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Inventory model for empty container reposition problem considering quality dependent returns and port capacity constraint

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A B S T R A C T

In this study, an Economic Return Quantity (ERQ) model for the Empty Container Reposition (ECR) problem using the reverse logistics (RL) approach is developed. Some of the model's primary considerations are the return rate that depends on the quantity and quality of the empty container, and the capacity constraints to hold the empty container in the port. The model of ERQ is optimized using an analytical approach. Based on the result of the hypothetical case, the authors examined that the acceptable quality level of reusable containers should be set at 67%, 55%, and 50% for the three types of containers to be able to obtain minimum inventory costs. Two cases of binding and nonbinding constraints are investigated, and it is found that the binding constraint gives 3.4% higher cost than the latter. The results of this study help the container depots to plan, manage, and handle empty containers so that the container utility can be increased, and inventory costs can be minimized.

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1. Introduction

Nowadays, the world's manufacturing industries, not to mention the maritime industry, are promoting campaigns related to the implementation of a supply chain (Seo et al., 2023). This is closely related to the management of used products end-of-life collected from consumers, often referred to as reverse logistics management (RL) (Sureka et al., 2019). According to Campos et al. (2017), RL management aims to promote sustainable development through the handling of end-of-life products that are efficient and by environmental regulations. In the context of RL, the quantity, quality, and availability of used products (product returns) are highly uncertain variables (Tarin et al., 2020; Mohapatra et al., 2020). The modelling of these variables needs to be developed because it has an essential role in RL management (Sanni et al., 2020).

In the maritime industry, Tong & Yan (2018) stated the need to plan strategy for reverse logistics practices can be observed in the management of empty containers which is known as Empty Container Repositioning (ECR). Adetunji *et al.* (2020) defines ECR as an activity to move containers around from areas over-supply to areas of need. This activity is generally carried out by a 3PL company, known as container depots. As one of the 'links' in the supply chain, container depots play an important role to ensure that the product supply chain runs smoothly (Islam et al., 2019; Basarici & Satir, 2019). Container depots refers to open areas in the port work environment area which are managed by a certain company and used as a place for all management and handling activities of full containers and / or empty containers (Barrera & Cruz-Mejia, 2014; Seo et al., 2023; Feng et al., 2024). Generally, activities to handle empty containers include collection, storage and piling, sorting, inspection, cleaning, maintenance and repair, disposal, and repositioning (Marsola et al., 2021). In general, the process of handling empty containers in container depots is shown in Fig. 1.

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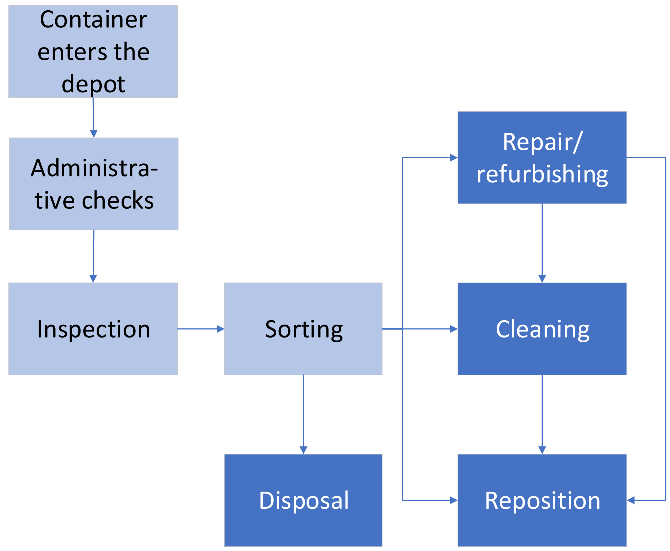


Fig. 1. Empty containers management process in container depots

In a port, the handling and management activities of containers are very dense due to the high demand and number of container flows (Basarici & Satir, 2019; Wang et al., 2024). According to Basuki *et al.* (2019), in 2016 the flow of containers handled by Indonesia Port Corporation alone reached 6,222,798.00 TEU for both international and domestic trades. Drewry (2013) stated that for more than 50% of its life cycle, containers are empty, whether in maintenance, repair, or storage and transit, with a total cost per container estimated at 675 USD. Given the fact that equipment and repositioning costs account for around 25% of total shipping costs. Efficient management of empty containers repositioning and utilization is one of the competitive factors in improving supply chain system performance (Yu et al., 2019).

In terms of quality and usability, often find poor quality containers, which are in damaged condition and no longer suitable for use, are still operating to transport logistics on transportation cost (Feng et al., 2024). Based on a survey conducted by the Indonesian Ministry of Transportation in 2018, only 20% of containers in Indonesia are fit for use, while 80% of them are in poor condition, they are either damaged or do not meet quality standards (Nur et al., 2018). Poor quality containers are considered unsafe and can increase the risk of accidents during transportation for shipments (Hemalatha et al., 2018). Therefore, the ECR management needs to be studied further by involving the quality factor of empty containers.

The inventory planning of empty containers can be done by utilizing the Economic Return Quantity (ERQ) inventory model. Adetunji et al. (2020) developed the Economic Return Quantity (ERQ) inventory model by considering warehouse storage limits and shared-cost shipping to plan the inventory of empty containers in the port. The ERQ model is an approach used to determine the optimal return quantity of a product that minimizes inventory costs. The concept is similar to the Economic Order Quantity (EOQ), in which the EOQ determines the optimal quantity of units a company should purchase to meet demand while minimizing inventory costs (Schwarz, 2008; Fiestras-Janeiro et al., 2024). If EOQ determines the optimal quantity of orders (Fiestras-Janeiro et al., 2024), then economic order quantity determines the optimal quantity of returns from customers in reverse logistics (Sanni et al., 2020).

This study will discuss a way to determine the optimal inventory policy of an ECR problem, including the ordering cycle time, purchasing lot size, and reposition lot size of empty containers. The proposed model develops an ERQ model by adding the quality factor of the repositioned empty container. The model was developed to optimize the acceptable quality level of the empty container. The specific purpose of the model is to minimize the overall inventory costs using RL approach. This study needs to be done due to the low utilization of containers that causes waste of waiting meaning the waste due to excessive waiting time. By planning and examining the system properly, container utility can be increased, inventory costs can be minimized, and resulting in a reduced supply chain cost.

The remainder of this paper is organized as follows. Section 2 discusses literature review of several studies regarding inventory modelling in similar cases. Section 3 describes the materials and methods used in the study, including systems descriptions, notations, and assumptions used to develop the proposed model. Section 4 gives the formulation of the proposed model as well as procedure to get the solution and numerical example. Section 5 analyses the results and provides sensitivity analysis to get better insights from the proposed model. Finally, Section 6 concludes the outcomes of the proposed study and gives directions for possible future development of the model.

2. Literature Review

Today, manufacturing industry trends are not only limited to forward logistics management, but also reversed logistic management (Campos et al., 2017). Forward logistics management is a management of logistics that focuses on the flow of raw materials, finished products, and information flow, which starts from suppliers to end consumers (Feng & Yu, 2023). Whereas, reversed logistics refer to the management of backward flow, that is, product returns in the form of used products that come from the consumers (Sureka et al., 2019). In a series of stages in the preparation of strategies and logistics network design, both forward and backward, one of the stages that is quite crucial and is the key to the success of creating an optimal logistics management is inventory planning and management (Özkan et al., 2024). Inventories held by a company must be controlled in such a way, to produce a minimum cost, customer loyalty, high service levels and revenue maximization (Güçdemir & Taşoğlu, 2024). In the transport industry, good inventory management of raw material supplies, spare parts, equipment, containers/pallets, and product returns must be planned and carried out optimally to minimize the costs of the supply chain (Londoño et al., 2023).

The inventory model that utilized the RL approach (Tarin et al., 2020). The demand is assumed to be deterministic, the return rate is constant, and no waste disposal activity is carried out (Bazan et al., 2016). Research on the inventory model in the RL system has evolved and expanded at the supply chain level involving parties to the supply chain network (Mohapatra et al., 2020). In this case, investigations are generally carried out at a multi-echelon level of two parties who accommodate integration between the manufacturer and a third party (serving as a collector). In real industry practice, the activities of collecting used goods are generally not carried out by the manufacturer itself, but through the help of a third party called a collector. Mitra (2009) developed a manufacturer-collector inventory model, a model with deterministic and stochastic demand and return rates. In this model, the level of demand and return is assumed to be mutually independent. Furthermore, the model was developed for conditions where the level of demand and return are mutually correlated Mitra (2012). The development of inventory models in the RL system that has accommodated integration between parties in the supply chain has also been carried out by Chung et al. (2008), Yuan and Gao (2010), Giri and Sharma (2015), and Dwicahyani et al. (2017).

Several recent studies that addressed the problem of empty container management were carried out by Bernat et al. (2016), Hosseini and Sahlin (2019), and Adetunji et al. (2020). Bernat et al. (2016) developed a stochastic optimization model in inventory management of empty containers with pollution, repair options, and street-turn policies. Hosseini and Sahlin (2019) developed a distribution network optimization model by considering uncertainties in terms of the type and quality of empty containers. In the context of inventory modelling, a recent study of empty container inventory management was conducted by Adetunji et al. (2020) who developed the Economic Return Quantity (ERQ) inventory model by considering warehouse storage limits and shared-cost shipping.

In the stochastic stream, many researchers have developed models with uncertain demand and returns. El Saadany and Jaber (2010) developed a manufacturing-remanufacturing model with a price and quality dependent return rate. The variable return rate is developed in an exponential function, which depends on two factors, which are the collection price and the acceptable quality level of the returned products. Mawandiya et al. (2017) developed an optimal production-inventory model of three entities, consisting of a retailer, a manufacturer, and a remanufacturer, with random demand and returns. They considered normally distributed correlated demand and return with full backorder. Liao and Deng (2018) developed an evolved environmental sustainability EOQ (EES-EOQ) model with uncertain demand and acquisition quantity. Giri and Masanta (2020) developed a model with price and quality dependent demand, random returns, and stochastic lead time. The model also involved learning in production. Giri and Masanta (2020) further developed the model with uncertain return, learning-forgetting effect in production, and consignment stock policy.

Various studies have been conducted in the RL system that consider integration between parties in the supply chain as well as uncertain environment (Barrera & Cruz-Mejia, 2014). However, in the area of inventory management of ECR problems, to the best of the authors knowledge, a study that has considered variable return rate, in terms of quantity, quality, or arrival of product returns, is still very limited. Therefore, this research develops an inventory management of Economic Return Quantity (ERQ) model for an ECR problem, which considers a variable return rate that depends on the quality of empty containers. As an implication of the quality dependent return rate, there is a waste disposal activity for empty containers that are no longer suitable for reuse (Marsola et al., 2021). The quality dependent return rate is modelled in the form of nonlinear functions. The results of this study provide managerial insights and directions for companies engaged in the business of container depots, to support the product delivery and distribution process.

2. Materials and Methods

In this study, the authors discuss how to optimally manage inventory for both repositioned and newly procured containers (Yu et al., 2019). The ERQ model is developed based on the model belonging to Adetunji et al. (2020), to an extent where the return rate depends on a variable, namely acceptable quality level of the empty containers. Consequently, there will be a disposal activity for returned containers that do not exceed the acceptable quality level. Multi-items container management system is considered, where each type of container is moved from one port to another (Wang et al., 2024). The used containers from customers are then returned to the port for reuse. However, not all the returned containers are reusable since some of them do not exceed the acceptable quality level and hence need to be disposed of and replaced with new containers. The developed model also incorporates constraints related to the limited storage capacity due to space restriction in the port. Table 1 gives the comparison of the proposed model to the previous model belonging to Adetunji et al. (2020).

Table 1
The comparison of the proposed model to its prior models.

Consideration	Adetunji et al. (2020)		This model	
Return Rate	Known, constant		Variable depends on quality	
Waste disposal	No		Yes	
Capacity constraint	Yes		Yes	
Type of container	Multi-type		Multi-type	
Cost-shared of shipping	Yes		No	
Objective	Annual total inventory cost		Annual total inventory cost	
Decision variables	T_j	cycle time for reposition of type-*j* container	T_j	cycle time for reposition of type-*j* container
	m_j	number of reposition cycles of type-*j* container	m_j	number of reposition cycles of type-*j* container
	Qr_j	shipment lot size of type-*j* container to reposition per cycle	Qr_j	shipment lot size of type-*j* container to reposition per cycle
	Qp_j	shipment lot size of type-*j* container to purchase per cycle	Qp_j	shipment lot size of type-*j* container to purchase per cycle
			q_j	acceptable quality level of the returned containers type-*j*

Fig. 2 shows the process of the container management system. The problems are to determine the optimal shipment lot size of containers to reposition and/or purchase per cycle, along with its cycle times, and optimal acceptable quality level of the returned containers. The objective is to minimize total inventory costs of both returned and newly purchased containers. The cost parameters considered in the model include holding costs for returned and newly procured containers, ordering costs for returned and newly procured containers, cost to purchase new containers, cleaning and maintenance cost for reusable containers, and disposal cost for unusable containers.

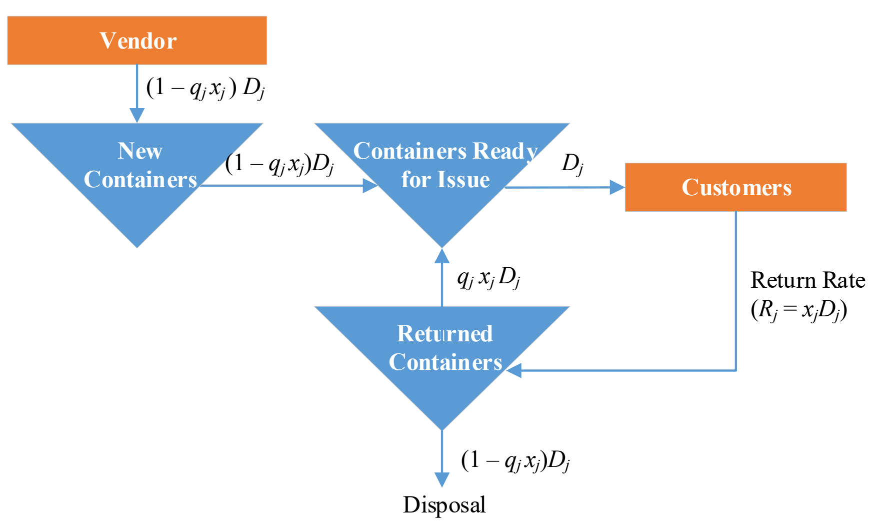


Fig. 2. The investigated containers management system

Parameters used to develop the models are given as follows.

j index for type of containers ($j = 1, 2, \ldots, J$), where J is the number of container types

D_j annual demand rate for type-*j* container

R_j annual return rate for type-*j* container $(R_j = x_j D_j)$

x_j return rate quality factor for type-*j* container $\left(x_j = b_j e^{-\varphi_j q}\right)$, where b_j and φ_j are constants.

T_j total cycle time for *m* cycles of type-*j* container reposition

hr_j annual holding cost for returned containers

hp_j annual holding cost for purchased containers

Kr_j ordering cost for returned containers

Kp_j ordering cost for purchased containers

cm_j cleaning and maintenance cost of type-*j* container

cp_j purchasing cost of type-*j* container

dc_j disposal cost of type-*j* container

s_j space requirement for type-*j* container

C total capacity available for storage

The following are decision variables of the model:

T_j cycle time for reposition of type-*j* container

m_j number of reposition cycles per one procurement cycle of type-*j* container

q acceptable quality level for returned containers

Qr_j shipment lot size of type-*j* container to reposition per cycle

Qp_j shipment lot size of type-*j* container to purchase per cycle

Q_j total shipment lot size (both reposition and purchase) of type-*j* container

3. Results and Discussion

3.1 Development of ERQ Model

Fig. 3 shows the quantity-time graph (inventory profile) for single container system.

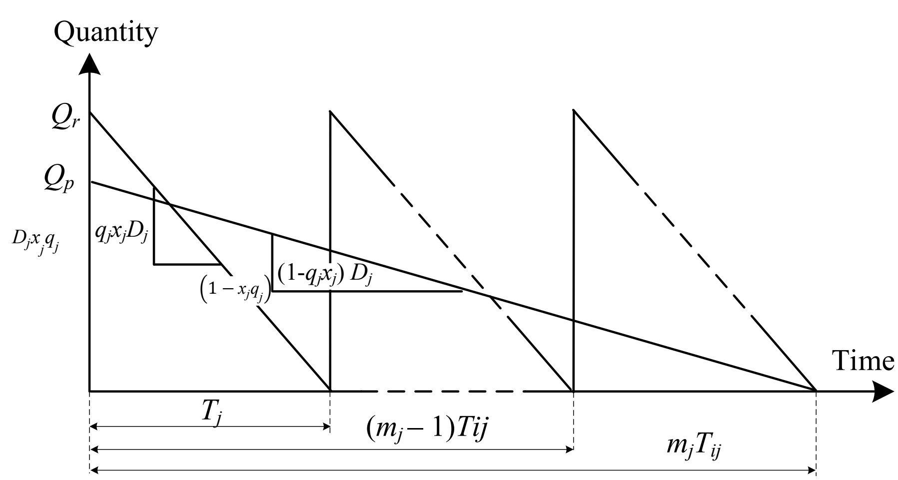


Fig. 3. Quantity-time graph (inventory profile) for single container system

For each cycle, the cost to manage inventory for both returned and new containers are given as Eq. (1) and Eq. (2). Eq. (1) gives the formulation of inventory cost of the returned containers which consists of ordering cost, holding cost, cost of cleaning and maintenance, and disposal cost. Whereas Eq. (2) gives the formulation of the new containers inventory cost which consists of ordering cost, holding cost, and purchasing cost, respectively.

$$\frac{K_{r_j} D_j x_j q_j}{Q_{r_j}} + \frac{h_{r_j} Q_{r_j}}{2} + c_{m_j} Q_{r_j} + \frac{d_{c_j} Q_{p_j}}{m_j} \tag{1}$$

$$\frac{D_j K_{p_j}\left(1 - x_j q_j\right)}{Q_{p_j}} + \frac{h_{p_j} Q_{p_j}}{2} + c_{p_j} Q_{p_j} \tag{2}$$

According to Fig. 3, the following relationships are obtained:

$$Q_{r_j} = D_j x_j q_j T_j \tag{3}$$

$$Q_{p_j} = D_j T_j \left(1 - x_j q_j\right) m_j \tag{4}$$

$$Q_j = Q_{r_j} + Q_{p_j} = D_j \left(x_j q_j + \left(1 - x_j q_j\right) m_j \right) T_j \tag{5}$$

Eq. (3) gives the formulation of return/reposition quantity of the type-j container, whereas Eq. (4) gives the formulation of purchase quantity of the type-j container. Eq. (5) then formulates the total quantity of type-j container which procured during the period Tj. By substituting Eq. (3) to Eq. (1) and Eq. (4) to Eq. (2), the cost functions with respect to cycle time, for both returned and new containers, are obtained as given by Eq. (6) and EQ. (7).

$$\text{Cost of Returned Containers} = \frac{K_{r_j}}{T_j} + D_j \left(\frac{h_{r_j} x_j q_j}{2} + c_{m_j} x_j q_j + d_{c_j}\left(1 - x_j q_j\right) \right) T_j \tag{6}$$

$$\text{Cost of New Containers} = \frac{K_{p_j}}{m_j T_j} + D_j \left(\frac{h_{p_j}\left(1 - x_j q_j\right) m_j}{2} + c_{p_j}\left(1 - x_j q_j\right) \right) T_j \tag{7}$$

Finally, the total inventory cost of both returned and newly purchased containers, $TC(T_j, m_j, q_j)$, for the multi-container system is given by Eq. (8).

$$TC = \sum_{j=1}^{J} \frac{K_{r_j}}{T_j} + \frac{K_{p_j}}{m_j T_j} + D_j \left(x_j q_j \left(\frac{h_{r_j}}{2} + c_{m_j} \right) + \left(1 - x_j q_j\right)\left(\frac{h_{p_j} m_j}{2} + c_{p_j} + d_{c_j} \right) \right) T_j \tag{8}$$

As explained earlier, qj denotes the acceptable quality level for the type-j container. The existence of the qj variable allows us to reposition only part of the existing empty containers, due to the quality level of containers that are not suitable for reuse. Meanwhile, the remaining needs will be met by purchasing new containers. Hence, the qj variable will affect the number of items to be repositioned, namely xj. The relationship of qj on xj, is modelled in the form of a quality dependent return rate function which was adopted from El Saadany and Jaber (2010). The exponential function of the quality dependent return rate is given by Eq. (9).

$$x_j = \left(b_j \mathrm{e}_j\right)^{-\varphi_j q_j} \tag{9}$$

With, b_j and φ_j denote the coefficient parameter of the quality dependent return rate. Finally, the optimization problem of the proposed model is given by the following set of equations.

$$min\, TC\left(T_j, m_j, q_j\right) \tag{10}$$

subject to

$$\sum_{j=1}^{J} s_j D_j \left(x_j q_j + m_j\left(1 - x_j q_j\right)\right) T_j \leq C \tag{11}$$

$$0 \leq q_j \leq 1 \; for \; j \in \{1, 2, \ldots, J\} \tag{12}$$

$$m_j = \{1, 2, 3, \ldots\} \; for \; j \in \{1, 2, \ldots, J\} \tag{13}$$

$$T_j > 0 \; for \; j \in \{1, 2, \ldots, J\} \tag{14}$$

$$Q_{r_j}, Q_{p_j} \geq 0 \; for \; j \in \{1, 2, \ldots, J\} \tag{15}$$

The objective function of the model is to minimize the total inventory costs for both returned and newly purchased containers in Eq. (10). Eq. (11) gives the capacity constraint to ensure that the port capacity is sufficient to store all the containers. Eq. (12) to Eq. (15) are the rationality, integrality and the non-negativity constraints for the decision variables.

3.2 Solution Procedure

The ECR inventory problems are divided into two cases for binding and nonbinding constraints. The unbinding constraint is required in cases where the maximum capacity limit can be violated. In the real case, this can illustrate whether we can save costs when the capacity constraint is violated. Meanwhile, the binding capacity constraint is needed in cases where there is no violation of the maximum capacity available at the port. This means that it is no longer possible to expand the storage area at the Port. Case 1 and Case 2 will later be compared with each other to illustrate how much cost savings can be obtained under such conditions. The solution procedure to find optimum levels of Tj and mj is given for each case.

Case 1: Constraint is not binding

For a case where the constraint is not binding, the objective function in Equation (8) is simply optimized as if unconstrained. The total cost function in Equation (8) is partially differentiated with respect to (w.r.t) T_j. By solving the equation, we get the optimum level of T_j denotes by $T_j^*(m_j, q_j)$ as given by Equation (16).

$$T_j^{\#}\left(m_j, q_j\right) = \sqrt{\frac{2\sum_{j=1}^{n}\left(K_{r_j} + \frac{K_{p_j}}{m_j}\right)}{\sum_{j=1}^{n} D_j\left(h_{r_j} x_j q_j + h_{p_j} m_j\left(1 - x_j q_j\right) + 2\left(c_{m_j} x_j q_j + \left(1 - x_j q_j\right)\left(c_{p_j} + d_{c_j}\right)\right)\right)}} \tag{16}$$

By substituting the function of $T_j^{\#}$ in Equation (16) into $TC_j(T_j, m_j, q_j)$ in Eq. (8), we obtain $TC_j(q_j, m_j)$. The optimal value of m_j, denoted by $m_j^{\#}$, can be obtained by letting the derivative of $TC_j(q_j, m_j)$ w.r.t m_j equal to zero. Thus, the function of $m_j^{\#}$ is given as

$$m_j^{\#}\left(q_j\right) = \sqrt{\frac{2\sum_{j=1}^{n} K_{p_j}\left(\left(c_{p_j} + d_{c_j}\right) - x_j q_j\left(\frac{h_{r_j}}{2} + c_{m_j} - c_{p_j} + d_{c_j}\right)\right)}{\sum_{j=1}^{n} h_{p_j} K_{r_j}\left(1 - x_j q_j\right)}} \tag{17}$$

The optimization of return quality q_j can be simply done by using an optimization tool (e.g. Solver from Microsoft Excel or Optimization function in Wolfram Mathematica). With $TC\,(T_j^{\#}, m_j^{\#}, q_j)$ being the objective function subject to Eq. (12).

Case 2: Constraint is binding

For a case when the constraint is binding, we use the Lagrangian approach to solve the problem. First, we derive the Lagrangian function as given by Eq. (18).

$$\boldsymbol{L}\left(\mathrm{T_j}, \mathrm{m_j}, \mathrm{q_j}\right) = \left[\sum_{j=1}^{J} \frac{\mathbf{1}}{\mathrm{T_j}}\left(\mathrm{K_{r_j}} + \frac{\mathrm{K_{p_j}}}{\mathrm{m_j}}\right)\right] + \left[\sum_{j=1}^{J} \frac{\mathrm{D_j T_j}}{2}\left(\left(\mathrm{h_{r_j}} + 2\mathrm{c_{m_j}} + 2\lambda\mathrm{s_j}\right)\mathrm{x_j q_j} + \left(1 - \mathrm{x_j q_j}\right)\left(\mathrm{m_j}\left(\mathrm{h_{p_j}} + 2\lambda\mathrm{s_j}\right) + 2\mathrm{c_{p_j}} + 2\mathrm{d_{c_j}}\right)\right)\right] - \lambda\mathrm{C} \tag{18}$$

By setting the partial derivative of Eq. (18) w.r.t. T_j equals to zero, we obtain the following function of $T_j^{\#}$ as given by Eq. (19).

$$\mathrm{T_j}^{\#}\left(\mathrm{m_j}, \mathrm{q_j}\right) = \sqrt{\frac{2\sum_{j=1}^{n}\left(\mathrm{K_{r_j}} + \frac{\mathrm{K_{p_j}}}{\mathrm{m_j}}\right)}{\sum_{j=1}^{n} \mathrm{D_j}(\boldsymbol{\psi} + 2\boldsymbol{\Pi})}} \tag{19}$$

With ψ and Π are given by Equation (20) and (21), respectively.

$$\psi = \left(h_{r_j} + 2\lambda s_j\right)x_j q_j + m_j\left(1 - x_j q_j\right)\left(h_{p_j} + 2\lambda s_j\right) \tag{20}$$

$$\Pi = c_{m_j} x_j q_j + \left(1 - x_j q_j\right)\left(c_{p_j} + d_{c_j}\right) \tag{21}$$

In a case where the constraint is binding, Eq. (11) holds true and the following relationshipapplies

$$T_j = \frac{C}{\sum_{j=1}^{n} s_j D_j \left(x_j q_j + \left(1 - x_j q_j\right) m_j\right)} \tag{22}$$

λ is obtained by adopting the m_j values obtained from Eq. (17) and subsequently solve the Eq. (19) and Eq. (22). Finally, the optimal value of qj is simply obtained by solving the model with Mixed-Integer Non-Linear Programming (MINLP) approach, for $0 \leq qj \leq 1$, with the help of any optimization software, such as Excel Solver or Wolfram Mathematica.

3.3 Numerical Example

Here, an ECR case with 3 types of containers (J = 3) is investigated. Table 2 shows the input parameters, which are adopted from Adetunji *et al.* (2020) and (El Saadany dan Jaber, 2010), to illustrate the problem for both Case 1 and Case 2. The space limitation to store all types of container (C) for Case 1 and Case 2 are given by 150,000 ft^3 and 100,000 ft^3, respectively.

Table 2
Hypothetical input parameters adopted from Adetunji *et al.* (2020) and El Saadany and Jaber (2010)

Parameter	Type-1 Container	Type-2 Container	**Type-3 Container**
Annual Demand (D_j)	15,000 units	20,000 units	25,000 units
Space requirement (s_j)	20 ft^3	15 ft^3	10 ft^3
Ordering cost for returned containers (Kr_j)	\$10,000	\$8,000	\$7,000
Ordering cost for new containers (Kp_j)	\$15,000	\$12,000	\$10,500
Annual holding cost for returned containers (hr_j)	\$40	\$30	\$20
Annual holding cost for new containers (hp_j)	\$50	\$40	\$30
Cleaning and maintenance cost (cm_j)	\$50/unit	\$40/unit	\$30/unit
Purchasing cost (cp_j)	\$2000/unit	\$1750/unit	\$1500/unit
Disposal cost (dc_j)	\$10/unit	\$8/unit	\$6/unit
b_j	0.95	0.90	0.85
φ_j	1.50	1.75	2.00

Optimization result of Case 1 (constraint is not binding) is summarized in Table 3, whereas Table 4 gives the optimization result of Case 2 (constraint is binding). Case 1 refers to a condition where the capacity constraint is not binding, meaning that the available space is still sufficient to store all types of containers. For case 1, the available space is 150,000 ft^3, whereas the requirement to store the three types of containers is C = 125,513.90 ft^3, resulting in an untapped capacity of 24,816.10 ft^3. The optimum repositions cycle times for the three types of containers are 7.5 days, 6.1 days, and 5.4 days, respectively. The optimum number of cycles for reposition per one procurement are 10 cycles, 10 cycles, and 11 cycles, respectively. Finally, the optimum acceptable quality levels are 0.67, 0.57, and 0.50, respectively.

Table 3
Optimization result of Case 1

j	q_j^*	x_j	T_j^* (years)	m_j^*	TC_j (/year)	C_j (ft^3)
1	0.67	0.347	0.02068	10	\$1,110,760	49,030.90
2	0.57	0.332	0.01669	10	\$1,098,160	41,544.30
3	0.50	0.312	0.01481	11	\$1,078,560	34,938.70
				∑ =	**\$3,287,480**	**125,513.90**

Table 4
Optimization result of Case 2

j	q_j^*	x_j	T_j^* (years)	m_j^*	TC_j (/year)	C_j (ft^3)
1	0.67	0.347	0.013852	10	\$1,201,740	32,841.90
2	0.57	0.332	0.013852	10	\$1,118,100	34,479.70
3	0.50	0.312	0.013852	11	\$1,080,680	32,678.40
				∑ =	**\$3,400,520**	**100,000.00**

Case 2 refers to a condition where the capacity constraint is binding, meaning that the available space, C, is not sufficient to store the optimum quantity, Q_j^*. Then, the solution becomes infeasible and results in a condition where C is the best quantity to select. As one can see in Table 4, the optimum repositions cycle times for the three types of containers have decreased to the same level, which is around 5.1 days. Compared to Case 1, the values of m_j^* and q_j^* in Case 2 remain, but the total cost increases to \$3,400,520 per year due to the condition in Case 2, which requires binding capacity constraint.

4. Discussion & Analysis

This section discusses how the acceptable quality level (q) of return containers affects the overall total cost (TC). In addition, we also conduct sensitivity analysis to understand the behaviour of the model regarding changes in several parameters, including annual demand (D), holding cost (h_p), and ordering cost (K_p and K_r). The analysis is done to explain how the effects of these parameters on the model's optimal solution are. We discuss the results from Case 2 where the constraint is binding.

4.1 Effects of the Acceptable Quality Level (q) on Total Cost (TC)

To further understand how the acceptable quality level of the returned containers affects the total cost, Fig. 4 shows a simulation plot for variable q against TC.

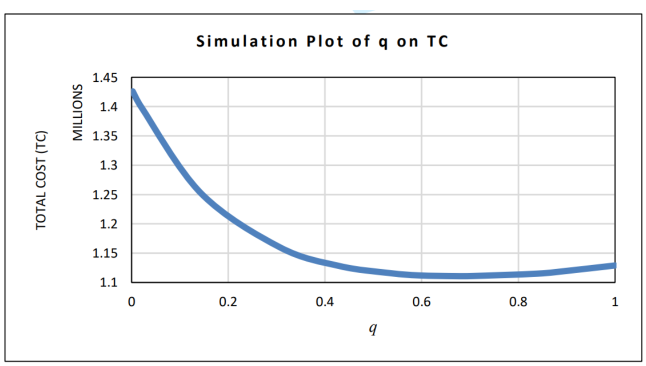


Fig. 4. Effects of the acceptable quality level of empty container on the overall total cost (j=1).

Fig. 4 clearly illustrates the effect of variable q on TC. From Fig. 4, we see that q has a convex effect on total cost, where the minimum TC value is obtained at q = 0.67. From the model, q = 0 indicates there is no empty container returned for repositioning, while q = 1 indicates all containers will be returned for repositioning and reuse. From Fig. 4, repositioning 100% empty containers will not necessarily minimize costs. This is due to a trade-off between the cost of repositioning and maintaining the empty container. As found in the practical case, not all entire empty containers have a quality that is suitable for reuse, even some may be in damaged or poor conditions. So, it will be inefficient for the system to reposition empty containers with poor quality. Determination of the acceptable quality level of the returned containers should involve the related costs, to get the optimal level that truly minimizes the overall cost of the system.

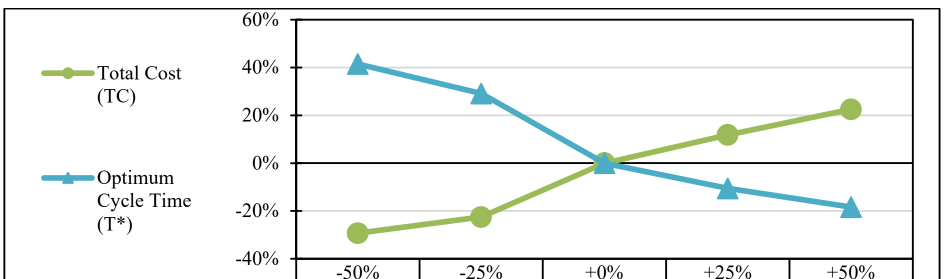
4.2 Analysis on Changes in Demand (D)

Analysis was carried out for the case of type-3 container with five variations in the value of annual demand (*D*), -50%, -25%, 0%, +25%, and +50%. The result given by the changes in demand on the total cost (*TC*) and reposition cycle time (*T*) are shown in Table 5.

Table 5
Effects of Demand Parameter on Total Cost and Reposition Cycle Time

Annual Demand (units)		Annual Total Cost (TC)	Reposition Cycle Time (T)
12,500	(-50%)	$ 762,608	7.6 days
18,750	(-25%)	$ 835,395	7.0 days
25,000	(+0%)	$ 1,078,490	5.4 days
31,250	(+25%)	$ 1,205,790	4.8 days
37,500	(+50%)	$ 1,320,880	4.4 days

As the demand varied, from -50% to +50%, it is found that the reposition cycle time (T^*) and the total cost are also changing. A decrease in demand will extend the cycle time and decrease the total cost, and vice versa. Figure 4 shows how *TC* and T^* will be changed in a case where the demand varied between -50% to +50%.



	-50%	-25%	+0%	+25%	+50%
Total Cost (TC)	-29%	-23%	0%	12%	22%
Optimum Cycle Time (T*)	41%	29%	0%	-11%	-18%

Fig. 5. How the annual demand changes the total cost and reposition cycle time ($j = 3$)

From Fig. 5, it is examined that when the demand decreases by 50%, the reposition cycle time is increased by 41%. However, by that scenario, it will also decrease the total cost by 29%. Whereas, in a scenario where the demand increases by 50%, the optimum time to reposition is shortened by 18%, while the total cost will increase by 22%. From these results it is clear that demand actually has a significant effect on the optimal solution of reposition cycle time and total cost. Where the level of the demand is lower, the system should shorten the empty container return cycle time, in order to minimize the total cost, and vice versa.

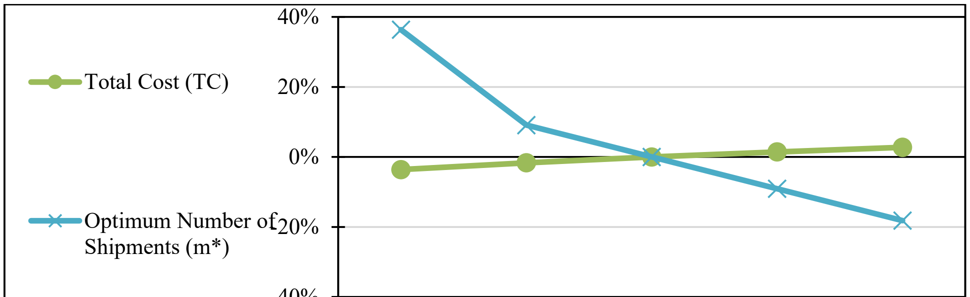
4.3 Analysis on Changes in New Container Holding Cost (h_p)

Here, an analysis on how the holding cost parameter for new container (hp) affects the optimal decisions is investigated. Analysis was carried out for the case of type-3 containers with five different inputs for h_p parameters, which are -50%, -25%, 0%, +25%, and +50%. The result, given by the changes in h_p parameter on the total cost (*TC*) and number of reposition cycles (*m*), are summarized in Table 6.

Table 6
Effects of Holding Cost Parameter on Total Cost and Number of Reposition Cycles

Cost to Hold New Container (h_p)		Total Cost (TC)	Number of Reposition Cycles (m)
$20/unit	(-50%)	$1,039,520	15
$30/unit	(-25%)	$1,060,680	12
$40/unit	(+0%)	$1,078,490	11
$50/unit	(+25%)	$1,094,220	10
$60/unit	(+50%)	$1,108,420	9

From Table 6, it is observed that in a scenario where the cost to hold a new container is cheaper, the solution will be to increase the number of return cycles, which obviously will lower the total cost. Fig. 6 shows how *TC* and m^* will be changed in a case where the holding cost of a new container varied between -50% to +50%.



	-50%	-25%	+0%	+25%	+50%
Total Cost (TC)	-4%	-2%	0%	1%	3%
Optimum Number of Shipments (m*)	36%	9%	0%	-9%	-18%

Fig. 6. How the new product holding cost changes the total cost and number of reposition cycles (*j*=3)

By examining Fig. 6, it is understanded that when there is a decrease in holding cost by 50%, the number of reposition cycles should be increased by 36%. Whereas, whenever the system faces a condition where the holding cost is increased by 50%, the solution will be to reduce the number of reposition cycles by 18%. However, variation in new product holding cost from -50% to +50% do not give a significant impact on total cost. From these results, it implies that variations in cost to store new containers will change decisions regarding repositioning cycles of empty containers, although the effect on total costs is not that great.

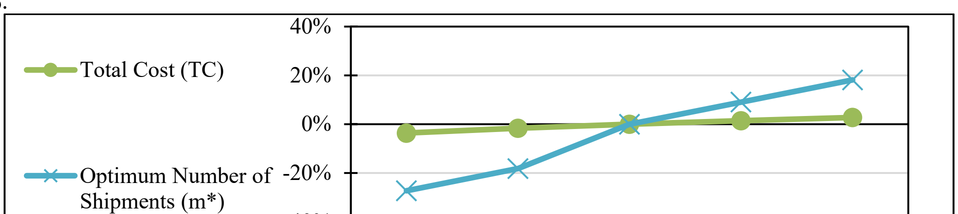
4.4 Analysis on Changes in New Container Ordering Cost (K_p)

Here, an analysis on how K_p parameter affects the model's optimal solution is also done, by varying five different values of new container ordering cost (K_p), which are -50%, -25%, 0%, +25%, and +50%. The result given by the changes in K_p parameter on the total cost (*TC*) and number of reposition cycles (*m*) are shown in Table 7.

Table 7
Effects of New Product Ordering Cost on Total Cost and Number of Reposition Cycles

Cost to Order New Container (K_p)		Total Cost (TC)	Number of Reposition Cycles (m)
$5,250	(-50%)	$1,039,520	8
$7,875	(-25%)	$1,060,680	9
$10,500	(+0%)	$1,078,490	11
$13,125	(+25%)	$1,094,220	12
$15,750	(+50%)	$1,108,420	13

As the new container ordering cost (K_p) varied, from -50% to +50%, it is found that the number of reposition cycles (m^*) is significantly changing, but not for total cost. A decrease in K_p will cause the number of reposition cycles to be lower, and vice versa. Fig. 7 shows how *TC* and m^* will be changed in a case where the cost to order a new container varied between -50% to +50%.



	-50%	-25%	+0%	+25%	+50%
Total Cost (TC)	-4%	-2%	0%	1%	3%
Optimum Number of Shipments (m*)	-27%	-18%	0%	9%	18%

Fig. 7. How new product ordering cost changes the total cost and number of reposition cycles (*j*=3).

A lower K_p, of 50%, reduces m^* by 27% and TC by 4%, while a higher K_p of 50% increases m^* by 18% and TC by 3%. From these results, it is understandable that the cost to order a new container has a significant influence on the number of reposition cycles, but not on total cost. A cheaper cost to order a new container will reduce the number of return cycles, and vice versa.

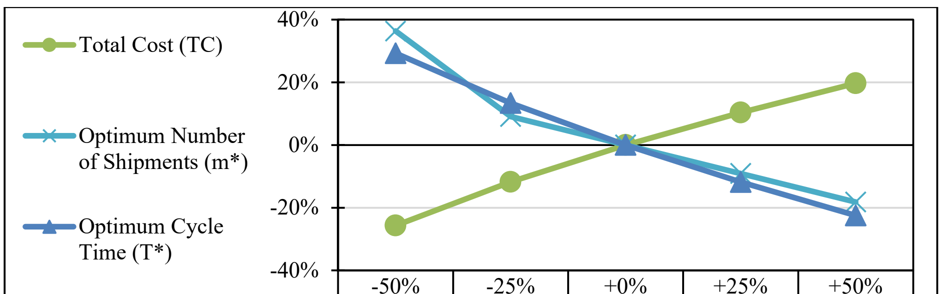
4.5 Analysis on Changes in Empty Container Repositioning Cost (K_r)

Similarly, an investigation on how K_r parameter affects the optimal solution of the model is also performed, by varying five different values of empty container repositioning cost (K_r), which are -50%, -25%, 0%, +25%, and +50%. The result given by the changes in K_r parameter on the total cost (TC), reposition cycle time (T), and number of reposition cycles (m) are shown in Table 8.

Table 8
Effects of Empty Container Repositioning Cost on Total Cost, Reposition Cycle Time, and Number of Reposition Cycles

Cost to Reposition Empty Container (K_r)		Total Cost (TC)	Reposition Cycle Time (T)	Number of Reposition Cycles (m)
$3,500	(-50%)	$ 801,608	3.8 days	15
$5,250	(-25%)	$ 951,850	4.7 days	12
$7,000	(+0%)	$1,078,490	5.4 days	11
$8,750	(+25%)	$1,190,100	6.0 days	10
$10,500	(+50%)	$1,290,980	6.6 days	9

As the empty container repositioning cost (K_r) varies, from -50% to +50%, it is known that the reposition cycle time (T^*) and the number of reposition cycles (m^*) are significantly changing, as well as total cost (TC). A lower price to reposition an empty container will elevate the reposition cycle time as well as number of reposition cycles and drop the total cost quite significantly. Fig. 8 shows how TC, T^* and m^* will react to a case where the cost to reposition an empty container varied between -50% to +50%.



	-50%	-25%	+0%	+25%	+50%
Total Cost (TC)	-26%	-12%	0%	10%	20%
Optimum Number of Shipments (m*)	36%	9%	0%	-9%	-18%
Optimum Cycle Time (T*)	29.29%	13.40%	0.00%	-11.80%	-22.47%

Fig. 8. How empty container repositioning cost changes the total cost, reposition cycle time, and number of reposition cycles (j = 3)

From Fig. 8, it is observed that a decrease in K_r by 50% increases m^* by 36% and T^* by 29.29% and decreases TC by 26%. On the other hand, an increase in K_r by 50% caused m^* and T^* to be reduced by 18 % and 22.47% and increased TC by 20%. From these results it is known that K_r has a significant effect on total cost, reposition cycle time, as well as number of reposition cycles. At an inexpensive reposition price, the system should set a higher level of reposition cycles number and times, to minimize the total cost, and vice versa. In addition, as Kr also gives a great effect on TC, the company should be focusing more on trying to make the reposition price lower. Many attempts may be considered, such as developing a better repositioning network and coordination, using better equipment to handle and transport the empty containers, or designing an optimal scheduling for the reposition itself. With good planning, both will lead to a lower reposition price of empty containers.

5. Conclusion and Further Remarks

This study developed a model of Economic Return Quantity (ERQ) for an Empty Container Reposition (ECR) problem. Uncertainty in terms of quantity and quality of product return, which is the empty container for this case, was modelled in the form of quality dependent return rate exponential function. The problem to be solved here is to minimize inventory related costs by optimizing several variables, including cycle time for reposition, number of return cycles, as well as acceptable quality level of the reusable containers. Here, the authors also consider limited space capacity to store containers in the port. The model was analytically optimized for cases where the constraint is either binding or not.

The results show that the acceptable quality level of reusable containers should be set at an optimum level to be able to obtain minimum inventory costs. For a case where the capacity constraint is binding, the annual total cost incurred to the system is higher than the latter, where the capacity constraint is not binding. This also leads to a finding where for Case 1 the proportion of space utility for type-1, type-2, and type-3 containers are 39.06%, 33.10%, and 27.84%, respectively. Whereas for Case 2, the proportion of space utility for the three container types are 32.84%, 34.48%, and 32.68%, respectively. The decision to determine which type of container to store more depends on the type of case.

In addition, the authors also observe that the price to handle a particular type of container, including the purchase price, cleaning and maintenance costs, and disposal cost, affects the optimal acceptable quality level. Containers with higher prices should be set at a higher acceptable quality level, and vice versa. This provides a managerial insight for companies engaged in port logistics, especially container depot companies. However, companies should still consider the condition and characteristics of their container management system. Some adjustments and subjective judgments may be needed, since this model was built on assumptions and limitations, which still need to be developed and improved in the future.

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