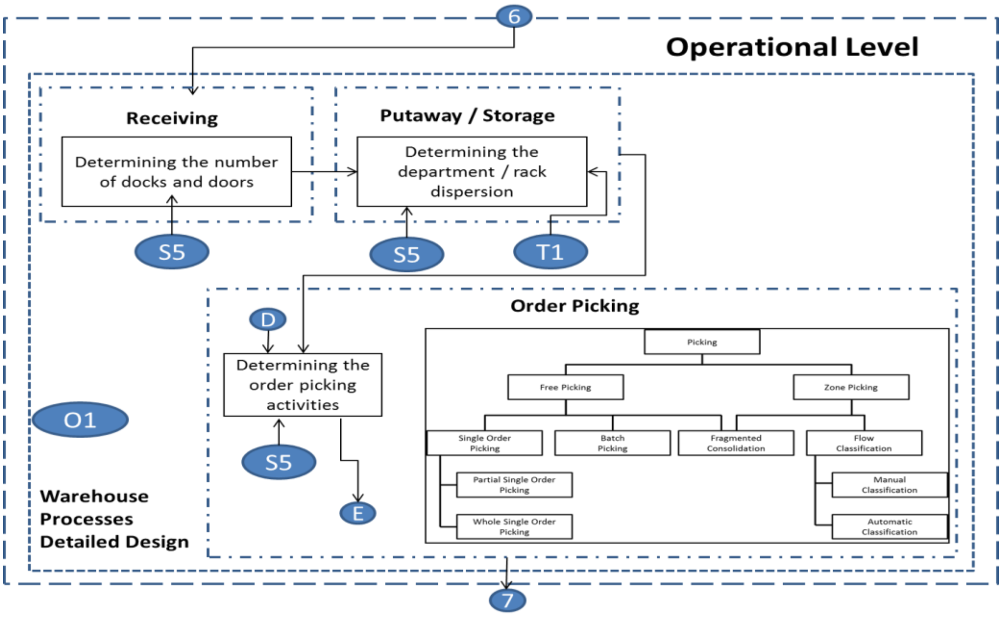

1
Strategic Level
Warehouse Sizing
Developing warehouse flow diagram
B
Determining warehouse units and dimensions
A
Conducting Pareto analysis
S3
Data Analysis
C
D
Number of storage units stored require automated solutions? (e.g. > 29.000-30.000 pallets*)
Yes
Number of storage units moved per hour require automated solutions (e.g. > 200-300 pallets*)
Yes
Automated Warehouse
No
No
S4
Conventional / Automated Warehouse
Conventional warehouse
Conducting planning timescale analysis to evaluate hybrid alternatives (e.g. partly automated warehouse)
Making final decision
* The numbers are proposed for Turkish market and may change for any other markets.
2

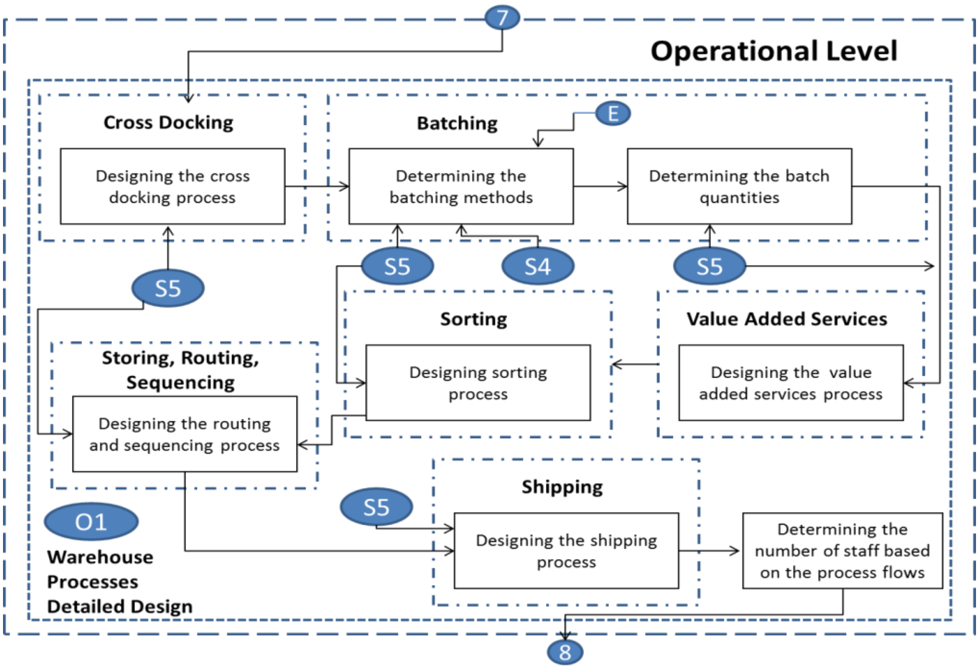

2
Strategic Level
Determining warehouse flow type
Receiving
Determining receiving area
Determining the area for returned goods
Determining vehicle loading / unloading /parking area
Putaway / Storage
Determining the storage area
Determining quarantine / blocked stock areas
A
Determining the stock area for customer / vendor / bonded stocks
Determining the area for cross docking / flow through
Order Picking
Determining the picking types and area
Shipping
Determining the shipping area
S5
Warehouse Process Principles
3


3
Strategic Level
Determining the other required areas (equipment charge areas, emergency exits, fire extinguishers, etc.)
Determining the area for Value Added Services
Determining the office areas
Developing the high level warehouse layout
Determining the total storage area
Determining the area for special goods (dangerous, cold, frozen, etc.
B
S6
High Level Warehouse Layout
4


4
Tactical Level
T1
Storage Policies
Determining the storage policies
T2
Aisle Configurations
S5
S6
Conducting aisle configurations
S3
C
Deciding on rack systems and equipments
S4
S5
Rack Systems and Equipments
T3
How many pallets per SKU?
1-4 pllts / SKU
4-12 pllts / SKU
> 12 pllts / SKU
Is throughput per SKU > 5 pllts / week?
Is throughput per SKU > 5 pllts / week?
No
No
Is cost of powered mobile justified?
Yes
Yes
No
Yes
No
Is it possible / cost effective for lift height to be:
Powered Mobile
Is it possible / cost effective for lift height to be:
Is it possible / cost effective for lift height to be:
< 11 m
Yes
Reach truck
11-14 m
Narrow aisle
> 14 m
AS/RS Single-deep
Double deep
Narrow aisle
AS/RS Double-deep
Block storage, drive-in
(Consider the options above and below)
AS/RS High-density
5


5
Tactical Level
Conducting the calculations of storage areas
Conducting the calculations of storage locations
T1
Calculating the total warehouse area
T4
Aisle Design & Detailed Warehouse Layout
F
6


6
Operational Level
Receiving
Determining the number of docks and doors
Putaway / Storage
Determining the department / rack dispersion
S5
S5
T1
Order Picking
D
Determining the order picking activities
S5
E
Picking
Free Picking
Zone Picking
Single Order Picking
Batch Picking
Fragmented Consolidation
Flow Classification
Partial Single Order Picking
Whole Single Order Picking
Manual Classification
Automatic Classification
O1
Warehouse Processes Detailed Design
7


7
Operational Level
Cross Docking
Designing the cross docking process
Batching
E
Determining the batching methods
Determining the batch quantities
S5
S5
S4
S5
Sorting
Designing sorting process
Value Added Services
Designing the value added services process
Storing, Routing, Sequencing
Designing the routing and sequencing process
Shipping
S5
Designing the shipping process
Determining the number of staff based on the process flows
O1
Warehouse Processes Detailed Design
8

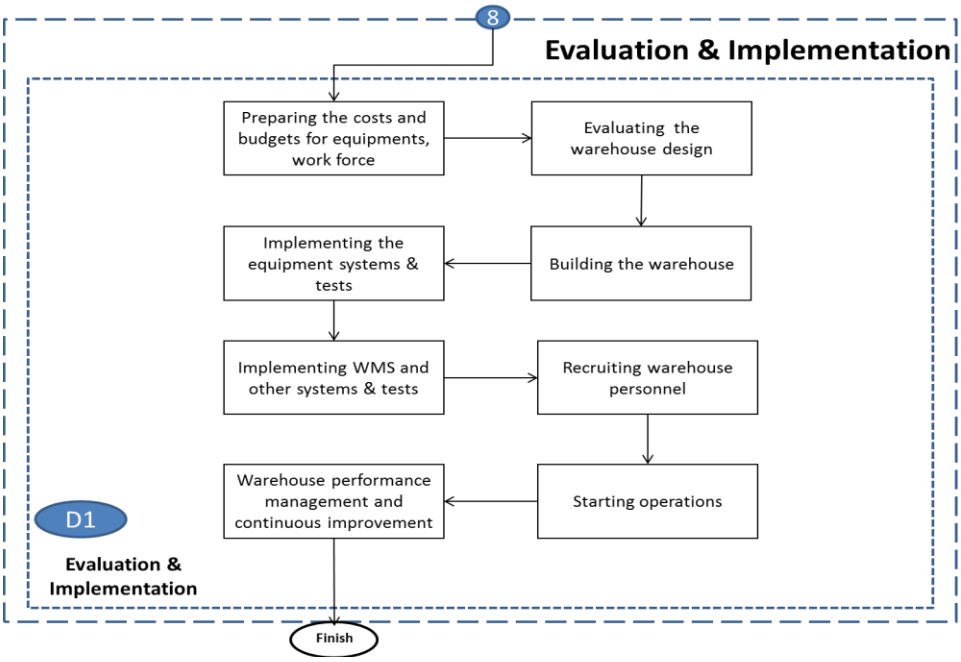


Figure 2. Hierarchical warehouse design approach.

IV. FINDINGS AND IMPLICATIONS

The proposed methodology was validated with top management executives of two out of seven logistics service provider companies interviewed (as described above). Iterated deep interviews were conductedwith afocus on the validity, usability, and applicability of the methodology for real life cases. This conceptual approach was validated by one of these leading logistics service providers that has operations across EU region as well through a recent real life warehouse design project.The outcomes of the proposed approach were compared with the actual results of an existing warehouse project named "Project Esenyurt 1" with a 22,000 m^2 area and a capacity of 14,000 pallets, 400,000 hanging garments, and 90,000 cases. The warehouse is a multi-purpose distribution centre that serves FMCG and textile companies. The warehouse project team re-worked the warehouse design on the basis of business requirements by utilizing the systematic methodology proposed in this paper. The outcomes of this application in terms of realized benefits are stated by the head of business and system development as follows:

- The proposed methodology is easy to use and helpful since it provides a systematic and intelligible way of completing an end-to-end warehouse design project.
- The methodology covers all the necessary steps of warehouse design and provides a better and more efficient way of managing the impacts of different phases on each other. In this application, it enabled mistake-proofing and reduced human errors by providing a standard approach for the entire design process. Therefore, the design phase duration of the project decreased from four months to three months. In other words, the model improved the total design phase duration by 25% since it reduced re-work efforts significantly compared to the period of time required for the original design of this distribution centre.
- The methodology was used as a reference model or checklist for the project team and provided for better monitoring and coordination across the whole project team, including third parties. For that reason, the seniority level of the project team decreased, and this resulted in a decline in the allocated human resources budget for the design phase from $98,500 to $49,250. This means an improvement of the human resources budget of 50%.
- The proposed model helped in figuring out and evaluating different design alternatives in a more rapid, robust, and consistent way.

The company has also stated that they will institutionalize the utilization of this methodology for their warehouse design projects in the future since the methodology is also useful for managing corporate intelligence for these types of projects.

Moreover, this methodology was utilized in another warehouse design project byanother local key logistics service provider that runs their operations not only in Turkey but also several countries. The Strategic Planning and Marketing Manager of the company stated that it is highly significant in warehouse design to have a systematic method because many decision points and tasks need to be undertaken, so the proposed design approach was useful in terms of providing a framework for designing more efficient warehouses. The methodology enabled positive outcomes with regard to human resource costs, duration of the design phase of the project, and efficiency of equipment and helpedin making decisions during the warehouse design process. This company has also confirmed that they will utilize this approach as a reference model on their future projects.

V. CONCLUSIONS

Warehouses are essential for any supply chain. Since most of the parameters that affect warehouse operations in terms of both costs and performance are determined during the design phase, warehouse design is becoming more crucial day by day.

It is obvious from the findings of the literature review that although there is a general consensus on the overall structure of approaches to warehouse design, there is less consensus on the tools to be used or on a systematic warehouse design approach (Baker and Canessa, 2009; Karakis*et al.*, 2011, 2012). In light of this, a design methodology called a hierarchical warehouse design approach was developed for distribution centresin the FMCG industry, as described in this paper.

The warehouse design process includes many tasks and decision points, some of which are interrelated. Therefore, it is hard to determine the optimum results for each decision since the results may be altered by factors encountered in real life situations (Rouwenhorst *et al.*, 2000). A conceptual model was therefore developed for systematic warehouse design with the purpose of making warehouse design more efficient and cost effective. In addition, there is an enormous gap between published warehouse research and the practice of warehouse design and operations, and effectively bridging this gap would improve warehouse design methodology (Gu*et al.*, 2010).

Because of the gaps between academic work and real life practices, deep interviews were conducted with seven key logistics service providers during the development of this hierarchical warehouse design methodology. The described methodology provides an end-to-end, holistic approach for warehouse design problemsby proposing a systematic flow for each design parameter and taking into consideration their interrelations. This methodology can be treated as a roadmap for warehouse design projects by both academicians and practitioners because these gaps are not only stated for Turkey by Karakis *et al.* (2012) but also stated for the UK by Baker and Canessa (2009). Therefore, the methodology can be a key guideline for warehouse design projects of companies across the Europe, as it is already validated two logistics companies which both have international operations.

The benefits of this methodology are the following:

- An end-to-end, holistic approach for overall warehouse design problems
- A systematic approach that covers all the key steps of warehouse design
- Addresses the sequence and steps of warehouse design tasks along with sub-problems/sub-tasks
- Assists in determining the relationships of these tasks with each other and the impacts of one task on others

VI. RESEARCH LIMITATIONS

For further research,this conceptual model should be extended to other types of warehouses. Moreover, it was realized during the development of the methodology thatthe steps and/or the tasks under the steps correspond to different issues to be solved by different techniques or methods. Further research can focus on these problems separately and determine the appropriate solutions in order to reveal the implications of that specific problem for overall warehouse design.

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