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A WAREHOUSE DESIGN WITH CONTAINERS FOR HUMANITARIAN LOGISTICS: A REAL-LIFE IMPLEMENTATION FROM TURKEY

Aysenur Sahin-Arslan[1], Mustafa Alp Ertem[2,*]

[1]Production Planning Department,
Turkish Railways Machines Industry Inc.
Sivas, Turkey

[2]Department of Industrial Engineering
Çankaya University
Ankara, Turkey
Corresponding author's e-mail: alpertem@cankaya.edu.tr

The purpose of this study is to investigate how and at what cost freight containers could be used as an inventory holding mechanism for humanitarian logistics. The layout and cost comparison of two alternatives are performed—stocking in a warehouse and material storage in containers. An optimum layout for storage in containers is proposed. It was found that container stockpiling uses the available area and space better than the warehouse option to stock the same number of material pallets. Leasing and purchasing costs of these alternatives are compared using present worth analysis. The results revealed that the container leasing option is not cost effective when land cost is included. Warehouse leasing results in the least setup cost, however, it incurs more operating costs, including lighting, ventilation, and maintenance as well as handling of the pallets. A real-life implementation of the proposed container stockpiling idea is presented for Turkey.

Keywords: warehouse design; cost analysis; humanitarian logistics; container warehouses; storage space utilization

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1. INTRODUCTION

Learning from the well-established methodologies of commercial logistics and applying these methodologies to humanitarian logistics problems is acceptable only if the special characteristics of humanitarian logistics are considered. Pre-disaster, non-urgent, "regular" (Holguín-Veras *et al*., 2012) humanitarian logistics have several common characteristics with commercial logistics. Thomas and Fritz (2006) indicated that commercial and humanitarian stakeholders can learn from each other. In this study, the utilization of commercial freight containers to pre-position relief supplies and expedite shipments after a disaster was analyzed using a real-life implementation by the Turkish government. A warehouse design of the optimum dimensions of the container stockpiling area and a cost comparison of different options (i.e., leasing and purchasing) are presented.

In commercial logistics, holding inventory is one of the "slack" measures (Knemeyer *et al.,* 2009) to achieve business continuity when customers request items on a date that is different from the production date. Thus, holding inventory adds "time" value to the product. For a simple two echelon supply chain, the inventory is held either at the supplier site, the customer site, or on vehicles during transport. In a fashion similar to commercial logistics (de Treville *et al.,* 2004), the pre-positioning of critical relief supplies is used in humanitarian logistics (Balçık and Beamon 2008, Duran *et al.,* 2011, Görmez *et al.,* 2011, Jahre *et al*., 2016) to decrease the lead time for the acquisition and delivery of relief supplies to beneficiaries following a disaster.

These inventories are kept in either supplier or customer warehouses that have a specific organization and design based on the type of product and customer requirements. However, in recent years, goods have been stored in large boxes (Notteboom and Rodrigue, 2009) and then shipped to customer locations. The most common equipment used to hold inventory in large boxes during long distance transportation are general purpose 40-ft-long freight containers. Compared with bulk transportation, the use of containers offers several benefits such as less product packaging, higher efficiency, and less damage. Containers are generally used in transportation and shipment by rail, sea, and highway (Vis and Koster 2003, Steenken *et al.,* 2004). The introduction of containerization has allowed more cargo to be stored on a smaller area of land. Despite the benefits of containers in storage and housing (Peña and Schuzer 2012), containers are overwhelmingly used as transportation units (Kozan and Preston 2006).

In contrast to the regular use of commercial freight containers solely for transportation, the main point of this

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reported study is to employ containers in humanitarian logistics. This study presents a practical solution to warehouse design and relief item delivery operations for "post-disaster humanitarian logistics (PD-HL) (Holguín-Veras *et al.*, 2012)." Hence, among the four phases of disaster lifecycle management (Altay and Green 2006) our study focuses on the preparedness (Joshi and Rys, 2011) and response phases. Mitigation and long-term recovery are beyond the scope of this study.

The objectives of this study are i) to propose a warehouse design for humanitarian logistics for an earthquake response, ii) to investigate how and at what cost general purpose freight containers could be used as an inventory holding mechanism in humanitarian logistics, iii) to present a real-life implementation of this concept in Turkey. The layout and cost comparison of two alternatives were performed: (1) stocking in a warehouse or (2) storage in containers. The organization of the paper is as follows. A literature review is given in the next section. In the third section, a layout model for container storage is proposed and the cost comparison of stocking in a warehouse and storage in containers is provided. The fourth section provides a real-life implementation of the proposed model by Turkish government. In the fifth section, insights for practitioners are presented. The study conclusions are presented in the sixth section.

2. LITERATURE REVIEW

The research in humanitarian logistics has grown over the last few decades, but empirical research is still very limited (Galindo and Batta 2013, Holguín-Veras *et al.,* 2012). One of the reasons for this limitation as presented by Holguín-Veras *et al.* (2012) is that fewer than two thousand humanitarian workers would consider themselves to be humanitarian logisticians. Among those that are registered with the database of Humanitarian Logistics Association, only about 200 could be used for the basis for a survey conducted about their life as a humanitarian logistician (Van Wassenhove and Allen 2012). Thus, academics who work on humanitarian logistics have a difficulty obtaining relevant information from the field as a base for their theoretical studies. Moreover, another limitation of empirical research stems from the very nature of humanitarian operations. Post disaster humanitarian operations are agile, ad-hoc, vital, and on-the-go. Academics who develop theoretical models for PD-HL cannot simply approach humanitarian organizations and request a test of academic models in a real-life disaster.

Warehouse design decisions are handled at the strategic, tactical, and operational levels. Decisions about high cost investments like a warehouse system and equipment selection are made at the strategic level. At the tactical level, the decisions related to dimensioning of resources (e.g., storage unit) and the organizational design are made. At the operational level, routine (daily or weekly) processes such as picking up a specific order are handled (Rouwenhorst et. al, 2000). At the strategic level, the efforts are focused mostly on the selection of warehouse system and process flow. At the tactical level, research on warehouse dimensioning and layout are limited. Roll *et al.* (1989) developed a procedure to specify the dimensions of a warehouse container. Berry (1969) and Bassan *et al.* (1980) (on which some of the calculations in this paper are based) analyzed the layout of the traditional warehouse to determine the optimum layout dimensions that could minimize handling costs and effectively utilize the available space. Rosenblatt and Roll (1984) analyzed the layout size of the traditional warehouse by simulation and various analytical methods. Other streams of research analyses have dealt with order picking systems and the effect of handling equipment selection on the warehouse layout. This latter stream of research is out of scope of this study. This reported study is related to strategic and tactical level warehouse design decisions (according to Rouwenhorst *et al.* (2000)'s classification), because the reported models are about the dimensions and the layout of the warehouse and the container stockpiling area and consider the costs of each alternative.

Containers are frequently used (Notteboom and Rodrigue 2009) in international transportation for movement of goods from one transportation mode to another at container terminals (Steenken *et al.,* 2004). Containers are loaded and unloaded at these terminals for shipping (Vis and Koster 2003). Container terminals have been studied in terms of performance and efficiency (Baird 2006), manpower planning (Legato and Monaco 2004), ship routing and scheduling (Gunnarsson *et al.,* 2006, Hsu and Hsieh 2007), material handling (Wang and Cullinane 2006, Chu and Huang 2005). One advantage of using containers is that containers can remain temporarily in a storage area while goods are preserved in place for a time interval.

The advances in supply chain management have provided a new meaning to the concept of temporary storage in terminals. "Instead of using the stacking area as a facilitator for a smooth synchronization between transport modes, shippers and logistics service providers started to use terminals as places for the cheap storage of goods" (Notteboom and Rodrigue 2009). This change in the use of terminals has stimulated the idea of using containers as storage units to respond immediately to the victims of a disaster in a better way. Containers are utilized for mass fatality management (Morgan *et al.,* 2006), as temporary housing (Peña and Schuzer 2012), and as medical units (Anonymous, 2014) in humanitarian logistics.

The model presented here might be considered to be on the material convergence problem (open research area #2 in Holguín-Veras *et al.*, 2012). Most of the delivered items would originate from a known source (i.e., local government) and the prepositioned items (i.e., tents, blankets, beds, electric heaters, kitchen sets) would be requested in a post-earthquake environment. Thus, there would be minimal need for extra non-consumable supplies, decreasing the number of unsolicited items. The high-priority items would be dispatched immediately using already packed and loaded containers. If the type of relief items stored in container warehouses is publicized widely, only the type of relief items that are needed would be donated. For example, after the Van (Turkey) earthquake in 2011, national capacity was enough for the needs of search and rescue teams. The Turkish government appealed and accepted donations only for winter tents, prefabricated houses, and living containers (Özkapıcı *et al.,* 2012).

The current literature about warehouse design research at the strategic and tactical level is limited. To the best of our knowledge there is no study of the intersection of warehouse design and humanitarian logistics. Yang *et al.,* (2011) and Baldini *et al.* (2012) have contributed to warehouse operations management in humanitarian logistics by the use of Radio Frequency and Identification (RFID) technology. Mukhopadhyay and Roy (2016) highlight the use of RFID for inter-organizational collaboration in humanitarian logistics workflow. Biswal *et al*., (2018) propose a newsvendor problem minimizing total expected cost including deficiency cost of RFID with two scenarios depending on the misplacements and outages. Other studies related to warehouses in humanitarian logistics are mostly concerned with facilities (e.g., warehouse, emergency medical center) location problems (Balçık and Beamon 2008, Duran *et al.*, 2011, Ko *et al.*, 2014) and inventory management systems (Beamon and Kotleba 2006, Acimovic and Goentzel 2016). Therefore, this study contributes to the warehouse design research on humanitarian logistics and presents the use of containers as storage units in a real-life humanitarian setting.

3. PROBLEM AND MODEL DESCRIPTION

The literature review revealed that previous studies have focused mostly on warehouse inventory policies and management, thus, the use of containers for longer terms to store products is a novel idea. This idea is useful when the demanded products are slow moving (i.e., frequency of disasters are low) and more durable (i.e., non-consumable items). Container stockpiling areas are more resilient to natural disasters than a warehouse building. Gu *et al.*, (2010) reviewed warehouse design related studies and discussed them in terms of major decisions and objectives. According to their framework, the current problem handled can be classified under the subtopic of optimizing the warehouse structure and dimensions for space utilization and cost.

The methodology used to determine the means and expense of using freight containers for inventory storage is composed of two parts. First, the optimum warehouse layout and container stockpiling area layout were determined (i.e., layout analysis). Second, two methods were cost compared using the present worth (PW) values based on lifetimes and interest rates (i.e., cost comparison analysis).

3.1 Layout Analysis

Optimum layouts for the warehouse and container stockpiling area alternatives are presented in this section. An optimum layout provides the peripheral dimensions of the designated area, the number of shelves and the number of storage spaces on a shelf for a given demand quantity. Material handling cost, perimeter cost and area cost are utilized to determine the optimum warehouse layout as described in Bassan *et al.*, (1980). The assumptions for the design of the warehouse and container stockpiling area layout are given as follows:

(1) The demand quantity for the warehouse and the container stockpiling area are the same. Total supply is assumed to be enough for the demand.
(2) Warehouse construction time is neglected, items are stored on double shelves and a special type of fork lift (i.e., reach truck) is used for handling.
(3) The container stockpiling area is on a concreted floor, items are stored in containers on pallets and a gantry crane is used for handling the container.
(4) There is only one type of item on each pallet and in each container.
(5) The warehouse and container layouts are rectangular to provide the optimum geometric shape for storing palletized items (Berry 1969).
(6) The aisle widths are sufficient to provide easy maneuvering of the material handling equipment.
(7) There are two doors for both design alternatives. One for entrance, one for exit. The doors are placed at the middle of the shorter walls. The width of doors is neglected.
(8) The height of the shelves and pallets are independent of the floor layout (Bassan *et al.*, 1980).

A typical layout for the warehouse is shown in Figure 1. This type of rectangular layout is chosen, because it has been frequently used in practice. The warehouse building is composed of a concrete floor and walls with an appropriate roofing structure. The items are handled in the warehouse by reach trucks and stored on the shelves using pallets.

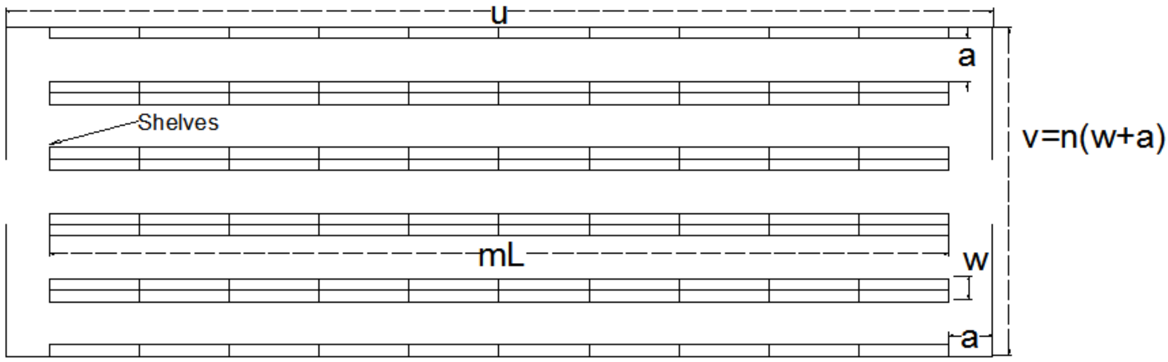

Figure 1. A Typical Layout for the Warehouse

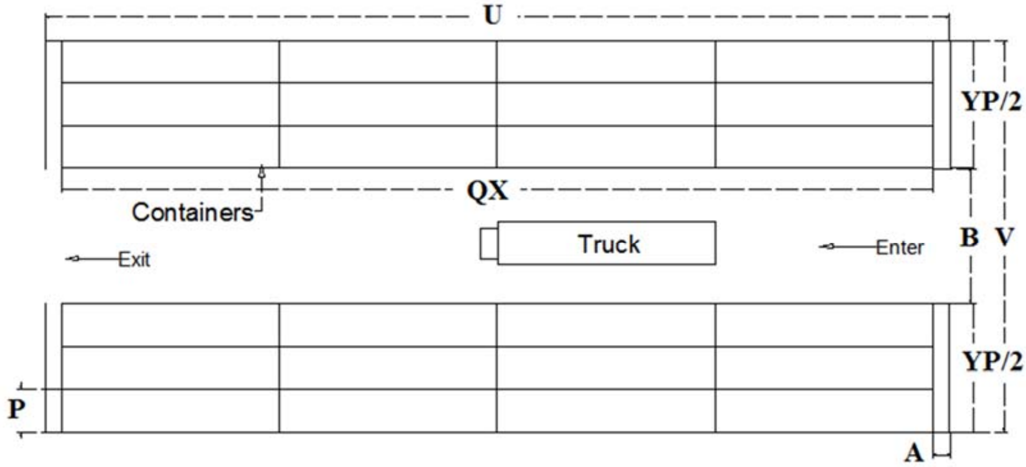

Figure 2. A Typical Layout for the Container Stockpiling Area

The layout design for the container stockpiling area is presented in Figure 2. The area is on a concrete pad and wire fenced. There is one door for receipt and one for shipment of the containers on trucks. When a container goes to be loaded for delivery, a truck arrives from the entrance door, parks at the space in between containers; a crane picks the container up from either side of the container stacks and places it on the truck. Then the trucks leave from the exit door. Storage operation is vice versa. The notation given in Table 1 is used for the warehouse layout and container stockpiling area analysis (See Figure 1 and Figure 2 for details).

Table 1. Notations Used for the Layouts of Warehouse and Container Stockpiling Area

Notations	Warehouse	Container Stockpiling Area
width of double shelf	*w*	-
width of container	-	*P*
length of a storage space	*L*	-
length of a container	-	*Q*
number of storage spaces along a shelf	*m*	-
number of containers along longitudinal dimension	-	*X*
number of storage levels in vertical direction	*h*	*H*
number of double shelves	*n*	-

number of containers along cross dimension	-	*Y*
total capacity in storage spaces	*K*(2*mnh*)	-
total capacity in container storage	-	*Cap*(*XYH*)
width of an aisle	*a*	-
width of aisles in front of doors	-	*A*
container loading aisle width	-	*B*
longitudinal dimension	*u*	*U*
cross dimension (width)	*v*	*V*
yearly throughput (demand) in storage units (pallets for warehouse, containers for container stockpiling area)	*d*	*D*
material handling cost of moving a storage unit one length unit	C_h^w	C_h^c
annual cost per unit of warehouse area	C_s^w	C_s^c
annual cost per unit length of external walls	C_p^w	C_p^c

Total annual cost, C_1^w was calculated from Bassan *et al.*, (1980) as,

$$C_1^w = d[4a + 2mL + n(w + a)]C_h^w + [(n(w + \alpha)(mL + 2a)]C_s^w + 2[(n(w + \alpha) + (mL + 2a)]C_p^w \quad (1)$$

Using algebraic manipulation and taking the derivative of equation (1) according to *m* and substituting *n* with ($n = K/2mh$), the optimum (m^*, n^*) pair are calculated as in Equations (2) and (3).

$$m^* = \frac{1}{L}\sqrt{\frac{\left(dC_h^w + 2\alpha C_s^w + 2C_p^w\right)}{2\left(dC_h^w + C_p^w\right)}S} \quad (2)$$

$$n^* = \frac{1}{w + \alpha}\sqrt{\frac{2\left(tC_h^w + C_p^w\right)}{\left(tC_h^w + 2\alpha C_s^w + 2C_p^w\right)}S}, \quad (3)$$

where $S = K(w+a)L / 2h$ is the minimal “operative” area which is needed for a capacity of *K* and *h* storage level (Bassan *et al.*, 1980).

Here, the formulation for the container stockpiling area is proposed by adopting the warehouse calculations in Bassan *et al.*, (1980) using the notations given in Table 1. The lengthwise dimension of the container stockpiling area is found as;

$$U = XQ + 2A \quad (4)$$

The crosswise dimension is

$$V = YP + B \quad (5)$$

The perimeter and the area of the container stockpiling area are

Perimeter: $$2[(YP + B) + (XQ + 2A)] \quad (6)$$

Area: $$[(YP + B)(XQ + 2A)] \quad (7)$$

When the utilization rate of the doors is taken as equal, the average travelling distance in the container stockpiling area along lengthwise dimension and crosswise dimension would be ($XQ+2A$) / 2 and ($YP+B$) / 4, respectively. Then, the expected annual travelling (EAT) distance for the demanded quantity of items is calculated as follows:

$$EAT = D[4A + 2XQ + YP + B] \tag{8}$$

It is assumed that the cost parameters; perimeter, material handling and area costs are linearly related to the travelled distance, perimeter and area (Bassan *et al.*, 1980). Then, the total annual cost for the container stockpiling area, C_1^c, will be

$$C_1^c = D[4A + 2XQ + YP + B]C_h^c + [(YP + B)(XQ + 2A)]C_s^c + 2[(YP + B) + (XQ + 2A)]C_p^c \tag{9}$$

By grouping the same parameters and new notations, the following equations are obtained

$$\theta = (4AD + (YP + B))C_h^c + (4A + 2B)C_p^c + (2AB + M)C_s^c \tag{10}$$

$$\delta = 2Q\left(DC_h^c + C_p^c\right) + B/2C_s^c \tag{11}$$

$$\mu = \left(2AC_s^c + 2C_p^c\right)M/Q \tag{12}$$

where $M = CapQP$ / H is the minimum "operative" area, which is required for a capacity of *Cap* and *z* storage level. The abbreviated version of C_1^c can be written in terms of *x* and *y*.

$$C_1^c(X) = \theta + \delta X + \mu/X \tag{13}$$

By taking the derivative of Equation (12) according to *X* and substituting *Y* with ($Y = Cap / XH$) the optimal (X^*, Y^*) pair is obtained as in Equations (14) and (15). Derivation is given in Appendix.

$$X^* = \sqrt{\frac{\left(2\alpha C_s^c + 2C_p^c\right)CapP}{\left(2Q\left(dC_h^c + C_p^c\right) + B/2C_s^c\right)H}} \tag{14}$$

$$Y^* = \frac{1}{P}\sqrt{\frac{\left(2Q\left(DC_h^c + C_p^c\right) + B/2C_s^c\right)M}{\left(2AC_s^c + 2C_p^c\right)Q}} \tag{15}$$

Substituting (X^*, Y^*) pair, the optimal lengthwise and crosswise dimensions of the container stockpiling area can be calculated by Equations (4) and (5). Similarly, the area and perimeter can be calculated by Equations (6) and (7).

3.2 Cost Comparison Analysis

The PW values of the cost items were calculated to compare the warehouse and container stockpiling area alternatives. Here, a concrete floor was used because it can serve for either a warehouse or for stockpiling containers. Lease options were also investigated for warehouse and container storage in addition to warehouse construction and container purchasing. The warehouse and container storage cost items are given in Table 2. The PW value of warehouse leasing and container leasing costs were calculated by Equation (16) (Blank and Tarquin 2005). In Equation (16), *i* is the interest rate, *n* is the duration of years, AW is the annual worth (AW). Other costs such as operating, handling and personnel were assumed to be the same for both alternatives.

$$PW = AW\ \frac{(1+i)^n - 1}{i(1+i)^n} \tag{16}$$

Duration (*n*) in years was used as the common variable for the warehouse and container stockpiling areas for comparison. After this, the PW value was used to express the present worth of each alternative. The alternative that had the lowest PW value was determined as most desirable. In the analysis, the purchasing option for the warehouse and container stockpiling area were evaluated separately and the leasing options for these alternatives were compared. Finally, an overall comparison was performed for these two options.

Table 2. Cost Items Used in Present Worth Analysis

Cost Type	Warehouse		Container Stockpiling Area	
	Purchase	Lease	Purchase	Lease
Construction	Construction cost of the warehouse	Leasing cost of the warehouse	N/A* (no construction in the area)	N/A (no construction in the area)
Storage	Purchasing cost of shelves	N/A (included in the leasing cost)	Purchasing cost of containers	Leasing cost of containers

* N/A: costs those are not applicable

4. IMPLEMENTATION OF THE PROPOSED MODEL

The concept of using containers as storage units was implemented by Republic of Turkey Ministry of Interior Disaster and Emergency Management Presidency (abbreviated as AFAD in Turkish) in Turkey. AFAD is the government institution that is responsible for all of the humanitarian logistics activities in disasters and emergencies. After suffering from several overwhelming earthquakes including the Marmara Earthquake (1999), which resulted in 17480 dead and 43953 injured people (EM-DAT, 2014), Turkey increased its efforts to cope with disasters. In one such effort, AFAD chose to implement the concept of using containers as storage units and deploying these containers to the disaster areas as quickly as possible to deliver the relief items. Performance metrics such as "fraction of demand served, weighted fraction of disasters completely served, and average cost (Acimovic and Goentzel, 2016)" have vital importance in evaluating humanitarian response capacity. Here, our proposed strategic warehouse design model implementation is compared using two performance metrics; (1) PW of cost figures and (2) storage space utilization. Then, a sensitivity analysis is provided for varying parameters.

4.1 Layout Model Implementation

In the warehouse, the storage shelves are perpendicular to the entrance and exit doors (See Figure 1). There is a reach truck for handling the pallets. In the container stockpile area, the containers are perpendicular to the entrance and exit doors (See Figure 2). The stockpiling area is fenced with a wire for security. A gantry crane handles the containers, because it is a suitable type of crane used in open land to handle heavy materials. There is a 10 m space in the middle of the stockpiling area for loading and unloading of the containers to/from trucks. The parameters used in the layout analysis are given in Table 3.

Table 3. Parameters Used in the Layout Analysis Application

Parameters	Warehouse	Container Stockpiling Area
width of double shelf	1.80 m	-
width of container	-	2.35 m
length of a storage space	1.35 m	-
length of a container	-	12.03 m
number of storage levels in vertical direction	3	3
total capacity in storage spaces	1200 pallets	-

total capacity in container storage	-	48 containers
width of an aisle	3 m	-
width of aisles in front of doors	-	3 m
container loading aisle width	-	10 m
yearly throughput (demand) in storage units (pallets for warehouse, containers for container stockpiling area)	1000 pallets	40 containers
material handling cost, of moving a storage unit one meter	0.0011 m.u pallet^{-1}	0.00064 m.u container^{-1}
annual cost per unit of warehouse area	0.1253 m.u m^{-2}	0.0665 m.u m^{-2}
annual cost per unit length of external walls	0.0333 m.u m^{-1}	0.0143 m.u m^{-1}

The disaster materials are stored on euro pallets in the warehouse; therefore the width and length dimensions of the double shelves are determined according to euro pallet sizes. The width of the shelf for two pallets is 2.7 m, the height is 2.025 m and the depth is 0.7 m per pallet. The stored items in the containers are also on euro pallets and one 40 ft dry container can host to 25 euro pallets. The number of storage levels was assumed to be three for both the warehouse and container stockpiling area. The capacity of the warehouse and container stockpiling area is the same in terms of pallets assuming 1200 pallets are stored in the warehouse and 48 in the containers (25 pallets in each container) for stockpiling area, since it is considered that this amount would be sufficient for the first response in case of an average magnitude earthquake – which is the most common type of disaster in Turkey.

4.1.1 Cost Comparison

The Euro (€) costs were converted to monetary units by a coefficient, because of the confidentiality rules of the companies from whom the costs were obtained. The cost parameters for handling equipment were obtained from Maerskline™ Turkey as the lower and upper values. The cost of working with a reach truck was considered to be 0.04 monetary unit (m.u.) per hour including the operator. The reach truck takes one pallet and moves it for one distance unit (as meter) in 60 and 140 seconds. The cost of working with a gantry crane including the operator cost is 0.24 m.u. per hour. The crane moves one container for one meter in 180 and 300 seconds. The average of the upper and lower values of moving time and costs were taken to obtain the handling cost of one container for one meter. Other cost intervals are shown in Table 4. The cost of handling for reach truck and gantry crane is calculated from Equation (17). The cost of handling one pallet is calculated as monetary unit per meter by multiplication of one hour handling with handling time in terms of seconds in Equation (17).

$$\begin{aligned}&Cost\ of\ handling\ of\ one\ pallet\ (m.u.)/meter\\&=\ Cost\ of\ handling\ one\ hour\ (m.u. 3600\ sec.^{-1})\ x\ Handling\ time\ (sec.)\\&/meter\end{aligned} \quad (17)$$

Table 4. Costs Related with Purchasing and Handling

	Reach Truck		Gantry Crane	
	Lower Bound	*Upper Bound*	*Lower Bound*	*Upper Bound*
Purchasing cost of handling equipment (m.u.)	250	480	1,817	1,833.70
Cost of handling one pallet (m.u.) per meter	0.00067	0.00156	0.00048	0.0008

Thus the cost of handling one pallet per meter with a reach truck is between 0.00067 and 0.00156 m.u/meter according to Equation (17). The cost of handling one container for one meter varies between 0.012 and 0.02 m.u/meter. This cost is 0.012/25 = 0.00048 m.u per pallet for the lower limit and 0.02/25=0.0008 m.u per pallet for the upper limit since one container takes 25 pallets. The cost of container handling was taken in terms of one pallet to provide a common ground for comparison. Then the cost of handling one pallet for warehouse (C_h^w) was taken as 0.0011 m.u./meter and the cost of handling one pallet for the container stockpiling area (C_h^c) was taken as 0.00064 m.u./meter by taking the average of lower and upper limits.

By using the Equations (2) and (3) the optimal ($m*$, $n*$) pair was found to be (24.49, 8.19). The ($m*$, $n*$) pair should be integer to be operable in a warehouse so $m*$ was taken as 25 and $n*$ was taken as 8. For the optimal ($X*$, $Y*$) parameters Equations (14) and (15) are used and found to be (2.98, 5.37). The pair was rounded to the nearest integer values considering the capacity of container stockpiling area (which was given in Table 3 as 48 containers with three storage levels), so $X*$ was taken as 3 and $Y*$ was taken as 5. As a result of rounding, the total number of stocked containers is calculated as 45 (=3x5x3), three containers less than the available capacity. The variables and their operable (i.e., integer) values are shown in Table 5

Table 5. Variables and Their Operable (i.e., integer) Values

Variables	Warehouse	Container Stockpiling Area
$m*$	25	-
$X*$	-	3
$n*$	8	-
$Y*$	-	5
U	39.75	42.09
V	38.4	24.1
Area (m^2)	1,526.4	1,014.4
Perimeter (m)	156.3	132.4
Handling Cost (m.u)	327,506	138,652

As seen in Table 5, the container stockpiling area uses less area to stock the same number of pallets than the warehouse. The handling cost of storing the same amount of pallets (138.652 m.u) is lower for the container stockpiling area than for the warehouse (327.506 m.u).

4.1.2 Storage Space Utilization Comparison

The storage space utilization (Tompkins *et al.*, 2003) is a cube metric commonly used in real life. It is the proportion of the used cube space to the cube capacity of the respective warehouse design. By using Equation (18) the storage space utilization values for alternative designs are calculated in the following.

$$Storage\ Space\ Utilization\ (\%) = 100\left(\frac{Cube\ space\ of\ material\ in\ storage}{Total\ cube\ space\ required}\right) \tag{18}$$

Total number of stored pallets' (i.e., 1200 pallets) width, length and one shelf height are considered to calculate the cube space of material in warehouse storage. Total cube space is calculated by multiplying the optimal area with total shelf height (3 storage levels) The storage space utilization of the warehouse is calculated as 25% as demonstrated in Equation (19).

$$Storage\ Space\ Utilization\ of\ Warehouse = 100\left(\frac{1200x0.8x1.2x2{,}025}{1526.4x3x2{,}025}\right) = 25\% \tag{19}$$

Total number of stockpiled containers' (i.e., 45 containers) width, length and height are considered to calculate the cube space of the materials in container storage. Total cube space is calculated by multiplying the optimal container stockpiling area with total container height (3 storage levels). The storage space utilization of the container stockpiling area is calculated as 42% as demonstrated in Equation (20).

$$Storage\ Space\ Utilization\ of\ Container\ Stockpiling = 100\left(\frac{45x2.35x12.03x2.59}{1014.4x3x2.59}\right) = 42\% \quad (20)$$

As calculated in Equations (19) and (20) the container stockpiling area utilization is higher than the warehouse storage. Thus, we can conclude that in terms of both metrics (i.e. cost and space utilization), the container stockpiling alternative is better than operating a regular warehouse.

4.2 Implementation Alternatives as Lease or Purchase

In this section present worth analysis is presented for leasing and purchasing options of two alternatives (i.e., storing in a warehouse and using containers). First, leasing and purchasing options for the warehouse alternative are compared. Then a similar analysis is performed for the container stockpiling area.

The purchasing costs of the handling equipment (reach trucks and a gantry crane) were assumed to be equal for both alternatives and not included in the PW analysis. Operating a gantry crane is about three times costlier than a reach truck. It was assumed that at least three reach trucks would be needed for the regular warehouse and one gantry crane would be enough for the container stockpiling area. Moreover, the handling cost comparison is covered in the layout analysis. The leasing cost of warehouse and leasing cost of containers; purchasing cost of containers and construction cost of the warehouse, are included in the PW analysis. The construction cost of the warehouse included the walls, shelf and roof costs. The related cost parameters are presented in Table 6.

Table 6. Cost Parameters Used in Present Worth Analysis

Cost Type	Warehouse		Container Stockpiling Area	
	Purchase	Lease	Purchase	Lease
Construction	229.91 m.u	366.34 m.u	N/A* (no construction in the area)	N/A (no construction in the area)
Storage	5.2 m.u/shelf	N/A (included in the leasing cost)	1,321.60 m.u	345.60 m.u

4.2.1 Analysis of the Warehouse

The warehouse construction option is compared with the warehouse leasing option to determine which is more cost effective. The mutual interest rate is taken as 5% (Turkish Republic Central Bank, 2013). By using Equation (16) the PW value was calculated for annual payments of warehouse leasing cost. The lifetime of the warehouse was assumed to be 50 years, since it is a concrete building and the lifetime of a container was assumed to be 25 years, since they will be used as storage units (GIB, 2014).

The annual leasing cost was 0.24 m.u per m^2 and calculated as 366.34 m.u (=1526.4x0.24) for the optimum warehouse area (1526.4 m^2). The warehouse construction cost (including building and shelf costs) (229.91 m.u) was added to PW value since it incurs once over the lifetime. So, the PW value of the warehouse construction is found as 1,269.91 m.u (=200x5.2+229.91) after adding cost of storage for 200 (25x8) shelves to the construction cost.

$$PW_{Wh\ leasing}\ (m.u.) = 366.34\frac{(1+0.05)^{50}-1}{0.05(1+0.05)^{50}} \quad (21)$$

By making the necessary calculations in Equation (21) for a 50 year-lifetime, the PW of leasing option was found to be 6,687.80 m.u. Thus, the PW value of the warehouse construction (1,269.91 m.u.) is less than the PW value of leasing (6,687.80 m.u.). Note that warehouse construction cost does not include the land cost, but warehouse leasing includes both the building and the land cost. Land cost is included in the sensitivity analysis. It was assumed that there will be no salvage value of the warehouse at the end of its lifetime.

4.2.2 Analysis of the Container Stockpiling Area

The container purchasing option is compared with the container leasing option assuming the annual land leasing cost per m^2 was the same (0.24 m.u/m^2). The annual container stockpiling area land cost was calculated as 243.4 m.u (=1,014.4x0.24) for the optimum stockpiling area (1,014.4 m^2). The cost of annual container leasing for 48 containers is 345.6 m.u (=48x7.2). By using Equation (16) the PW value for container leasing was calculated for a 50 year-lifetime.

$$PW_{Container\ \ leasing}\ (m.u.) = 345.60\frac{(1+0.05)^{50}-1}{0.05(1+0.05)^{50}} \quad (22)$$

Solving Equation (22) for a 50 year-lifetime, the PW of container leasing option is found to be 6,309.25 m.u. The useful life of the warehouse is 50 years, while the containers are replenished once every 25 years. The purchasing cost of 48 containers (1,321.60 m.u) is added as the replenishment cost of containers for future worth (FW) value, so the calculations are made according to Equations (23) and (24) to find the PW of container purchasing.

$$PW_{Container\ \ purc\,hasing}\ (m.u.) = PW + FW\frac{1}{(1+i)^{25}} \quad (23)$$

$$PW_{Container\ \ purc\,hasing}\ (m.u.) = 1{,}321.60 + 1{,}321.60\frac{1}{(1+0.05)^{25}} \quad (24)$$

The PW value of the container purchase for 50 years was found as 1,711.78 m.u. Total cost (=1,711.78+243.4) which is 1955.18 is less than the leasing value of containers plus its land cost (6,552.65 m.u). It was assumed that there will be no salvage value of the containers at the end of their lifetime.

4.2.3 Sensitivity Analysis

Sensitivity analysis is made for varying land leasing costs and interest rates. The interest rate was taken as 5% in PW analysis (in sections 4.2.1 and 4.2.2) for the implementation alternatives analysis. By using Equation (16), the PW value of the warehouse leasing, container purchasing, and container leasing were calculated and compared.

The land leasing cost that was used as 0.24 m.u per year per m^2 area in our analysis was an average value obtained from various storage firms. To see the effect, land leasing cost is varied as 0.12, 0.24, 0.36 and 0.48 m.u. and the PW of warehouse leasing cost is calculated as 3,343.90, 6,687.80, 10,031.70 and 13,375.61 m.u respectively. As expected, an increase in the land leasing cost per m^2 led to an increase in the PW of the warehouse leasing. The container stockpiling area leasing cost was used the same as warehouse land leasing, annually 0.24 m.u per m^2 area, and it varied as 0.12, 0.24, 0.36 and 0.48 m.u. The respective PW of container leasing values by adding land leasing costs were found as 3,398.02, 6,552.65, 9,707.27 and 12,861.89. In Figure 3, the PW values of the leasing options are depicted when the land leasing cost is changed both for the two alternatives. It is observed that the container leasing cost is almost the same as warehouse leasing cost for 0.12 m.u land cost and it is about **96%** of the warehouse leasing cost for 0.48 m.u land cost.

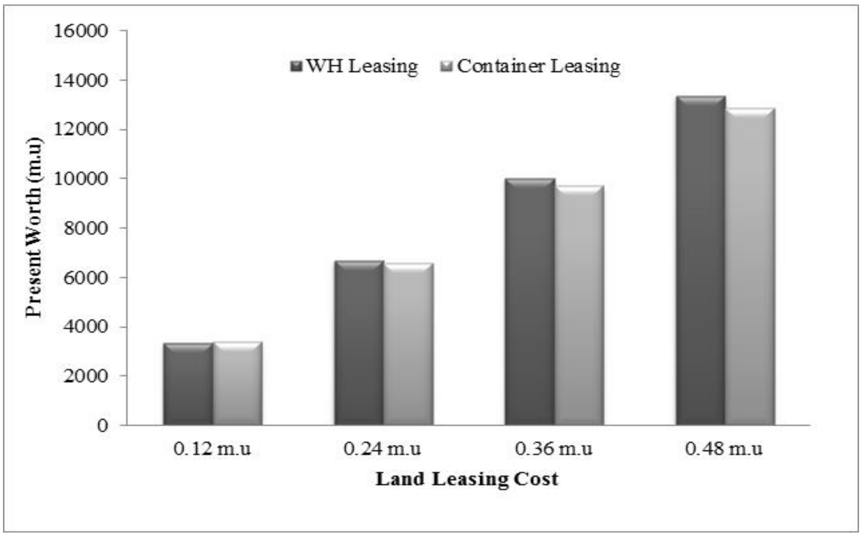

Figure 3. Present Worth Values with Varying Land Leasing Costs

In the PW analyses the land cost for warehouse construction, container leasing and container purchasing alternatives are not included while the warehouse leasing cost includes the land cost. To better represent the PW values, the land purchase cost is added as 6000 m.u. which is an average value taken from several companies. The interest rate used in the PW analysis was increased to 10% to determine the effect of interest on PW values. The result is given in Figure 4. The PW value of each alternative is decreased when the interest rate increased, except the PW of the warehouse construction, since the invested capital can be accepted in the warehouse construction as its PW value. The decrease in the leasing alternatives' PW values can be explained as the monetary depreciation, since the interest rate is increased. There is about a 46% decrease in the PW values of the leasing options and 5% decrease in the PW value of the container purchase stemming from monetary depreciation. Although the warehouse leasing option is the best alternative for the 10% interest case, the warehouse construction alternative can be thought of as the second-best alternative if the interest rate is expected to be high in the future.

As seen from the sensitivity analysis of leasing cost and interest rate, there are worthwhile results in the PW analysis, but still the most attractive alternative is constructing the warehouse if the land cost is not too high. In order to determine the effect of land cost on PW values, the land cost was varied between 1000 m.u and 10000 m.u and the effect of the PW values is obtained as shown in Figure 5.

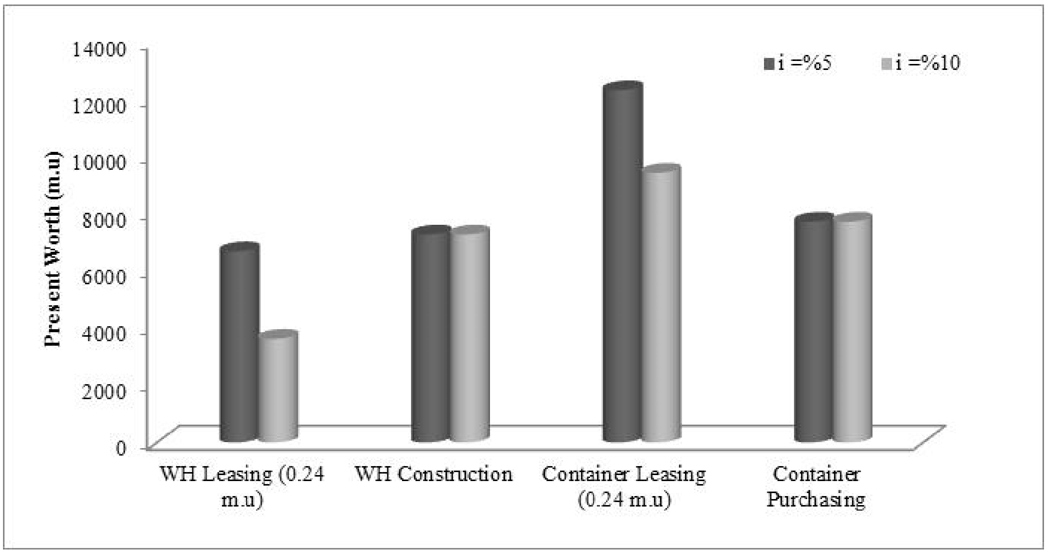

Figure 4. PW Values with Varying Interest Rates (5% and 10%) and Land Purchase Cost (6000 m.u)

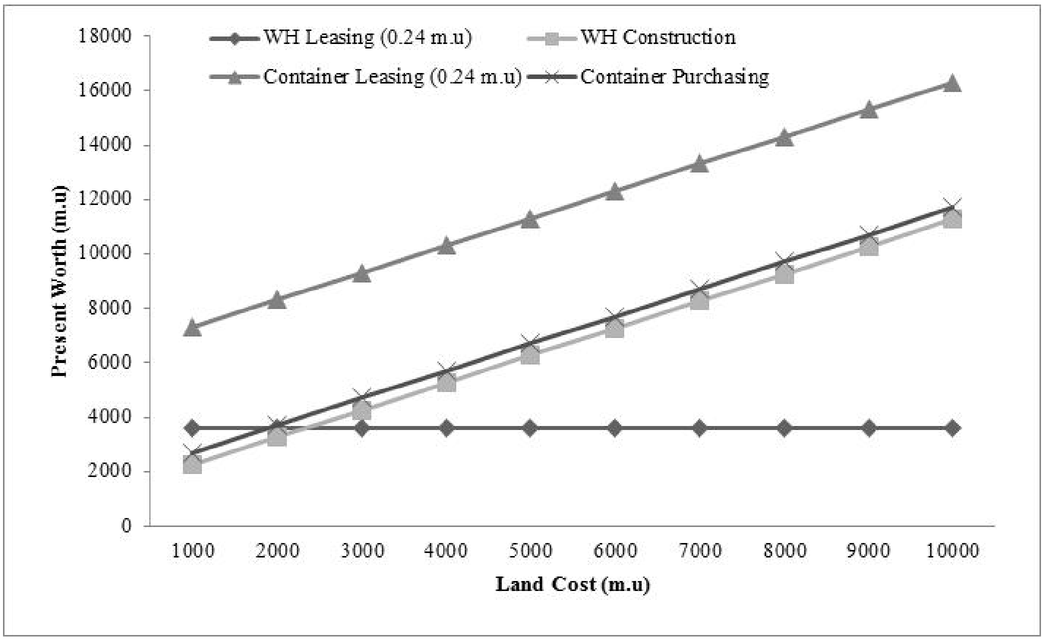

Figure 5. PW Values with Varying Land Costs and 10% Interest Rate

It was deduced from Figure 5 that when the land cost is less than 2,300 m.u., warehouse should be constructed. However, if resiliency is desired in case of an earthquake, the container purchase option could be chosen after breakeven point (2,000 m.u). The cheapest alternative is warehouse construction for a 10% interest rate up to a land cost of 2,300 m.u and after this, warehouse leasing is the cheapest. The most expensive alternative is container leasing. If the container storage would be used, then the container purchasing is the most cost effective and resilient option. The PW of either container purchase or warehouse construction are close to each other. One should also consider storage space utilization metric as well while deciding on each option.

5. LESSONS LEARNED

To the best of our knowledge, the concept of using containers as storage units was put in practice at a national scale for the first time in Turkey. Traditional warehouses require time consuming handling activity after a disaster. To eliminate delays, a novel idea was implemented: using containers directly as storage units and transferring them immediately and easily to the site after a disaster. Additionally, in order to respond to disasters as fast as possible, transportation plays an active role and alternative means (i.e., transportation mode) become important. When filled containers are positioned closer to alternative mode connections, transportation will be more robust, allowing for alternative modes and intermodal transfer. Here, the container locations are modelled as a stockpiling area, which did not have a building cover similar to container terminals in ports. In practice, AFAD implemented this model in 27 container locations built up on public land taking governmental support (Jahre *et al*., 2016) in order to save from land costs. AFAD covered the containers with walls and a roof determining that this would be a better way to store the containers safely and to prevent looting. It was found that practitioners who would desire to implement this idea should take the looting problem seriously (Jahre *et al*., 2016).

There are other strategic decisions related with the exact location of the containers requiring feasibility studies for each alternative location. The locations should be determined considering the climate and geological conditions if the containers are to be exposed in an open area. Locating containers at the intersection of transportation modes is another important issue so that the containers can be transferred by alternative means. Land costs affect the results, local governments implementing this idea can choose public lands to achieve a cost advantage.

The management of 27 container locations having a total of 1500 containers places a strain on ordering policy, inventory tracking and material handling activities. A gantry crane should be the handling equipment of choice, since the containers require loading and unloading on trucks. A forklift or reach truck can be also provided when pallets are loaded or unloaded. In order to ensure inventory tracking, information technology should be used (AFAD installed warehouse management software for this purpose).

The safety of stocks and security of containers are important issues while managing the containers properly since the lost goods could be resulted undesirable public insight in terms of donor's image, health of organization and future supplies (Jahre *et al*., 2016). It is suggested that to provide the security of container location, the area should be enclosed with wire, cameras, and a fire alarm system should be used and security personnel should be deployed to deter theft or looting. In order to ensure the longevity of stocks, containers should be insulated. Additionally, container ventilation can be performed for three to four containers monthly in each container location.

6. CONCLUSION

This study presents the use of containers for humanitarian logistics as a novel mobile warehouse design example employed in Turkey. The use of traditional warehouses and the use of containers as storage units are compared using storage space utilization for each layout and Present Worth (PW) analyses that include leasing and purchasing options. An operable layout configuration for the container stockpile area is proposed for a given demand, capacity, annual cost per unit of area, annual cost per unit length of external fence and material handling costs for moving one storage unit. An application of the proposed design in humanitarian logistics was conducted in Turkey.

In the layout comparison, it was found that container stockpiling uses the available space better than the warehouse option to stock the same number of material pallets. The handling cost of storage in containers is less than storage in a warehouse. The PW analysis for the container stockpiling alternative was tested with two options; leasing containers and purchasing containers. When these two options were compared, purchase of containers appeared to offer lower cost. When the leasing option of containers is compared with warehousing, warehouse construction was found to be cheaper than container leasing. Container purchase offers the advantages of freedom from disruptions, and faster transport, despite this being slightly more expensive than warehouse construction. Nevertheless, it can be concluded that warehouse leasing option is the cheapest option for a considerable land cost.

Warehouse options seem to have smaller cost figures, but they require more area than container stockpiling. Moreover, traditional warehousing incurs higher operating costs including lighting, ventilation, pallet handling and maintenance. With the proposed container stockpiling, lighting costs are incurred, but not roof maintenance. The handling of pallets within containers using a crane is cheaper than the handling in the warehouse since a container takes 25 pallets and they are handled altogether.

It should be noted that the PW values in this study will vary depending on the costs in different countries and regions, but relative comparisons of the alternatives would not significantly change. Different interest rates and warehouse leasing costs were tested to determine the robustness of these conclusions. It can be concluded from these analyses that these factors affect the costs, but the land costs change the ranking among the alternatives. Thus, land cost should be the primary concern when choosing the location of the container stockpiling area.

In the future, other operating costs such as ventilation, electricity, etc. of each alternative should be included in the total cost comparison. Future analyses may consider what effect multiple types of storage items in one container may have on these cost comparisons. Moreover, a future study should be extended by adding replenishment strategies for available inventories.

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APPENDIX A – DERIVATION OF EQUATIONS (14) AND (15)

Derivation of container warehouse area layout formulations

$$C_1^c = D[4A + 2XQ + YP + B]C_h^c + [(YP + B)(XQ + 2A)]C_s^c + 2[(YP + B) + (XQ + 2A)]C_p^c$$

$$\theta = (4AD + (YP + B))C_h^c + (4A + 2B)C_p^c + (2AB + M)C_s^c$$

$$\delta = 2Q\left(DC_h^c + C_p^c\right) + B/2C_s^c$$

$$\mu = \left(2AC_s^c + 2C_p^c\right)M/Q$$

$$C_1^c(X) = \theta + \delta X + \mu/X$$

By taking the derivative of $C_1^c(X)$ according to X and equating it to 0,

$$\frac{dC_1^c(X)}{dX} = \delta - \frac{\mu}{X^2} = 0$$

then

$$X^2 = \frac{\mu}{\delta} = \frac{\left(2AC_s^c + 2C_p^c\right)M/Q}{2Q\left(DC_h^c + C_p^c\right) + B/2C_s^c}$$

and

$$X = \sqrt{\frac{\left(2AC_s^c + 2C_p^c\right)M/Q}{2Q\left(DC_h^c + C_p^c\right) + B/2C_s^c}} = \sqrt{\frac{\left(2AC_s^c + 2C_p^c\right)CapP}{(2Q\left(DC_h^c + C_p^c\right) + B/2C_s^c)H}}$$

Substituting with

$X = Cap / YH$

$$C_1^c(Y) = \theta + \delta Cap / YH + \mu H/CapY$$

By taking the derivative of $C_1^c(Y)$ according to Y and equating it to 0,

$$\frac{dC_1^c(Y)}{dY} = \frac{-\delta Cap}{hY^2} + \frac{\mu H}{Cap} = 0$$

$Y^2 = \frac{\delta Cap^2}{\mu H^2}$ then

$$Y = \sqrt{\frac{\delta}{\mu}}\frac{Cap}{H} = \sqrt{\frac{(2Q\left(DC_h^c + C_p^c\right) + B/2C_s^c)}{\left(2AC_s^c + 2C_p^c\right)M/Q}}\frac{M}{PQ} = \frac{1}{P}\sqrt{\frac{(2Q\left(DC_h^c + C_p^c\right) + B/2C_s^c)M}{\left(2AC_s^c + 2C_p^c\right)Q}}$$

where

$M = CapQP$ / H

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