A study on supporting the choice between purchased pallet and rental pallet using a comparison model

Master's Thesis

A STUDY ON SUPPORTING THE CHOICE BETWEEN PURCHASED PALLET AND RENTAL PALLET USING A COMPARISON MODEL

March 2022

Graduate School of Marine Science and Technology

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1. Introduction

1.1. Trends in Pallet Usage

It is well known that the six basic functions of logistics are transportation, storage, packaging, cargo handling, distribution processing, and information processing. But it is often overlooked that pallets have been serving as the foundation for all those functions, which means increase in efficiency and decrease in cost of using pallets, translates directly into better logistics efficiency.

The history of modern pallet started in Europe around 1920, when it was still called by other names such as 'skid'. During those times, other types of packing such as wooden crates, barrels, kegs and cardboard boxes were mainly used. Pallets gained increased popularity when the forklift was invented around the same time, and more so when a bottom plank was added to the design, enabling stacking(1). From there, pallets became an important tool to gain logistics advantage, which was crucial to any country, during the World Wars.

The use of pallet in Japan developed mainly after the World War II, when they were introduced by the United States Army. Before long, local production of forklifts started in Japan and industrial standard for wooden flat pallets was developed in 1958. The Japan Pallet Association was founded in 1964(2). The popularity of pallets is proved by the number of pallets being used nowadays: 5 billion worldwide and 500 million in Japan and is expected to continue to grow exponentially(3). Figure 1.1 shows the estimated growth of the revenue of the pallet market worldwide from 2019 to 2027.

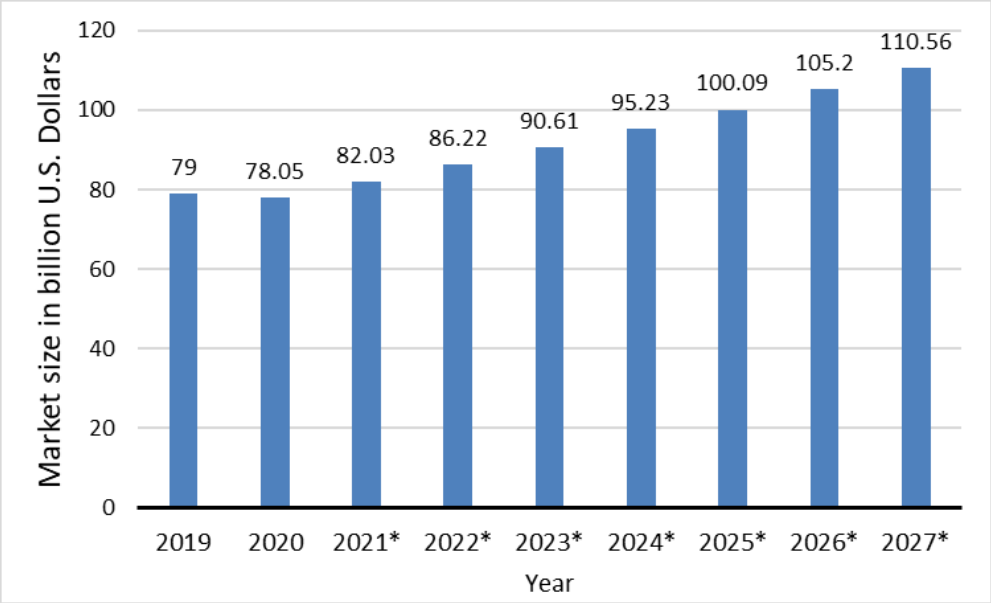

Figure 1.1 Revenue of the pallet market worldwide from 2019 to 2027 (Source: Statista, 2021)

As pallets gained increasing recognition, pallets of different shapes and materials have been developed. Pallets have been made of wood for a long time, but recently plastics pallets have increased in popularity along with those made of metal and paper related materials. Flat pallets to be used with forklifts are still the majority of pallets, but different shapes of pallets such as box pallet, roll box pallet, post pallets etc. have been developed to suit the different needs.

Moreover, the design details and the exact dimensions of the same type of pallets differ in a wide range.

Pallets are essential tools in today's logistics, and is a potential solution for standardization, supporting modal shift and manpower efficiency, as defined in Comprehensive Distribution Policy Principles 2021-2025 by Japan Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Chapter 2: Measures against labor shortage and promotion of structural reform of logistics (logistics friendly to the persons in charge)[(4)].

However, efficient management is needed to maximize the benefits and minimize the waste of utilizing pallets. Pallet management starts from choosing the pallet system (purchasing or renting) and deciding the type of pallet. It also includes storage, loading and discharging, repair and sanitization. The followings are a few of the many problems facing the logistics society right now.

1. Inappropriate cargo loading and handling can damage the cargo and the pallets themselves. Moreover, pallets can be lost due to theft and idle pallets need to be properly stored. In Japan alone, where there are an estimated 500 million of pallets in use, around 20 million of new pallets are required every year[(5)].
2. When the ownership of pallets between the sender and receiver of goods are different, the goods already loaded on pallets have to be shifted again onto another owner's pallets, which are also wasteful actions in the supply chain[(6)]. This also defeats the goal of intermodal palletization and unit-load system, which is one of the main aims of palletization.
3. After pallets are used to transport goods, what to do with the empty pallets afterwards have to be considered. Most companies want their pallet back, and if they do not have any backhaul planned, it will result in deadhead trucking, which means a trip back without any cargos but just empty pallets. Moreover, it takes time to discharge the cargo from the pallets, which causes waiting time for the return trip. Some systems to avoid this have been developed:
    a. Direct interchange systems in which the two sender and receiver of goods agree on the quality and type of pallets. The receiver will prepare the number of empty pallets equal to that used for delivering, and the sender will load them and carry them back after the cargo has been discharged.
    b. Postponed interchange systems in which the sender and receiver of goods agree on a record system and time limit to delay the return of pallets. In these kinds of systems, the receiver will first issue vouchers to the sender, and return the pallets later, within the time limit[(7)]. These are workarounds but do not actually address the problem at its root.

1.2. Introduction of Rental Pallets

The authors would like to introduce pallet rental services or pallet pooling as a potential solution to the aforementioned problems and better logistics efficiency. Pallet pooling is a form of sharing economy. Earliest pallet pooling attempts can be traced to the era of World War II. Deserving a mention is Commonwealth Handling Equipment Pool (CHEP), which originates from the Allied Materials Handling Standing Committee, developed by the Australian government to provide efficient handling of defence supplies during World War II. After World War II, the US Army leaves behind a wealth of materials handling equipment at their military

bases in Australia. The Australian government combines this asset base with existing infrastructure to form the Commonwealth Handling Equipment Pool, or CHEP[8].

For the problems mentioned in Chapter 1.1, if rental pallets are used:

1. Rental pallets are expected to be used for a longer time, so they are more often of tougher designs and materials such as plastics. And the user does not need to be concerned about the maintenance such as repairing and sanitization, and their storage when not in use.
2. The logistics waste of pallet transferring can be reduced if both parties are using rental pallets from the same provider[9]. Figure 1.2 shows the conventional supply chain without using rental pallets. When the goods are delivered from maker (A, B, C) to retailer (A, B, C), the retailer will have to transfer the goods to their own pallets before proceeding. Figure 1.3 shows the supply chain when using rental pallets or a joint collection system. If the makers and retailers are using the same pallet rental service, it will manage the delivery of pallets to the start of the supply chain and the recollection of pallets at the end of the supply chain (joint collection system), to the most convenient or nearest depot. And there will be no need of unnecessary pallet transfer in the middle.
3. Pallet rental services can also reduce deadhead trucking. Transporting pooled pallets can make a load of empty pallets profitable. Some pallet pooling providers will pay a flat fee for companies to transport empty pooled pallets to the pallet pooling service's depot or another location, turning a deadhead leg into profit[10]. Moreover, If the makers and retailers are using the same rental pallet provider, the sender's truck can proceed to the next destination (from A to B and B to C) instead of carrying back empty pallets. This reduces logistics waste and improves route planning efficiency.

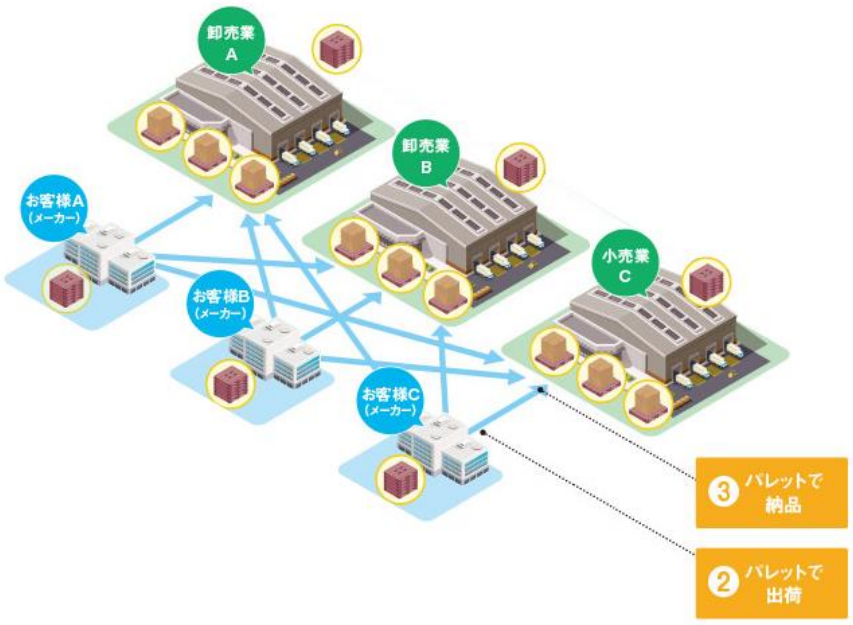

Figure 1.2 Supply chain without pallet rental service (Source: JPR Corporation)

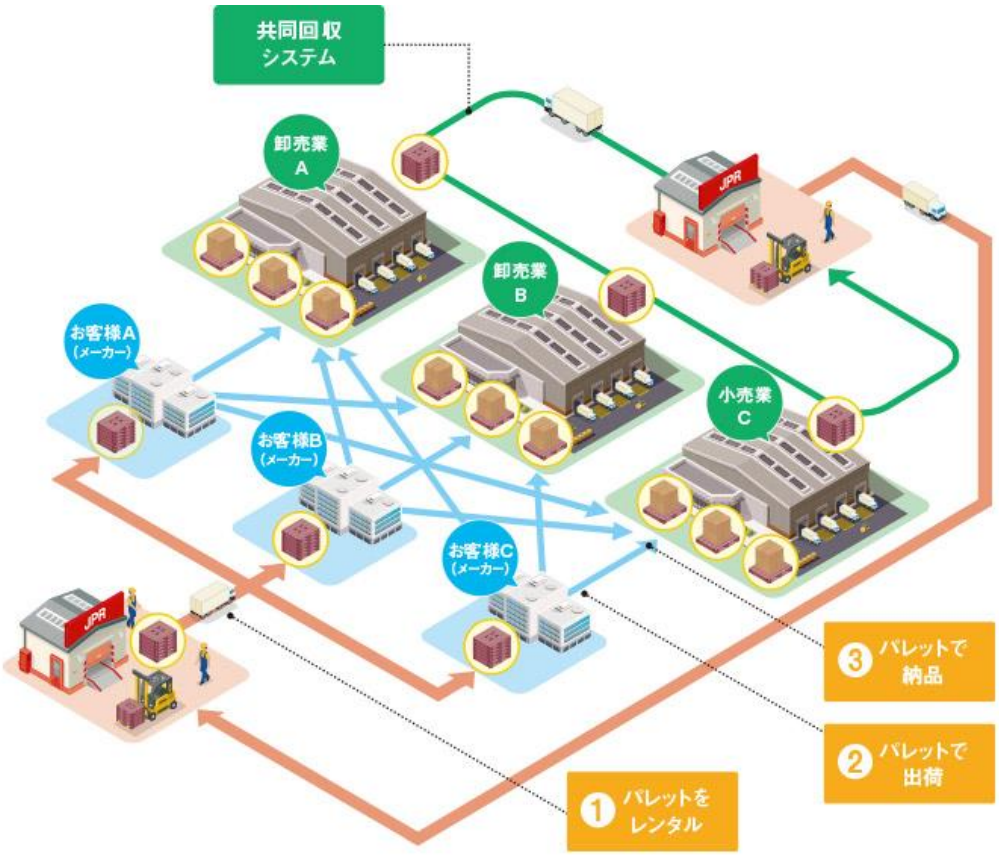

Figure 1.3 Supply chain using pallet rental service (Source: JPR Corporation)

These are probably some of the main reasons why rental pallets are becoming increasingly popular nowadays. Using rental pallets can reduce cost, improve logistics efficiency, and also gives more flexibility, as some rental services offer rental pallets for a short time (starting from 10 days) and for small quantities (starting from 50 pallets)[11], in addition to the aforementioned benefits.

While one can expect such benefits when using rental pallets over purchased pallets, more work is needed to accurately compare the two systems and deciding which one to use because renting pallets also have their own disadvantages.

Basically, when renting pallets, the company will not own any assets and it is deemed to be more expensive than buying them. This is true when the pallets are used for a short term[12]. But when long-term costs related to pallets, other than just the purchasing and renting costs, are considered, there is a break-even point of usage time, when renting pallets becomes more cost efficient than buying them. This research will be focusing on comparing the long-term cost between the two systems.

1.3. Research Purpose

Following the discussions made in the previous section, this research aims to make the decision of choosing between purchased pallet and rental pallet easier. Factors influencing the decision, present and future economic trends will be discussed. Also, global and Japanese local problems in the logistics industry, which can be alleviated by the improvement of efficiency by optimal pallet usage will be explored.

In this study, a mathematical model which will compare the different costs related to the usage of different pallet system is developed. Using the model, trends of the cost under specific conditions are studied. It is assumed that purchasing pallets has a higher initial upfront cost and operating cost, but it can be more cost-effective in the long term, compared to renting pallets. The turning point, which is the exact length of usage time up to when renting pallets are more cost effective will be mathematically calculated. The change in this turning point caused by the change in some conditions of interest will be analyzed.

From the results obtained from the model, the better choice of pallet system in each different condition is found out, along with the effect of each condition on the cost, and the trend of cost. This study aims to fill the gap of making an informed and calculated decision between using purchased pallets and rental pallets. By doing so and contributing to an easier and more accurate choice of the more suitable pallet system, the authors aim to contribute to the progress of palletizing, intermodal palletization and increase in logistics efficiency.

1.4. Thesis Structure

In this research, chapter 1 discusses the background and trends in pallet usage and the current challenges in the field. In addition, the adoption of pallet rental systems and their characteristics is discussed. The chapter then explores the purpose of the study carried out in this paper.

Chapter 2 will discuss about the literature related to pallet systems and their impacts, focusing on rental pallet system. The following aspects are focused: economic impacts, environmental impacts and SDGs, intermodal palletization, emerging technology in pallet cargo operations and the impact on working environment. In addition, the usage of one-way pallet, which is another type of pallet usage, is discussed. Moreover, usage status of pallets in Japan is explored in detail.

Chapter 3 explains the theoretical background of the model constructed and used in this study. It introduces the structure of the model, the assumptions made, and the equations and symbols used for calculation. And then the chapter explains the data input into the model for this paper, and the calculations made.

In chapter 4, the results obtained from the model through sensitivity analysis are explored. The resulting trends are discussed and evaluated.

Chapter 5 discusses about conclusions and suggestions for future studies. Brief conclusions on the literature background and findings from the model are discussed. Then, suggestions on how the research can be continued and improved will be presented.

2. Literature on Pallet Systems and Their Impacts

Even with the increasing usage and popularity of pallets, there are still many aspects about pallets left to be studied and scientific literature is still limited, especially for the Japan region. Some of the reasons for this might be the fact that the logistic industry is particularly complex with each field having its own uniqueness, and that most of the industry data is not generally available to the public and researchers. Some of the available literatures will be introduced.

Elia V. and Gnoni M. (2015) did a literature review about pallet management and classified them into 3 main issues[7]:

1. the product design problem: studies regarding the material and design of pallets, with the aim of improving the durability and reducing the weight and environmental burdens. Nippon Express has developed styrofoam pallets that weights around 25% of a plastic pallet[13]. Lighter pallets mean more efficient transportation, cargo handling and less burden on the workers, especially for women and elders.
2. the pallet loading problem: studies regarding the optimal loading level of a pallet in order to optimize its warehouse and transportation costs. As each individual goods and its package comes in different dimensions, loading them onto pallets takes a different approach each time. The optimal loading layout is required to maximize the benefit of palletization. In recent years, robotic systems that will automatically pick each package, decide the most optimal place and orientation to place it, and perform the task, have been developed and used[14].
3. the pallet logistic system design problem: designing the supply chain when using pallets is usually complex as it could involve both direct and reverse flows. There are studies related to the average usage time of pallets, and their economical and environmental effects. Since this study is closely related to this issue, it will be discussed in more details.

Ren et al. (2019)[15] stated that the most common and widely accepted pallet management systems include extensive management of pallets (EMP), transfer of pallet's ownership (TPO), and pallet rent (PR). The paper addresses mainly on how to help pallet managers choose a certain kind of PMS from the perspective of supply chain cost.

2.1. Rental Pallet System

The opinion from the perspective of cost of rental pallet systems compared to purchased pallet systems are divided.

Ray et al. (2006) studied about 13 large pallet-using grocery companies in various regions of the United States and stated that rental pallets are on average more costly to the customers[16].

Doungpattra et al. (2012) studied the costs related to pallets and concluded that the best practice depends on the nature and speed of the flow of goods[17].

Roy et al. (2016) studied existing industry strategies for managing pallets, (single-use expendable pallets, buy/sell programs, and leased pallet pooling programs), by analyzing and comparing using push and pull inventory control policies. For the base case, the single-use expendable pallet approach presents the least cost of all strategies, but the leased pallet pooling programs outperform the buy/sell programs in terms of total cost. The strategy which is most

attractive differs with respect to pallet cost, salvage cost, dwell fees, effective issue fees, retention rates, and transportation costs[18].

From the above, it can be concluded that the most cost-effective pallet system depends on the conditions in which a company will use the pallets. Therefore, the authors decided a simple mathematical model is needed, which will help decide the better pallet system, based on the conditions.

2.2. Environmental Impacts and SDGs

In recent years, Sustainable Development Goals (SDGs) has gained increasing popularity and attention. They are worth discussing, especially with the worsening global environment. Below are the goals and targets related to the usage of pallets[19], and respective discussions:

1. Workforce diversification and improvement of working conditions
    a. **Goal 8**: decent work and economic growth; **target 8.2**: achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labor-intensive sectors; **target 8.5**: achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value

    On the field logistics work can be labor-intensive; cargo loading, discharging, and walking long distances during picking etc. This can be one of the obstacles preventing the diversification of the workforce, which is a big problem especially for fields and countries lacking manpower. Increasing use of pallets combined with forklifts can reduce the physical burden on workers. This can open up new and better work opportunities for all women and men and alleviate the lack of manpower.

2. Improve consumption efficiency and reduce environmental damage
    a. **Goal 8**: decent work and economic growth; **target 8.4:** improve global resource efficiency in consumption and production and endeavor to decouple economic growth from environmental degradation
    b. **Goal 9:** industry, innovation and infrastructure; **target 9.4**: upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes
    c. **Goal 12**: responsible consumption and production; **target 12.5**: substantially reduce waste generation through prevention, reduction, recycling and reuse
    d. **Goal 15:** life on land; **target 15.1:** ensure the conservation, restoration and sustainable use of terrestrial and ecosystems and their services, in particular forests

    Growth of economy is synonymous with the growth of the logistics industry. As the logistics market grows and more efficiency is pursued, the demand of pallets rises. Wood and plastic are currently the main materials being used for pallet manufacturing and their effects on the environment have to be considered.

Moreover, recent studies showed that using rental pallet also have preferable ecological advantages over purchased pallet and other pallet systems.

Kobayashi (2008) studied the effect of pallet usage on environment. In the research, the effects on global warming and air pollution were studied by calculating the resources used and waste generated throughout the life cycle by life cycle assessment (LCA) method using LIME index. The study stated that (1) using rental services put less burden on the environment compared to using purchased pallets, for both wooden and plastic pallets, (2) using plastic pallets have lower effect on the environment for both rental pallet and purchased pallet[20].

Similarly, Japan Pallet Rental Corporation (JPR) did a joint research with Associate Professor Kurokawa (at the time) from TUMSAT in 2007, about the environmental burden comparison between using purchased pallet and rental pallet from JPR. The research calculated the life cycle CO_2 of three stages related to pallets: production, usage and disposal. Based on the joint research, Kanso Technos Co., Ltd. did a recalculation with the data from 2020, supervised by Professor Kurokawa. The results showed that using rental pallet and joint collection system can reduce life cycle CO_2 by around 76% (430,000 t per year). This is equal to the CO_2 absorption amount per year of 30,790,000 cedar trees[21]. The reasons are because (1) less transportation is needed to retrieve empty pallets from the delivery destination and they can be returned to a depot nearby, (2) proper management and maintenance of pallets can achieve a longer pallet service life and reduce pallet loss, (3) using pallet rental services can reduce the total amount of pallets needed[22].

Following is Japan's roadmap to tackle the challenge of climate change, which is marked by three key milestones. Firstly, Japan's commitment under the United Nations Climate Change Convention to reduce greenhouse gas (GHG) emissions by 26% from 2013 levels by 2030. The second milestone is to promote the development of innovative technologies by 2050 that enable Japan to contribute to the reduction in accumulated atmospheric CO2 globally to "Beyond Zero". The third and most ambitious milestone unveiled by Prime Minister Suga Yoshihide on October 26, 2020, calls for Japan to achieve net zero GHG emissions by 2050. This bold pledge sets Japan on a course to become Carbon Neutral in 30 years[23].

2.3. One-way Pallets

One-way pallets or disposable pallets occupy a strange role in the pallet category. They usually have more minimal designs, which result in less material needed and less cost to produce. They are usually favored for supply chains ending overseas or far away, because they do not need to be sanitized before using, and there is less worry of damage. In such cases, return trips are also more costly so companies usually plan the pallets to be disposed after they reach their destinations. However, there are services that retrieve supposedly one-way pallets and resell or recycle them.

Even though they might be cheaper, the reusability of one-way pallets is definitely inferior to rental pallets and can result in more environmental pollutions. Moreover, their characteristics are somewhat similar to purchased pallets, so they will not be considered in the model used in this research.

2.4. Role of Pallets in Japan and Current Status

As introduced in above, Japan started using domestically produced pallets in 1945 and in 1964, the Japan Pallet Association was founded. During the years from 1970 to 1990, various Japanese Industrial Standards (JIS) for pallets were decided and surveys related to usage of pallets conducted.

Regarding pallet pooling, the idea was first received in the country around 1952. From there, it was realized that one unified size of pallet is necessary for efficient pallet pooling. In 1970, the standard size for pallet pooling was determined (JIS Z0601). It is called T11 type and has the dimension of $1100mm \times 1100mm \times 144mm$[24].

Figure 2.1 shows the recent trend in pallet manufacturing and Figure 2.2 shows the recent trend in number of pallets used by pallet rental services. From these, it can be seen that although there is no notable trend in the total production numbers, the pallet rental market has been growing consistently over the years.

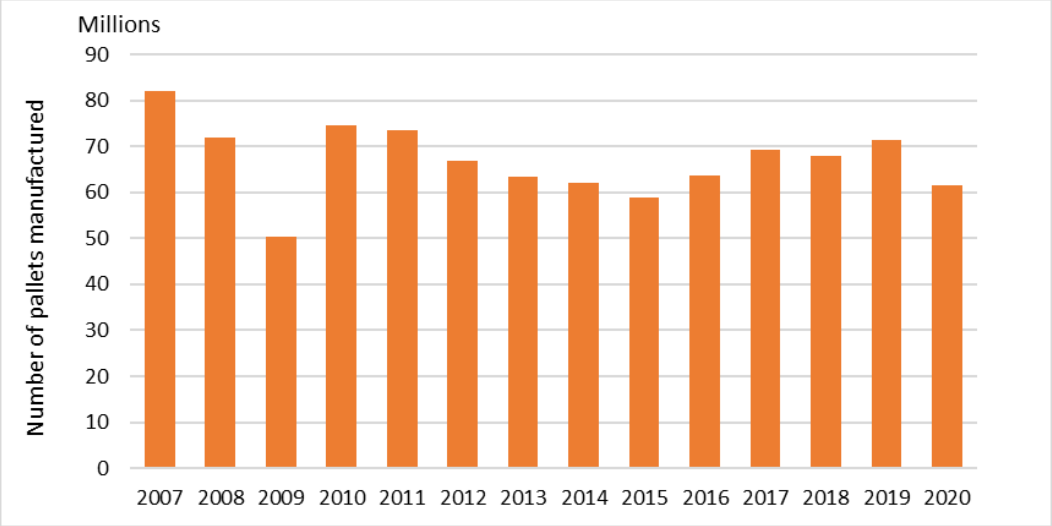

Figure 2.1 Number of pallets manufactured in Japan by year (Source: JPA)

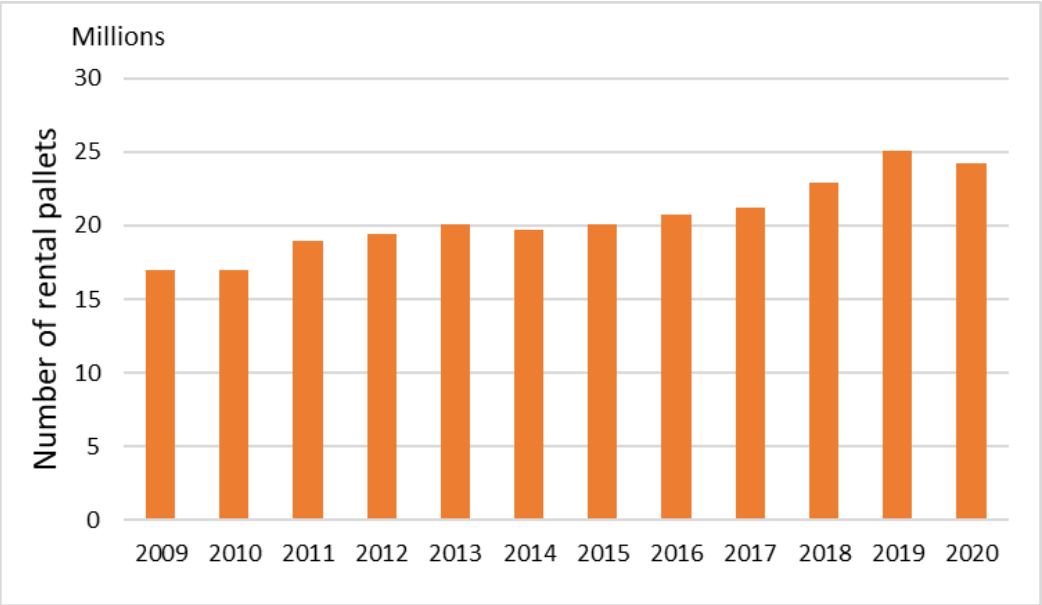

Figure 2.2 Number of pallets used by pallet rental services in Japan by year (Source: JPA)

2.4.1. Intermodal Palletization

One of the most apparent issues related to the usage of pallet in Japan is unifying the pallet size used, which is crucial for Intermodal palletization. Even though the standard pallet size for pallet pooling has been decided by the Japanese Industrial Standards, its usage is still low compared to other countries. Two reasons can be considered for this situation:

1. Many Japanese companies consider pallet as a storage tool, rather than a transportation tool. When pallets were first used in the country, they were made of wood. Since wood is expensive in Japan, the price of wooden pallets were high and logistics managers hated the extra costs incurred by pallet losses. This led to pallets being considered as a tool used within one's own facilities, rather than an intermodal transportation tool providing better efficiency for all[25].
2. The culture of Japanese people and companies to customize products to fit their own optimal needs. Also owing to the reason introduced above, after pallets were introduced into Japan from foreign countries, Japanese companies proceeded to alter the design and size of the pallets to better suit their own needs. This partial optimization is good for the efficiency of each company, but hazardous to the aim of standardizing pallet size for intermodal palletization, aimed at improving efficiency for everyone[26].

To improve pallet standardization, (1) standardization of sizes and (2) acceleration of usage by the companies has to be considered.

(1) As mentioned above, the standard size for pallet pooling, T11 type, has been determined by JIS since 1970. But, before then, there were already many other standard sizes in use. The width and height restrictions of roads can also decide the pallet size used. Moreover, the common modes of transport also determines the common sizes of pallets. The standard sizes of pallet in Japan along with those used in other countries can be seen in Figure 2.3[27]. It can be understood that there are some countries with just 1 or 2 standard sizes, and some countries with many

standard sizes, like Japan. When the industries already use one pallet size, they find it hard to change to a different one, even if it means better efficiency for everyone.

A well-known example of such a case is the P-Pallet Common Users Association. The association promotes the common usage of “Beer Type 9 plastic pallets”, which has a dimension of $900mm \times 1100mm$ and is commonly used for liquor and drinks, and mainly beer. The association has 126 associated companies as of January 2022[28]. This kind of industry unification maybe beneficial for the said industry but can be detrimental to the standard unification for the whole country.

■世界主要国のパレット寸法規格

国別	ISO	日本	韓国	台湾	中国	米国
規格名	ISO	JIS	KS	CNS	GB	ANSI
寸法	1100×1100	JIS			800×1000	1219×1981
		一貫輸送用	一貫輸送用	一貫輸送用	800×1200	1219×1219
	1067×1067	T11	T11	T11	1000×1200	1219×1067
	1140×1140	1100×1100	1100×1100	1100×1100		1219×1016
	1200×800					1219×914
	1200×1000	1100×800	1100×800	1000×1200		1168×1168
	1219×106	1100×900	1100×900	1100×800		1118×1118
		1100×1100	1100×1100	1100×900		1067×1067
		1100×1300	1100×1300	1100×1100		1016×1016
		1100×1400	1100×1400	1200×1400		914×914
		1200×800	1200×800	1200×800		1194×889
		1200×1000	1200×1000	1200×1000		762×762
				1200×1400		
種類数	6	7	7	8	3	12

国別	独国	英国	スウェーデン	豪州	旧ソ連	スイス
規格名	DIN	BS	SIS	AS	GOST	SNB
寸法	平パレット			1100×1100	800×1200	800×1200
	600×800	1200×800	400×500	1165×1165	1200×1600	
	800×1200	1200×1000	600×800		1200×1800	
	1000×1200	1140×1140	800×1200		1000×1200	
		1219×1016	1200×1600			
	ボックスパレット他					
	800×1200					
	800×1600					
	1000×1200					
	1000×1600					
	1000×2000					
	1200×1600					
	1200×1200					
種類数	10	4	4	2	4	1

※日本ロジスティクス関連資料より抜粋したもの

Figure 2.3 Standard pallet sizes based on country (Source: TSK Corporation)

According to the survey conducted in 2021 by Japan Association for Logistics and Transport, T11 type is used by more than 50% of the companies (Entering warehouse: 60%, Storage: 53%, Departing warehouse: 61%). This is a comparatively small percentage compared to other countries and to promote intermodal palletization.

(2) As for acceleration of usage by the companies, there has been numerous plans and measures conducted. According to the report by the Japan Industrial Vehicles Association, some of the problems that has been inhibiting the progress of intermodal palletization for a long time include: (i) Loss of pallets (around 20%), (ii) decrease in loading efficiency for certain goods and (iii) the problem of collecting empty pallets[25].

As explained in Chapter 1, using pallet rental services can alleviate (i) and (iii), because when using rental pallets, companies no longer have the need to own and manage them. Pallet rental services also have better facilities, practice and knowhows concerning inventory management and maintenance of large amounts of pallets. Due to this, they can also prevent pallet loss better and achieve higher pallet retrieval rates compared to typical companies. JPR has been found to be able to achieve pallet retrieval rate of 99.2% (2020, PT-11 Type)[22].

Pallet pooling can also promote unifying the pallet sizes, and thus help improve standardization. Figure 2.4 shows the trend in change of the proportion of wooden flat pallets used by rental services and Figure 2.5 shows that of plastic flat pallets respectively. While T11 size used in plastics pallets maintain a high ratio of above 80%, the ratio of T11 pallets in wooden pallets have been decreasing over the years, recently around 50%[29].

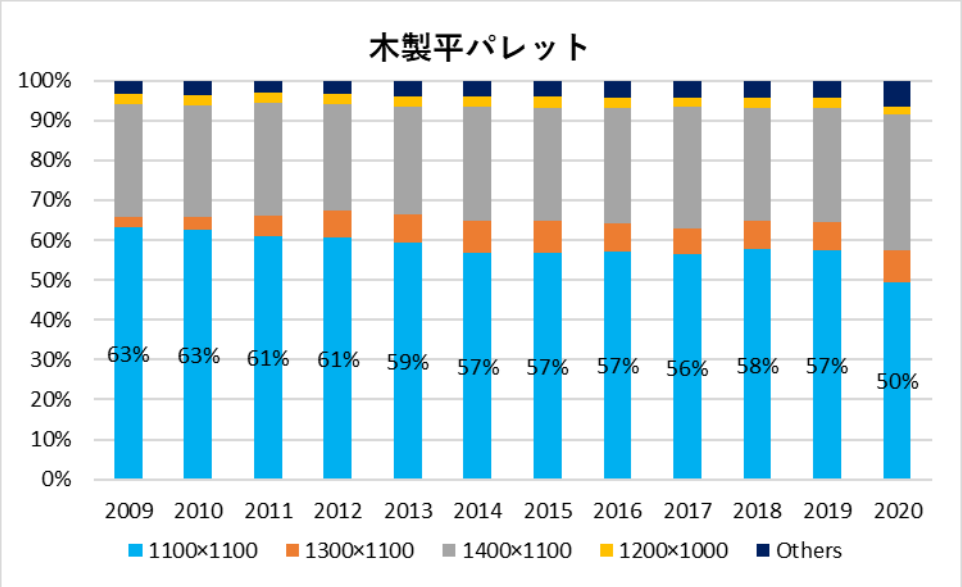

Figure 2.4 Proportion of wooden flat pallets used by rental services (Source: JPA)

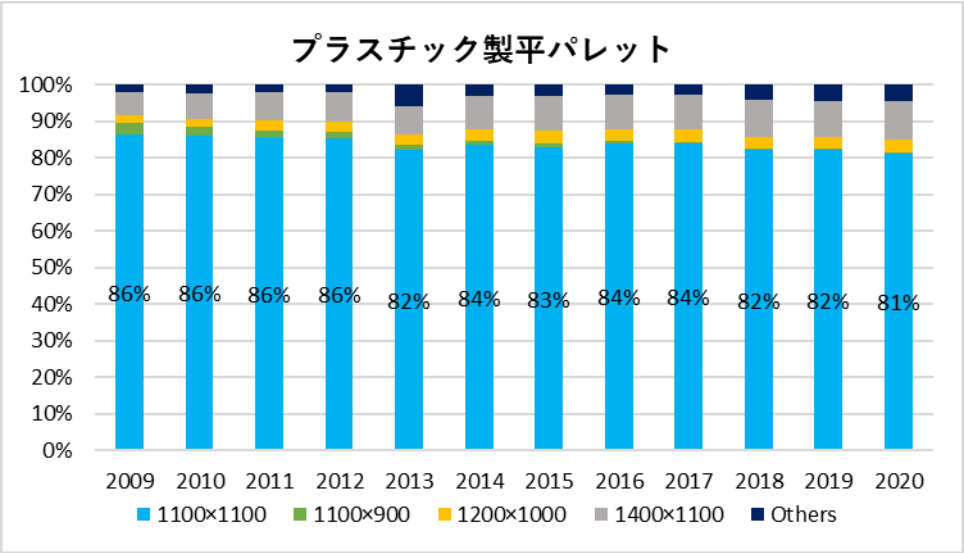

Figure 2.5 Proportion of plastic flat pallets used by rental services (Source: JPA)

This can be assumed to be the fact that the major material of pallets used by rental services has been shifting from wood to plastics, as shown by Figure 2.6[29]. A high trend in the T11 size of pallets used by rental services can contribute to the progress of pallet size unification, as more companies use their services.

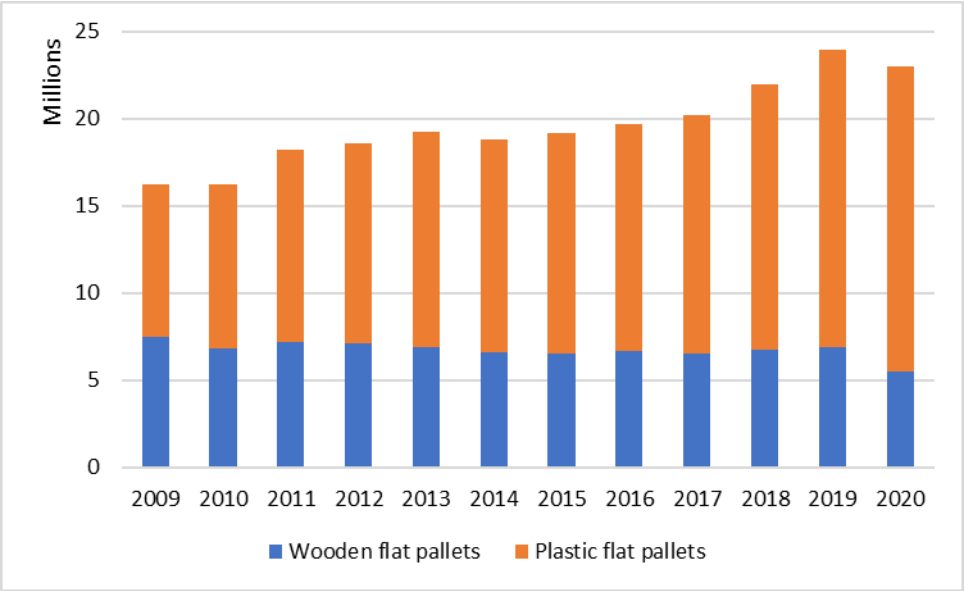

Figure 2.6 Trend in the material of pallets used by rental services (Source: JPA)

2.4.2. Working Environment Improvement and Future Technology

In addition to the logistics issues and SDGs that are relevant globally, Japan faces its own unique issues related to logistics. Comprehensive Distribution Policy Principles 2021-2025 by MLIT, outlines the goals and direction the nation is going to take. Some of them include: (1) measures against the declining population and diminishing workforce, (2) realization of Society 5.0 and Digital Transformation (DX), (3) realization of SDGs and (4) making logistics infrastructure more resilient to disasters and pandemics[(4)].

(1) With the declining birthrate and aging population in the background, there is a serious lack of logistics workers, especially truck drivers. This and inefficiencies in the logistic industry result in longer work hours and harder working environments for the workers, which in turn make working in the logistics industry unattractive for those who are finding a job[(30)]. To solve these issues, the combined effort to reduce inefficiencies from all stakeholders is required. MLIT has also started a white logistic movement for this purpose[(31)].

(2) Society 5.0 is defined as a society where we can resolve various social challenges by incorporating the innovations of the fourth industrial revolution (e.g., IoT, big data, AI, robot, and the sharing economy) into every industry and social life. It aims to provide people with only the products and services in the amounts and at the time needed[(32)]. For this society, efficient and smart logistics will be an essential and important foundation. Palletizing goods and introducing forklifts eases the physical burden on logistic workers. This potentially opens up more job positions and better working environments to women, elders, and younger people. Recently motor assisted hand forklifts have been developed. They do not require extensive training like conventional forklifts, and also easier to use than non-assisted hand forklifts. Palletizing also have big effects on increasing cargo handling efficiency, which can reduce delays for truck drivers.

Palletizing can also facilitate unit-load system, which enable new possibilities for robotic and automated cargo handling. Robotic arm systems, Automated Guided Vehicles (AGV), unmanned transportation and drone logistics are a few of the promising future technologies.

Another major field needing improvements is data visualization and information management. For this, Japan needs to progress from physical paperwork to digital systems. For example, paper vouchers need to be replaced by Electronic Data Interchange (EDI) systems. Efficient management of pallets can be achieved with technologies such as Radio Frequency Identification (RFID) combined with Warehouse Management Systems (WMS).

3. Methodology

3.1. Outline of the Mathematical Model

The basic costs related to using pallets for delivering goods from node A to B, in a supply chain will be compared, for using: (1) Purchased pallet and (2) Rental pallet. It is assumed that there is a constant pallet demand *D*, and cargo loading at A (from empty pallets, A' to loaded pallets, A) and unloading at B (from loaded pallets, B to empty pallets, B') are done every day. T_A, T'_A, T_B, T'_B are the average holding times at each point respectively. Time required per trip T_t, and transportation cost per trip C_t are assumed to be the same for both cases.

Table 3.1 Symbols and terms used in the model

Name	Symbol	Unit
pallet demand	D	pallet/day
average holding time	T_A, T'_A, T_B, T'_B	day
Time required per trip	T_t	day
Transportation cost per trip	C_t	yen
transportation cost for delivery during time T_t	C_T	yen
time interval between delivery trips	f	day
time interval between return trips	f'	day
Pallet cost	PC	yen/day
Transportation cost	TC	yen/day
Storage cost	SC	yen/day
total cost associated with using purchased pallet	$C_{P,Total}$	yen/day
total cost associated with using rental pallet	$C_{R,Total}$	yen/day
pallet usage cost	C_P	yen/pallet/day
pallet rental fee	C_R	yen/pallet/day
average storage and transportation time required from A to B and back to A	T_P	day
average storage and transportation time required from A to B	T_R	day
warehouse rental cost per unit area	C_S	yen/m^2/day
surface area of pallet	S	m^2/pallet
number of pallets per stack	n	unitless
average holding time for buffer stock	BT', BT'	day

3.1.1. Model for Purchased Pallet

When using purchased pallet, the empty pallets are to be returned to the initial loading point, node A, thus requiring a return trip as depicted in Figure 3.1. The delivery trips have intervals of f and return trips have intervals of f'respectively.

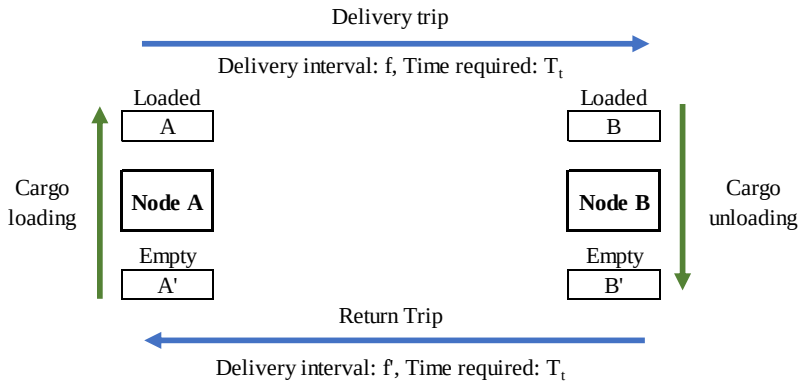

Figure 3.1 Model for using purchased pallet

3.1.2. Model for Rental Pallet

When using rental pallet, the required number of pallets can be ordered to node A to be delivered at the required time. After being used to carry goods to node B, the pallets are retrieved by the rental service at a convenient time as depicted in Figure 3.2. For simplicity, it is assumed that T'_A *and* T'_B are negligible.

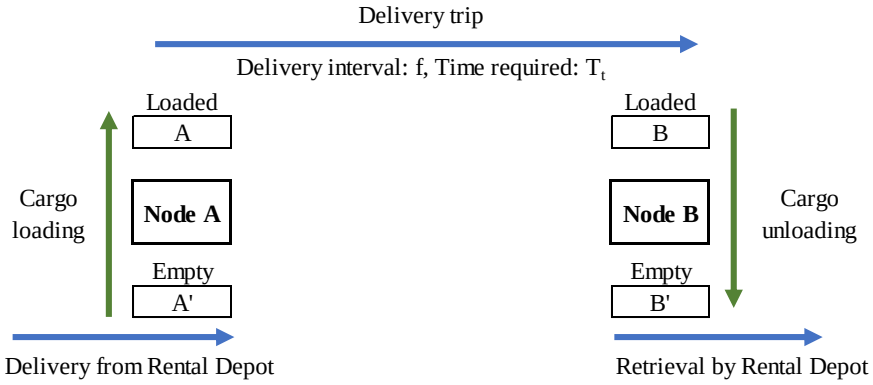

Figure 3.2 Model for using rental pallet

3.2. Mathematical Equations

The total costs are compared in units of 'yen per day' at any given time. The total cost associated with using pallets will be summarized as follows:

$$Total\ cost = PC + TC + SC \quad (1)$$

where PC is the pallet cost,

TC is the transportation cost,

SC is the storage cost

Each cost will be broken down differently for purchased pallet and rental pallet.

3.2.1. Equations for Purchased Pallet

The pallet cost when using purchased pallet can be defined as:

$$PC_P = C_P \times D \times T_P \quad (2)$$

where PC_P is the pallet cost when using purchased pallet, which is calculated by the purchasing price and service life,

C_P is pallet usage cost,

D is the pallet demand,

T_P is the average storage and transportation time required from A to B and back to A

The transportation cost when using purchased pallet can be explained by the following equations.

Transportation cost for delivery during time T_t is defined as:

$$C_T = \frac{T_t}{f} \times C_t \quad (3)$$

where C_T is the transportation cost for delivery during time T_t

T_t is the time required per trip,

f is the time interval between delivery trips,

C_t is the transportation cost per trip

Transportation cost for return during time T_t is defined as:

$$C_{T'} = \frac{T_t}{f'} \times C_t \tag{4}$$

where $C_{T'}$ is the transportation cost for return during time T_t,

f' is the time interval between return trips

When using purchased pallets, the total transportation cost is the sum of costs for delivery and return trips. The total transportation cost when using purchased pallet can be mathematically calculated as:

$$TC_P = \frac{C_T}{T_t} + \frac{C_{T'}}{T_t} \tag{5}$$

$$TC_P = \frac{C_t}{f} + \frac{C_t}{f'} \tag{6}$$

where TC_P is the transportation cost when using purchased pallet

To calculate storage costs when using purchased pallets, the time stored will be taken as $(T_A + T'_A + T_B + T'_B)$, and it will be assumed that the pallets are stored in stacked piles of n pallets, which is typical for warehouses. The storage cost when using purchased pallet will be mathematically expressed as follows:

$$SC_P = C_S \times S \times \frac{D \times (T_A + T'_A + T_B + T'_B)}{n} \tag{7}$$

where SC_P is the storage cost when using purchased pallet,

C_S is the warehouse rental cost per unit area,

S is the surface area of pallet,

n is the number of pallets per stack

From equations (1, 2, 6, 7), the total cost associated with using purchased pallet can be summarized by the following equation:

$$C_{P,Total} = \quad PC_P + TC_P + SC_P \tag{8}$$

where $C_{P,Total}$ is the total cost associated with using purchased pallet

3.2.2. Equations for Rental Pallet

The pallet cost when using rental pallet can be defined as:

$$PC_R = C_R \times D \times T_R \quad (9)$$

where PC_R is the pallet cost when using rental pallet,

C_R is pallet rental fee,

D is the pallet demand,

T_R is the average storage and transportation time required from A to B

When using rental pallets, the total transportation cost is only for delivery trips. Similarly to purchased pallets, the total transportation cost when using rental pallet can be mathematically calculated as:

$$TC_R = \frac{C_t}{f} \quad (10)$$

where TC_R is the transportation cost when using rental pallet,

C_t is the transportation cost per trip,

f is the time interval between delivery trips

To calculate storage costs when using rental pallets, the time stored will be taken as $(T_A + T_B)$. The storage cost when using rental pallet will be mathematically expressed as follows:

$$SC_R = C_S \times S \times \frac{D \times (T_A + T_B)}{n} \quad (11)$$

where SC_R is the storage cost when using rental pallet,

C_S is the warehouse rental cost per unit area,

S is the surface area of pallet,

n is the number of pallets per stack

From equations (1, 9, 10, 11), the total cost associated with using rental pallet can be summarized by the following equation:

$$C_{R,Total} = PC_R + TC_R + SC_R \quad (12)$$

where $C_{R,Total}$ is the total cost associated with using rental pallet

3.2.3. Comparison of the Two Models

Figure 3.3 shows a comparison between the mathematical models of purchased pallet and rental pallet, based on the 3 different costs.

	Total Cost					
	Pallet		Transport		Storage	
	Purchased	Rental	Purchased	Rental	Purchased	Rental
Cost	Purchasing price/ Service life	Rental fee	Both Delivery and Return	Only Delivery	Same	
Time	$T_A+T'_A+T_B+T'_B+2T_t$	$T_A+T_B+T_t$			$T_A+T'_A+T_B+T'_B$	T_A+T_B

Figure 3.3 Comparison of different costs

3.2.4. Buffer stock

In practical cases, companies have to prepare inventory of more than is estimate needed to prevent stockouts. This is also true for pallets. This extra inventory is called buffer stock. Figure 3.4 shows an example of the change in stock levels with time.

(Left picture) Assuming that at A and B', the pallet amount increases at a constant rate due to loading and unloading, until they are transported to B and A' respectively.

(Right picture) Assuming that at A' and B, the pallet amount decreases at a constant rate due to unloading and loading, until new pallets arrive from B' and A respectively.

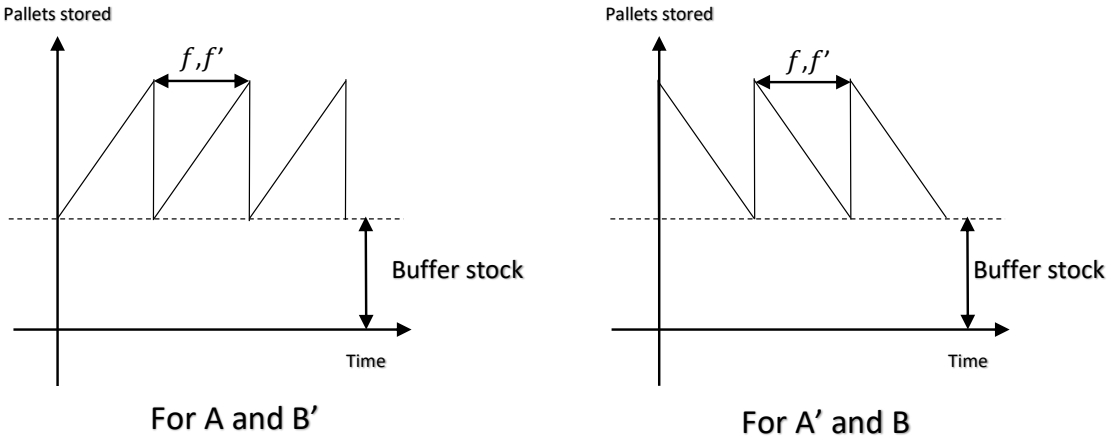

Figure 3.4 Pallets stored vs time

In this condition, the inventory level of the 4 points of interests $A, A', B \; and \; B'$ will be as follows:

$$Average\ holding\ time = Average\ holding \text{ time } of\ buffer\ stock + \frac{Time\ interval\ between\ trips}{2} \qquad (13)$$

$$T_A = T_B = BT + \frac{f}{2}$$

$$T_{A'} = T_{B'} = BT' + \frac{f'}{2}$$

where $BT \; and \; BT'$ are the average holding times for buffer stock

For simplicity, the calculations done in this research will assume a buffer stock of zero.

3.3. Data Description

For the calculations done for this research, practical assumed values typical to the field will be used.

Warehouse rental cost is based on Kanto region of Japan[33].

Surface area of pallet is calculated for T11 type which is the standard for pallet pooling of Japanese Industrial Standards (JIS Z0601). The pallets are assumed to be stored in stacks of 10, which means every 10 pallets will only take the storage area of a single pallet.

The purchasing price and rental fee of pallets are taken from Nippon Pallet Pool Co.,Ltd.[34].

Transportation cost is based on the standard fare decided by the Japan Trucking Association[35].

There are two types of fare tables, one based on distance, and another based on time. The authors confirmed that distance-based fares as shown in Table 3.2, will be more suitable for our model. Extra charges will occur for refrigerated vehicles, transportation during weekends and holidays, transportation during late nights and earlier mornings and for waiting. Basic charges will be used for the calculation in this research, as shown in Table 3.3. And since the pallet demand (D) is assumed to be 20, 10 t class of truck which can carry from 16 to 32 sheets of T11 pallets will be used[36]. It is assumed that each transportation trip can carry all pallets at each node. The relationship between distance and time required per trip will be calculated using the average truck speed of 30km/hr.

Table 3.2 Distance-based fare table (Source: Japan Trucking Association)

Ⅰ 距離制運賃表

関東運輸局

（単位：円）

車種別 / キロ程	小型車（２ｔクラス）	中型車（４ｔクラス）	大型車（10ｔクラス）	トレーラー（20ｔクラス）
10km	15,790	18,060	22,540	27,940
20km	17,600	20,160	25,330	31,550
30km	19,410	22,270	28,120	35,160
40km	21,220	24,370	30,920	38,770
50km	23,040	26,480	33,710	42,380
60km	24,850	28,580	36,500	45,990
70km	26,660	30,690	39,290	49,600
80km	28,470	32,790	42,090	53,200
90km	30,280	34,890	44,880	56,810
100km	32,090	37,000	47,670	60,420
110km	33,910	39,090	50,390	63,930
120km	35,730	41,170	53,110	67,430
130km	37,550	43,260	55,830	70,940
140km	39,360	45,340	58,550	74,440
150km	41,180	47,430	61,270	77,950
160km	43,000	49,510	64,000	81,450
170km	44,820	51,600	66,720	84,960
180km	46,630	53,690	69,440	88,460
190km	48,450	55,770	72,160	91,970
200km	50,270	57,860	74,880	95,470
200kmを超えて500kmまで20kmを増すごとに加算する金額	3,630	4,140	5,370	6,910
500kmを超えて50kmを増すごとに加算する金額	9,070	10,360	13,430	17,280

Table 3.3 Parameters used in calculation

Variable Name	Symbol	Value	Unit	Remarks
Pallet demand	D	20	pallet/day	
Warehouse rental cost	C_S	40.40	yen/m^2/day	Japan, Kanto region
Surface area of pallet	S	1.21	m^2/pallet	T11 Type (JISZ0601)
No. of pallets per stack	n	10		
Purchasing price		7000	yen/pallet	Nippon Pallet Pool Co.,Ltd.
Service life		3650	day	10 years
Pallet rental fee	C_R	8	yen/pallet/day	Nippon Pallet Pool Co.,Ltd.
Distance between node A and B		30	km	
Time required per trip	T_t	0.04	day	calculated with average travel speed of 30km/h
Transportation cost per trip	C_t	28120	yen	10 ton class

3.4. Computation

The comparison model was structured based on the mathematical equations. Calculations and visualizations were carried out by applying the above-mentioned values, using Microsoft Excel, version 2107. Various kinds of sensitivity analysis are performed, and a few significant results and trends will be discussed in the next chapter.

4. Results of Sensitivity Analysis

4.1. Cost Breakdown vs Average Holding Time

The authors observed the change in each cost due to the change in the average holding time of goods, which is denoted by $(T_A + T_B)$. The average holding time will be dependent on the nature of goods and how the company manage their inventory and seasonal demand fluctuations. It is also one of the most useful metrics used in determining whether the company should use purchased pallets or rental pallets.

With the increase in average holding time, the pallet cost when using rental pallet (PC_R) showed a higher increase rate than the pallet cost when using purchased pallet (PC_P), as shown in Figure 4.1. Even though initial costs when using purchased pallet is higher, daily usage cost would be cheaper compared to using rental pallet, in the long term.

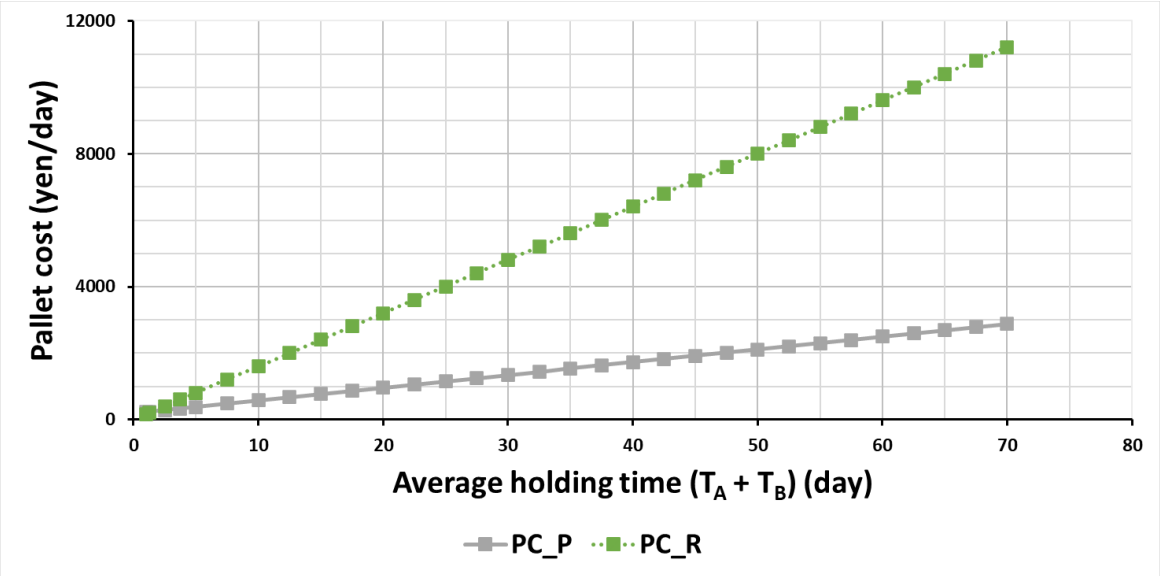

Figure 4.1 Pallet cost vs Average holding time

With the increase in average holding time, the transportation cost when using rental pallet (TC_R) showed a much higher decrease rate than the transportation cost when using purchased pallet (TC_P), as shown in Figure 4.2. Higher average holding time means more time interval between each trip, which means lower cost. The downward slope in cost is shallow, but TC_P is higher than TC_R at all times, due to the fact that there is no need for return trips in the case of using rental pallet, which means less transportation cost.

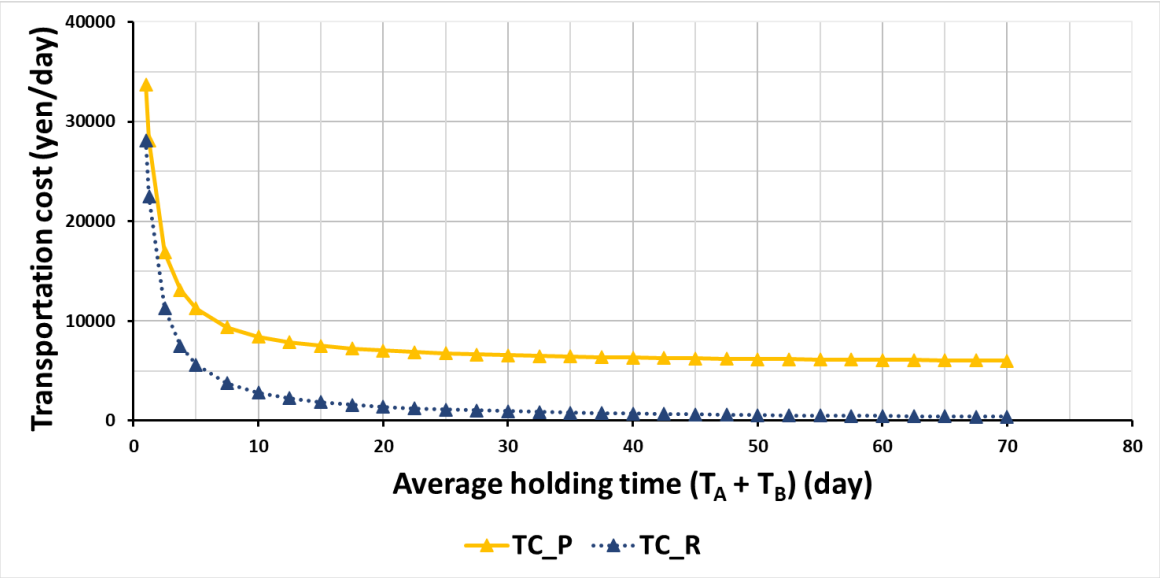

Figure 4.2 Transportation cost vs Average holding time

With the increase in average holding time both the storage cost when using purchased pallet (SC_P) and the storage cost when using rental pallet (SC_R) increased proportionally with similar slopes, as shown in Figure 4.3. It is to be noted that a constant value is used for the time interval between return trips for this research. The variable between the two is the time stored at the warehouse. Longer storage time when using purchased pallet results in higher storage cost, compared to using rental pallet.

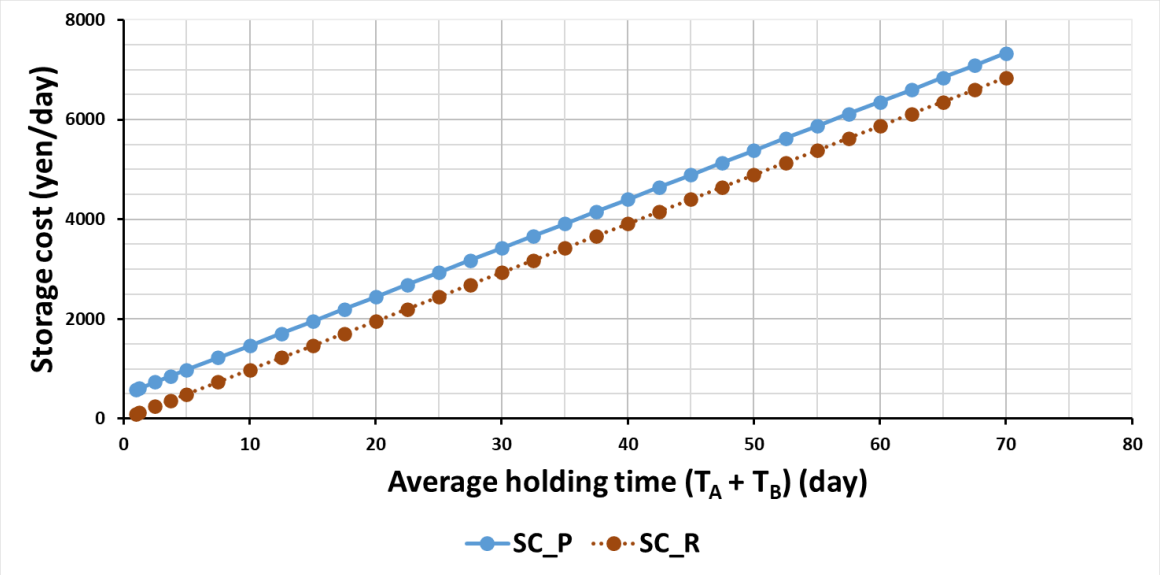

Figure 4.3 Storage cost vs Average holding time

As such, for the parameters used in this research, the 3 different pairs of costs showed different trends with the increase in average holding time, as summarized in Figure 4.4. They also constitute different proportions of the total costs. Figure 4.5 depicts the proportion of each cost as a percentage of the total cost when the average holding time is 35 days. For purchased pallet, transportation cost made up the majority of the total cost at 54.12% and for rental pallet, pallet cost made up the majority of the total cost at 57.02%

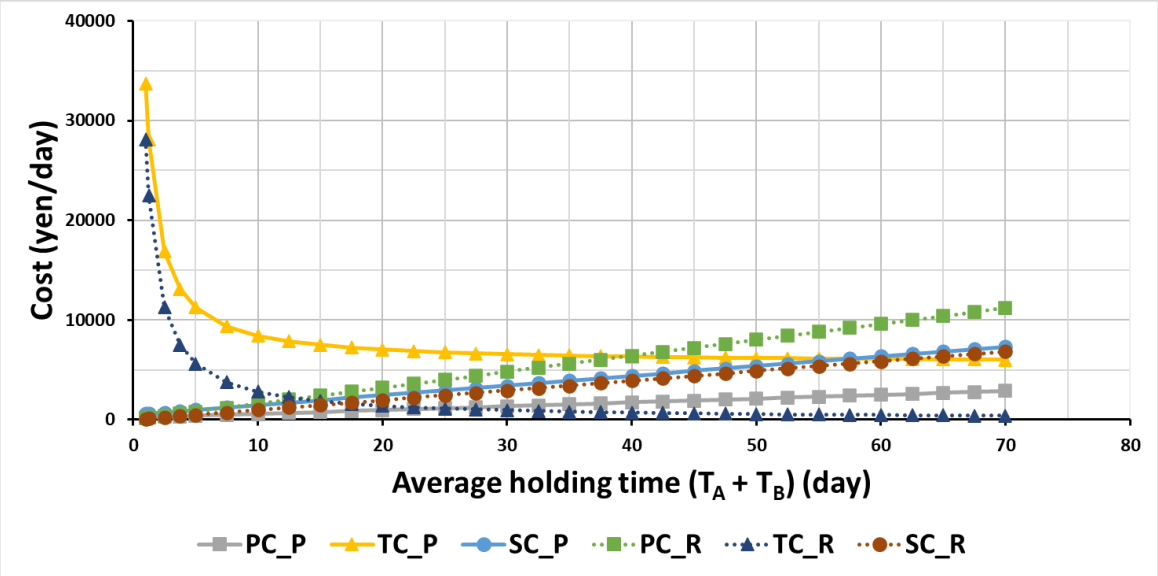

Figure 4.4 Cost breakdown vs Average holding time

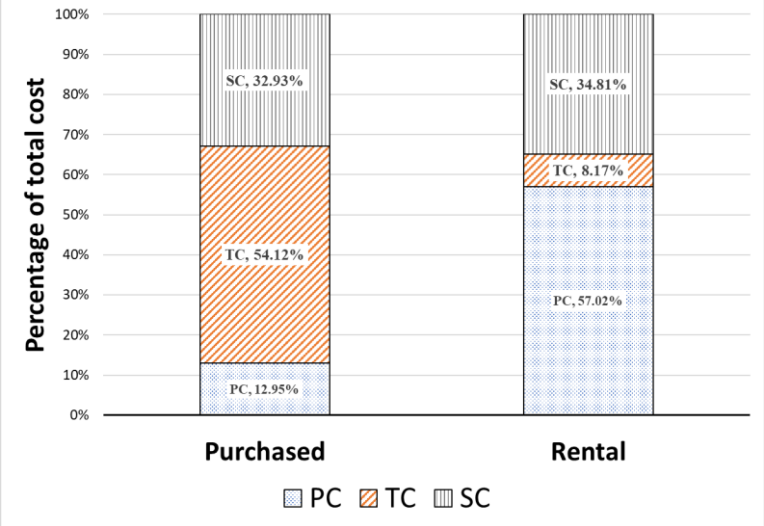

Figure 4.5 Proportion of each cost as a percentage of the Total cost (T_A+T_B =35)

4.2. Total Cost vs Average Holding Time

Figure 4.6 depicts the change in the total cost of using purchased pallet ($C_{P,Total}$) and rental pallet ($C_{R,Total}$) with the increase in average holding time. When the average holding times were low, $C_{R,Total}$ was lower than $C_{P,Total}$. But as the average holding time increased, $C_{R,Total}$ showed a much sharper increase until it finally overcame $C_{P,Total}$ at $T_A + T_B$=51.8, which is the "turning point". Simply said, logistic managers should use rental pallet if the predicted average holding times are lower than the turning point, and they should use purchased pallet if not. The turning point will also shift with the change in other parameters, and we will study the effects of a few of them in this research.

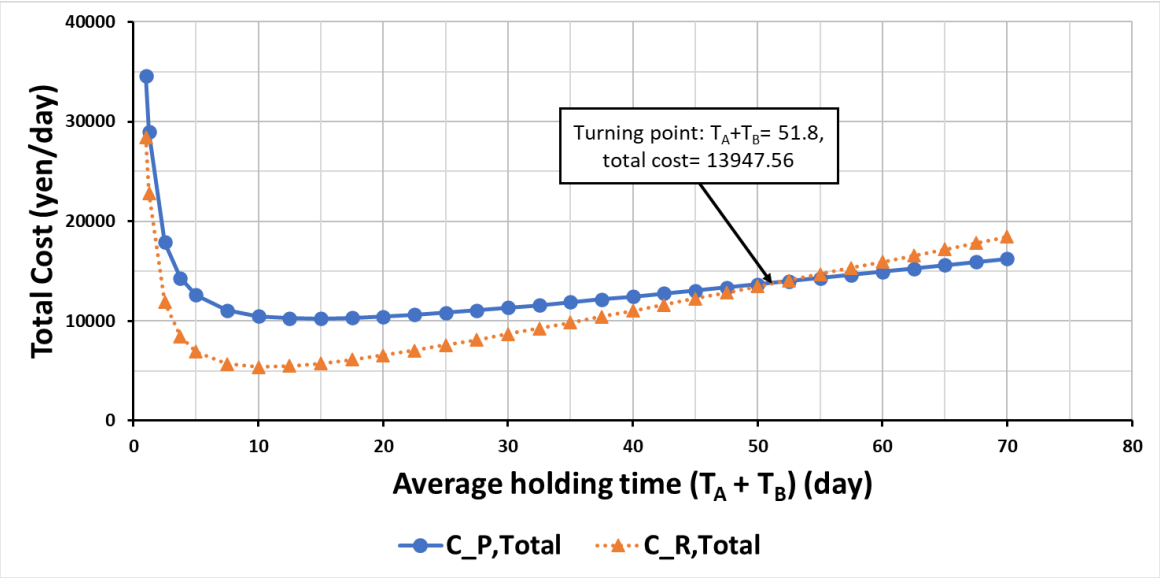

Figure 4.6 Total cost vs Average holding time

4.3. Effect of Pallet Rental Fee on Turning Point

One of the major reasons against using rental pallet is the apparent high cost of rental fee. Figure 4.7 depicts the effect of changing pallet rental fee (C_R) on the turning point. Under the otherwise same conditions, just a decrease of C_R from 8 to 6, can make the turning point shift from $T_A + T_B$=51.8 to 77.2.

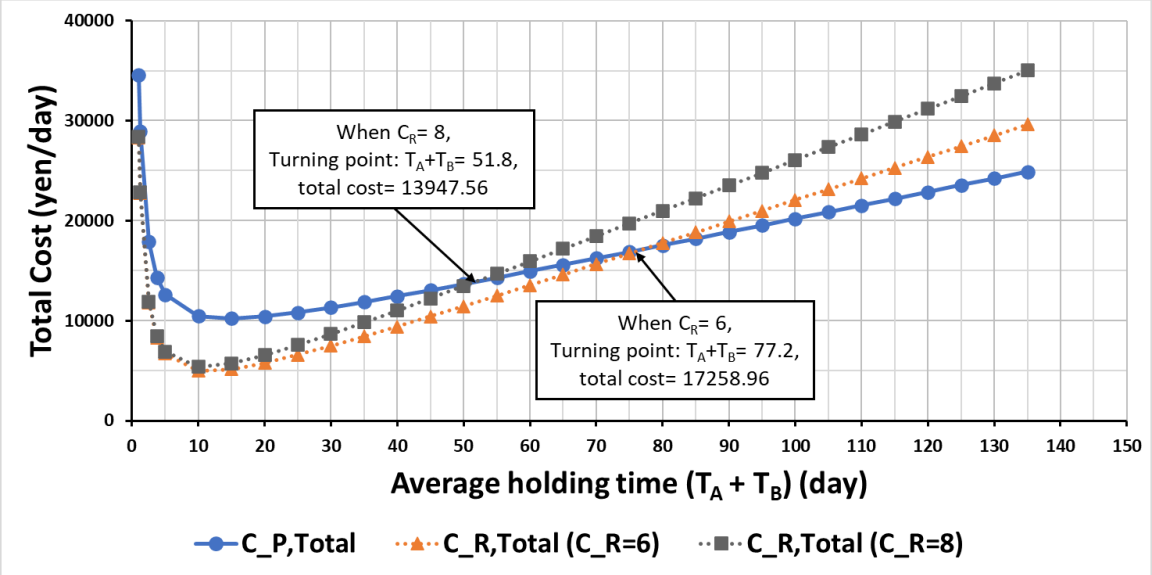

Figure 4.7 Effect of change in pallet rental cost on turning point

Figure 4.8 shows the trend of turning points with the change in C_R, varied from 3.0 to 12.0 yen. The area under the curve can be taken as the conditions preferring the use of rental pallet and the area above the curve are the conditions favoring the use of purchased pallet. As pallet pooling and renting pallets become more common, pallet rental fees are also predicted to decrease.

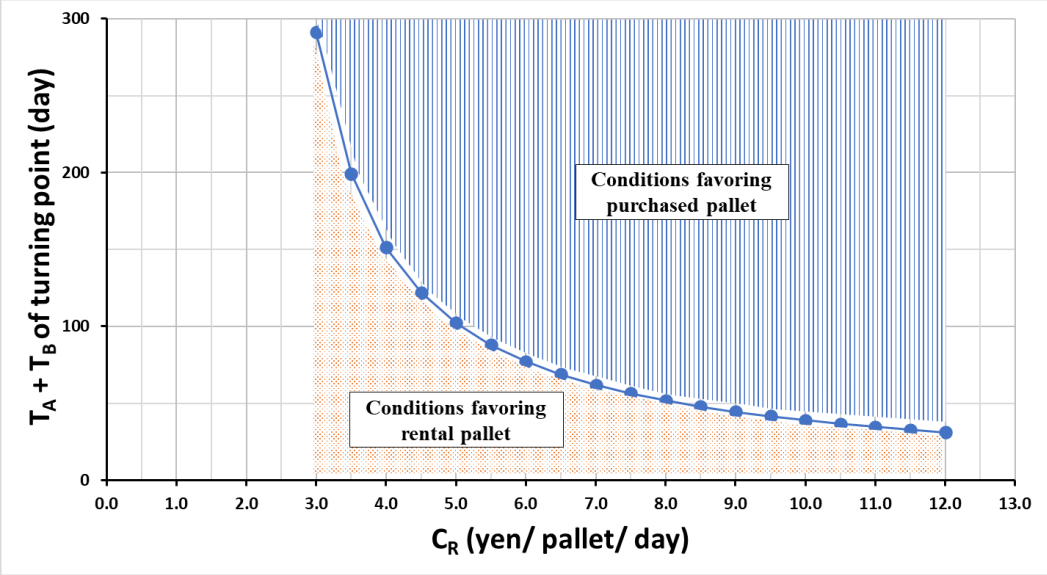

Figure 4.8 Turning point vs Pallet rental fee (C_R)

4.4. Effect of Pallet Purchasing Price and Service Life on Turning Point

Next, we analyzed the effects of changing pallet cost (PC_P). As pallet cost is calculated by purchasing price and service life, their separate effects are found out. Figure 4.9 shows the change in turning point when the service life is changed from 1095 days to 7300 days. As shown in the graph, the service life has an exponential effect on the turning point though not as much as pallet rental fee.

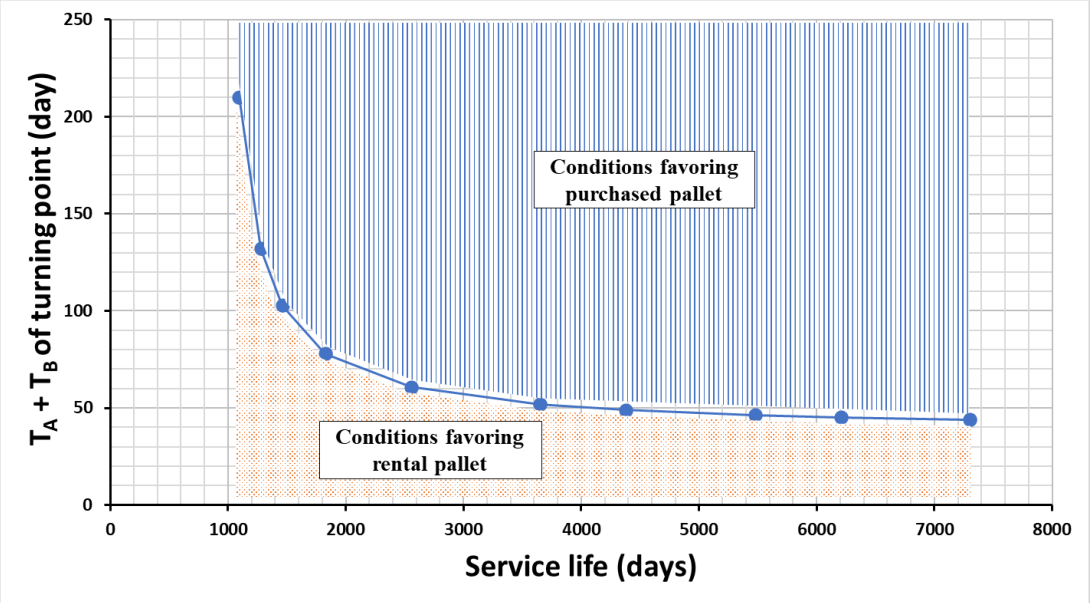

Figure 4.9 Turning point vs Service life

Figure 4.10 shows the change in turning point when the purchasing price is changed from 2000 yen to 12000 yen. As shown in the graph, the effect is almost proportional.

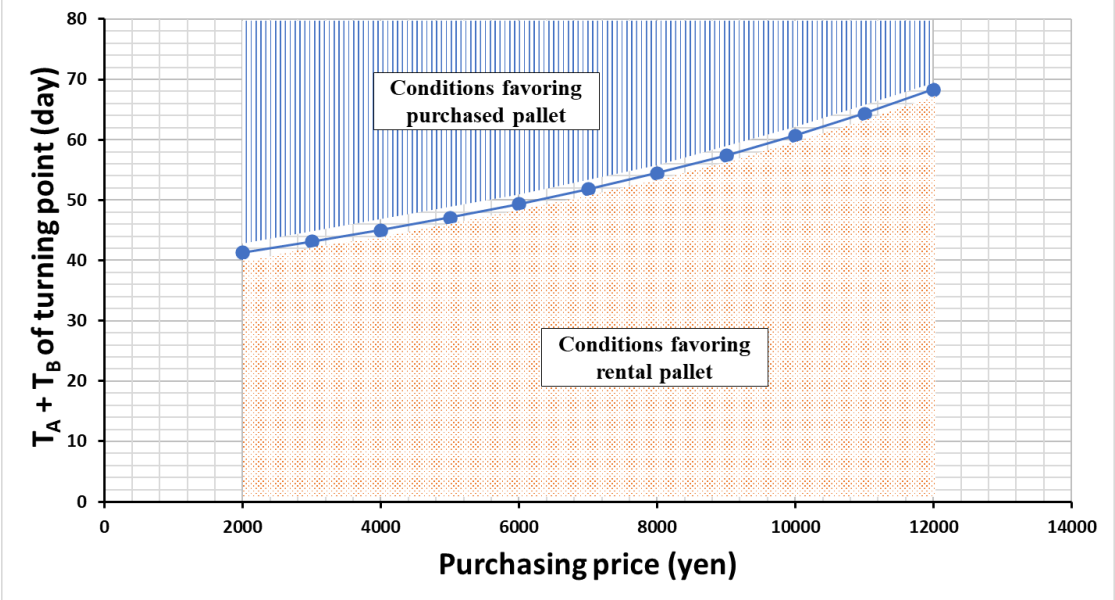

Figure 4.10 Turning point vs Purchasing price

4.5. Effect of Transportation Cost on Turning Point

Finally, we observed the effect of changing transportation times (T_t) and costs (C_t). Figure 4.11 shows the change in the turning point when the distance between nodes A and B are changed from 30 km to 60 km. The average holding time for turning point when the distance is 30 km is 51.8 days, which increased to 65.55 days when the distance is 60 km. This can be explained by the fact that the transportation cost occupies a bigger proportion of the total cost when using purchased pallet compared to when using rental pallets, as also explained by Figure 4.5. Figure 4.12 shows that the total cost using purchased pallet increased when the distance was increased, but Figure 4.13 shows that the total cost when using rental pallet remained almost the same even when the distance was increased.

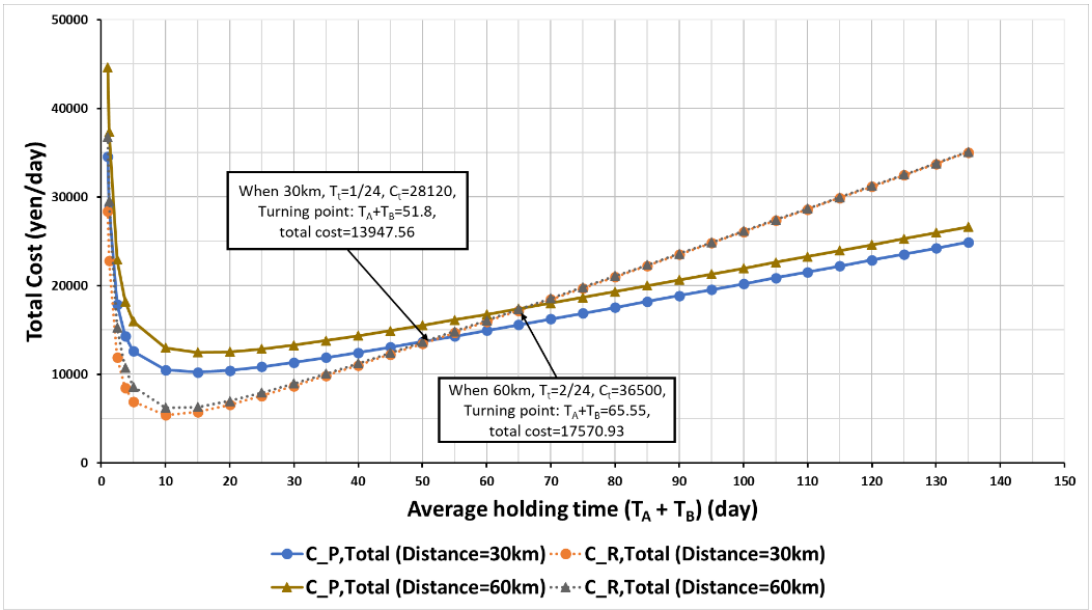

Figure 4.11 Effect of change in transportation cost on turning point

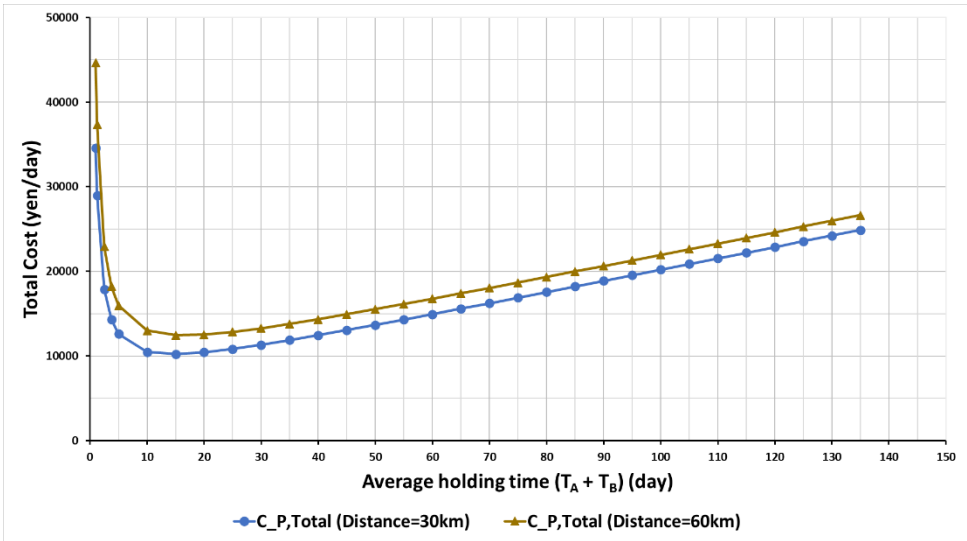

Figure 4.12 Effect of change in transportation cost on total cost when using purchased pallet

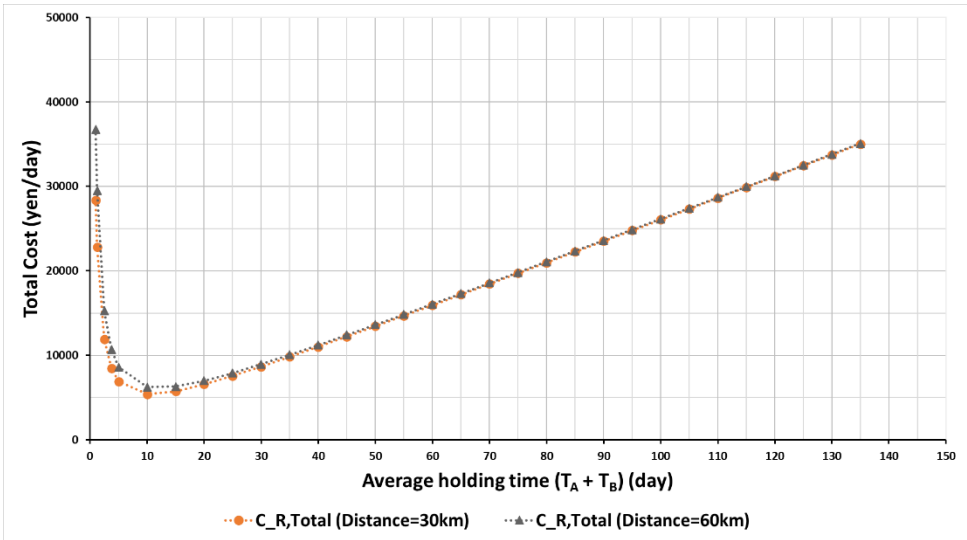

Figure 4.13 Effect of change in transportation cost on total cost when using rental pallet

This means the rental pallet services are more resilient against the increase in transportation costs, due to further distances or the nation's socioeconomy. It is expected that transportation costs in Japan will rise in the future due to the lack of manpower and increase in fuel prices[30].

Figure 4.14 shows the trend of turning points with the change in distance between node A and B, varied from 10 to 200 km. Similar to Figure 4.8, the graph divides the areas of conditions favoring the use of rental pallet and the use of purchased pallet.

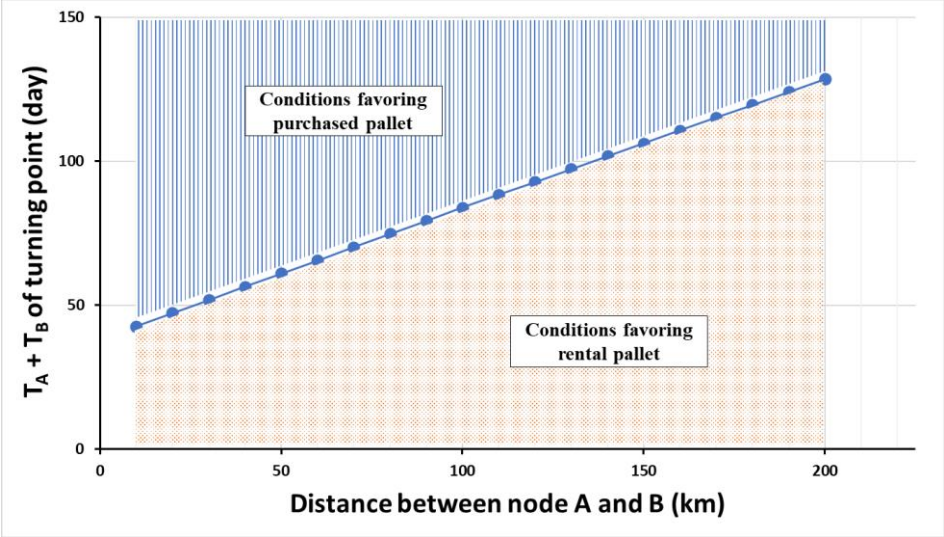

Figure 4.14 Turning Point vs Distance between node A and B

5. Conclusions

Logistics has been the backbone of any nation's development. Smarter and more efficient logistic systems will become more and more essential with the change from society 4.0 to society 5.0. Pallet pooling and renting services, which is a kind of sharing economy, will serve as a foundation for a new era of logistics, especially when current issues discussed in this study are solved. To contribute to this cause, this research aims to support companies to make informed decisions regarding renting and purchasing pallets, and encourage them to introduce more pallets into their workflow when they realize the lower initial cost but more benefits of renting pallets.

The mathematical model developed in this research can compare the different costs related to the usage of purchased pallet and rental pallet. The 3 different pairs of costs: pallet costs, transportation costs and storage costs may show different trends under each condition, but the total costs can be compared to find the turning point. The turning point can be a reference point for logistic managers when choosing between purchased pallet and rental pallet. From the calculations, it is found that for goods planned to have a long holding time, purchasing pallet is more cost-effective. But for goods with a short holding time, using rental pallets has more profound benefits.

Logistic managers should also consider the effect each variable has on the total cost, especially when that variable has potential to vary considerably in the near future. In this research, the effects of pallet rental cost and transportation cost are thoroughly analyzed. The average holding time of the turning point changes exponentially with the change in pallet rental cost. The transportation cost has a bigger effect on the total cost when using purchased pallet but only a slight effect when using rental pallet, which makes the latter more desirable in the future, as the transportation costs in Japan are predicted to rise, due to the lack of manpower and increase in fuel prices.

The effects of pallet service life and purchasing price of purchased pallets are also analyzed. The service life has an exponential effect on the turning point although not as much as pallet rental fee. The purchasing price has a near proportional effect on the turning point.

More accurate comparison can be done by adding more types of costs related to the usage of pallets to the model, such as cost of equipment used together with pallets, labor wages, maintenance, disposal fees and so on.

In this study, practical values typical to the field are used but some are assumed. Further analysis can be done more realistically by applying actual logistics data, and comparing with the results from this model.

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References

(1) National Pallets - European Express Pallet Delivery. “A Brief History of the Pallet: Shipping for Business.” https://www.nationalpallets.co.uk/blog/a-brief-history-of-pallets.

(2) 一般社団法人　日本パレット協会. パレットの歴史. 2018. https://youtu.be/ovxr5qW5Ouk, (accessed 2021-12-27).

(3) Statista. Global pallet market size 2019-2027. https://www.statista.com/statistics/1228432/global-pallet-market-size/, (accessed 2021-09-05).

(4) 国土交通省. “物流：総合物流施策大綱（2021年度～2025年度）.” https://www.mlit.go.jp/seisakutokatsu/freight/seisakutokatsu_freight_tk1_000179.html, (accessed 2021-08-20).

(5) 物流ウィークリー. パレット流出を防げ 毎年２０００万枚投入. 2017. https://weekly-net.co.jp/news/21242/.

(6) 国土交通省 九州運輸局. 北東アジア物流資材（パレット（T11 型））の標準化に向けた調査報告書. 2010. https://wwwtb.mlit.go.jp/kyushu/gyoumu/koutuu/file03/file03_24.pdf.

(7) Elia, Valerio, Gnoni, Maria Grazia. Designing an effective closed loop system for pallet management. International Journal of Production Economics. 2015, vol. 170, p. 730–740. (accessed 2020-07-28).

(8) CHEP UK. “History of CHEP.” https://www.chep.com/our-company/our-history, (accessed 2021-12-29).

(9) JPR 日本パレットレンタル株式会社. “レンタルパレットサービス: 製品・サービス.” https://www.jpr.co.jp/demand/internal_rental/rental.html, (accessed 2021-08-20).

(10) iGPS Logistics, LLC. “Deadhead Trucking: Avoiding Empty Miles.” https://igps.net/blog/2018/12/11/deadhead-trucking-avoiding-empty-miles/.

(11) レフォルモ株式会社. “必要な時に必要な枚数だけ借りるレンタルパレットサービス 物流業務（保管、輸送、荷役）に最適なプラパレット.” https://rental-pallet.net/, (accessed 2021-09-05).

(12) Chatterjee, Shantanu. “Renting Pallets? Burning Cash!” https://www.linkedin.com/pulse/renting-pallets-burning-cash-shantanu-chatterjee/.

(13) 日本通運. “パレ（輸送）のサイズ・価格・素材に革新　e-light pallet / e-light pallet PLUS.” https://www.nittsu.co.jp/v-site/18.html, (accessed 2022-01-09).

(14) Kawasaki Robotics. “Palletizing Robots: Applications.” https://robotics.kawasaki.com/en1/applications/robotic-palletizing/, (accessed 2022-01-09).

(15) Ren, Jianwei, Zhao, Qingqing, Liu, Bo, Id, Chunhua Chen. Selection of pallet management strategies from the perspective of supply chain cost with Anylogic software. PLoS ONE. 2019, p. 18. https://doi.org/10.1371/journal.pone.0217995.

(16) Ray, Charles D., Michael, Judd H., Scholnick, Bruce N. “Supply-chain system costs of alternative grocery industry pallet systems.” Forest Products Journal.

https://www.researchgate.net/publication/279560762_Supply-chain_system_costs_of_alternative_grocery_industry_pallet_systems, (accessed 2022-01-10).

(17) Doungpattra, N., Jarupan, L., Ongkunaruk, P. Simulation for Transport Pallet Cost Reduction in Pet Food Manufacturing: An Empirical Case Study. Packaging Technology and Science. 2012, vol. 25, no. 6, p. 311–319. https://onlinelibrary.wiley.com/doi/full/10.1002/pts.976, (accessed 2022-01-05).

(18) Roy, Debjit, Carrano, Andres L., Pazour, Jennifer A., Gupta, Akash. Cost-effective pallet management strategies. Transportation Research Part E: Logistics and Transportation Review. 2016, vol. 93, p. 358–371. (accessed 2020-07-28).

(19) United Nations. “THE 17 GOALS | Sustainable Development.” https://sdgs.un.org/goals, (accessed 2022-01-09).

(20) 小林穂高. 2008年度東京海洋大学卒業論文. LCA を用いたパレット運用における総合的な環境影響に関する研究. 2008.

(21) JPR 日本パレットレンタル株式会社. “JPRレンタルパレットサービスのCO2削減効果.” https://www.jpr.co.jp/company/environment/service.html.

(22) Japan Credit Rating Agency, Ltd. JCR グリーンローン・フレームワーク評価 by Japan Credit Rating Agency, Ltd. 2021. https://www.jcr.co.jp/download/a6f1705723a30787058587e81771a9a103f348321f7f4219a0/21d0356.pdf.

(23) Ministry of Economy, Trade and Industry. “Japan’s Roadmap to ‘Beyond-Zero’ Carbon.” https://www.meti.go.jp/english/policy/energy_environment/global_warming/roadmap/.

(24) 一般社団法人日本パレット協会. パレット標準化の現状と課題. 2021. https://www.mlit.go.jp/seisakutokatsu/freight/content/001424794.pdf, (accessed 2022-01-08).

(25) 一般社団法人日本産業車両協会. ＩｏＴを有効に活用した全体最適なサプライチェーンシステムの構築調査事業報告書. 2017. https://www.meti.go.jp/meti_lib/report/H28FY/000182.pdf.

(26) GEMBA. 物流容器「パレット」から読み解く、日本の物流システムの課題. 2020. https://gemba-pi.jp/post-197361.

(27) ＴＳＫ株式会社. “世界主要国のパレット寸法規格.” https://butsuryukiki-kaizen.com/buturyu/wp-content/uploads/2014/02/sekaipare.pdf, (accessed 2022-01-08).

(28) 一般社団法人Pパレ共同使用会. “Pパレとは.” https://p-pallet.jp/about.html, (accessed 2022-01-18).

(29) 一般社団法人　日本パレット協会. “データ集(生産数量＆レンタル保有数量).” https://www.jpa-pallet.or.jp/data/, (accessed 2022-01-08).

(30) 国土交通省. 一般貨物自動車運送事業に係る 標準的な運賃の告示について. 2020. https://www.mlit.go.jp/common/001340658.pdf.

(31) white logistics movement. “「ホワイト物流」推進運動ポータルサイト.” https://white-logistics-movement.jp/.

(32) Cabinet Public Affairs Office. Realizing Society 5 - Government of Japan. https://www.japan.go.jp/abenomics/_userdata/abenomics/pdf/society_5.0.pdf.

(33) 悠暉渡邊. 物流倉庫の賃貸相場は？倉庫を賃貸するメリット・デメリットを紹介！. 2021. https://x-work.jp/journal/logistics/6241?utm_medium=organic_m&utm_campaign=6241.

(34) 日本パレットプール株式会社. “コスト比較.” https://www.npp-web.co.jp/about/cost.php, (accessed 2021-08-20).

(35) 全日本トラック協会. “一般貨物自動車運送事業に係る標準的な運賃について.” https://jta.or.jp/member/kaisei_jigyoho/kaisei_jigyoho_202008.html#1.

(36) toishi.info. “トラックに積載可能なパレット枚数.” https://www.toishi.info/boueki/truck_pallet.html.