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Smart and Sustainable Supply Chain and Logistics—Challenges, Methods and Best Practices

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Karolina Werner-Lewandowska
Editors

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Preface

The COVID-19 pandemic has caused numerous disruptions in supply chains and has significantly changed customer's behaviours. Moreover, these new challenges had been merged with the existing pledge for sustainability and greenhouse gas emissions reduction. As a result, companies and public entities need to adapt their processes to meet new challenges in the macro environment. New smart technologies are becoming increasingly important and support business operations amid staff shortages and restrictions on the movement of people and goods. Smart technologies are also increasingly being used in crisis management to reduce risk and make supply chain processes more resilient to disruption caused by natural disasters or pandemics.

This book entitled *Smart and Sustainable Supply Chain and Logistics—Challenges, Methods and Best Practices: Volume 2* presents the original methods, tools and case studies on topics, as follows:

- Smart solutions for supply chain management,
- Modelling, simulation and optimization of supply chain, production and logistics operations,
- Sustainable, social and legal challenges in supply chain management and logistics.

This book includes the selected papers which have been submitted to the 15th International Congress on Logistics and SCM Systems (ICLS 2021) organized by the Faculty of Engineering Management, Poznań University of Technology and the International Federation of Logistics and SCM Systems (IFLS). We would like to express our gratitude to the Board of the International Federation of Logistics and SCM Systems (IFLS) for the invaluable contribution to the volume:

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This scientific monograph has been doubled blind reviewed. We would like to thank all Reviewers whose names are not listed in the volume due to the confidentiality of the process. Their voluntary service and comments helped the authors to improve the quality of the manuscripts. Although not all of the received manuscripts appear in this book, the efforts spent and the work done for this book by the Authors and Reviewers are very much appreciated.

Poznań, Poland — Paulina Golinska-Dawson
Kaohsiung, Taiwan — Kune-Muh Tsai
Poznań, Poland — Karolina Werner-Lewandowska

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Elkafi Hassini, Mohamed Ben-Daya, and Zied Bahroun

1 Introduction

The food supply chain (FSC) is a complex network of farmers and food producers, including makers of farm equipment and chemicals, agribusinesses and processors, distributors and support industries, such as transportation and financial services, retailers and consumers. It is a critical component of the global economy. For example, one billion people, or one in three of all world employees, are employed in agriculture, and employees in FSC businesses account for more than half of the total employment in sub-Saharan Africa and South Asia (FAO 2012).

The practice of supply chain management in FSCs has its distinctive challenges. While in a typical supply chain, such as in retail, we largely focus on reducing costs, in a FSC other important dimensions must be considered such as minimizing food waste and loss as well as meeting certain health and safety regulations at all phases of the supply chain. IoT application in FSCs reduces the time between data capture and decision making. This enables supply chains to react to changes in real-time and reduces food waste. In addition, it allows for quick action in case of recalls or safety concerns. Most of the IoT applications in the FSC focus on technological solutions or deal with conceptual models. The reader is referred to Ben-Daya et al. (2021) for a recent review of IoT applications in the FSC. Using IoT data for better decision making and for dealing with various operations management aspects are issues that

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are not addressed adequately in the literature (e.g., see Ben-Daya et al. 2019 and Ivanov et al. 2021). Another important issue that needs further investigation is the justification of IoT investment through adequate cost–benefit analysis. It is thus our goal in this paper to develop models for assessing the efficiency and impact of IoT technologies applications in FSCs.

We consider a fresh produce product with a quality that deteriorates over time. The introduction of IoT sensors allows for the continuous monitoring of the product quality parameters through the supply chain. Consumer demand is a function of price and quality. We develop Stackelberg game models that allow us to quantify the impact of the use of IoT at the retailer or distributor levels. Such models can be used to justify the investment in IoT infrastructure in the FSC and if it is viable, it can help decide in which echelon of the FSC the investment will have more impact on FSC performance improvement. To the best of our knowledge, models that quantify the impact of IoT on FSC management and that can be used to make the business case of IoT investment are lacking in the literature.

The remainder of this paper is organized as follows. A literature review of relevant research is discussed in the next section. In Sect. 3, we present the problem statement, notation and assumptions. We then present two Stackelberg pricing models in Sect. 4 where one includes IoT and the other does not. The two models will be used in the following two sections to study the impact of IoT. In Sect. 5, we provide a numerical study to investigate the impact of IoT as well as the impact of IoT investment on profits and supply chain coordination. In Sect. 6, we provide some concluding remarks and directions for future research.

2 Literature Review

Ben-Daya et al. (2019) have reviewed the literature on IoT and supply chain management and pointed out the need for the development of analytical models to assess the impact of IoT on supply chain operations. They have also found that a promising area for IoT applications is in FSCs. IoT can enhance product freshness and aid in quality management. A more detailed review of the role of IoT in supply chain quality management can be found in Ben-Daya et al. (2020). Here we would like to focus on the following two related literature areas: (i) food waste inventory control models and (ii) the role of pricing and quality in supply chain coordination. In each area we focus on the literature that is most relevant to our research problem and methodology.

(i) *Food waste inventory control models*: There is evidence that a retailer's choices for how to manage inventory and consumer choice behaviour are key drivers of food waste at the retail level (Cicatiello et al. 2017). Thus, inventory models for produce retail must account for their impact on food waste. Unfortunately, this has not been the prevailing practice in the operations management literature, where food cost is often lumped up with inventory costs (Ozbilge et al., 2021). Yavari and Geraeli (2019) proposed a multi-objective model for designing a sustainable food supply chain where one of the objectives is to minimize the environmental footprint. Janssen et al. (2018) consider waste minimizing in a grocery retail store by explicitly incorporating non-sale periods, such as when the store closes. Mallidis et al. (2020a, b) and Ozbilge et al. (2021) have considered the use of donations to minimize food waste.

(ii) *Role of pricing and quality in supply chain coordination*: The literature on supply chain coordination is vast. In this paper we investigate the impact of IoT investment, using the leverage of pricing and quality, on reducing the double marginalization effect between the retailer and the distributor. Ma et al. (2013) have considered a two-stage supply chain where the retailer tries to sell, and the supplier invests in quality. They find that the two-part tariff as well as the two-part tariff combined with the supplier quality effort do not coordinate the supply chain. They offer a new contract that can achieve coordination. In a similar way we show, and quantitatively determine, the impact of coordination through two-part tariff and IoT quality investment. Taleizadeh et al. (2018) consider closed-loop supply chains of a manufacturer, a retailer and a third party. They use Stackelberg game models to find optimal prices, quality levels and sales and recycling collection efforts and consider channel structure impacts on coordination.

There are several opportunities for studying the emerging field of IoT quality-controlled supply chain operations. This study is one of such efforts and makes the following contributions: (1) A quantitative assessment framework for IoT impact of FSC operations; (2) We investigate how pricing can play a role in food waste reduction with the aid of IoT technology; (3) Analysis of IoT investment thresholds that allow for deciding on who should invest in IoT and how much they should invest; and (4) An assessment of the role of IoT investment in enhancing coordination in the supply chain.

3 Problem Statement and Assumptions

We use the following notation:

t	Time
i	Supply chain entity, $i \in \{1(\text{producer}), 2(\text{distributor}), 3(\text{retailer})\}$
q_i	Quality level at supply chain echelon i
t_i	Product arrival time at supply chain echelon i
$q(t)$	Quality at time t
μ_i	Instantaneous quality deterioration rate at supply chain echelon i
μ_{31}	Instantaneous quality deterioration rate at the Retailer without IoT
μ_{32}	Instantaneous quality deterioration rate at the Retailer with IoT
q_h	Highest quality level beyond which a customer is indifferent to quality
t_h	Time at which customer starts recognizing different quality levels
q_c	Critical quality level below which a customer considers the product unsalable

t_c	Time beyond which a customer finds the product unsalable due to bad quality
$D(p, t)$	Demand rate at time t for price p
D_0	Market size
α	Demand sensitivity to price
β	Demand sensitivity to quality
T	Replenishment period, $T = t_c - t_3$
c	Distributor's cost
$w_1(w_2)$	Price charged by the distributor to the retailer without IoT (with IoT)
$p_1(p_2)$	Unit selling price at the retailer without IoT (with IoT)
D_1, D_2	Total demand with IoT

We assume that the producer starts with perfect item quality. The product quality then deteriorates linearly at rate μ_i that change at times t_i. To analyze the impact of different quality levels, we assume that the product is at a premium quality when it reaches the retailers' premises at the time t_3 and remains at that state until the time t_h. During the time interval $[t_1, t_h]$, the product quality cannot be visibly differentiated, and it is referred to as apparent stability. After t_h, the product quality becomes regular and the customer can visibly tell the product quality level, such as due to discoloration. The product quality remains acceptable until time t_c at which point all remaining inventory is not sellable and becomes food waste. Thus, we experience two types of quality: a visible quality that remains constant at the level q_h and then linearly decreases with the rate μ_3 and an effective quality level that reflects the actual quality level that would be measurable if we use IoT technology.

4 Models

We use a Stackelberg game to model the retailer pricing problem in the absence and presence of IoT.

4.1 Without IoT

Similar to Bahroun et al. (2020), we use the following quality dependent demand functions in the absence of IoT:

$$D(p_1, t) = \begin{cases} D_0 - \alpha p_1 + \beta q_h & t \leq (q_3 - q_h)/\mu_{31} \\ D_0 - \alpha p_1 + \beta(q_3 - \mu_{31} t) & t > (q_3 - q_h)/\mu_{31} \end{cases} \tag{1}$$

$$D_1 = \frac{1}{\mu_{31}} \left\{ -\frac{1}{2}\beta\left[(q_3 - q_h)^2 + (q_3 - q_c)^2\right] + (D_0 - \alpha p_1 + \beta q_3)(q_3 - q_c) \right\} \tag{2}$$

Using a Stackelberg game theory model, the distributor acts as a leader and the retailer as a follower. The retailer optimizes the retail price p_1 to maximize his profit, which is subsequently used by the supplier to optimize the wholesale price w_1 to maximize her profit. We first determine the retailer and distributor profit as

$$\pi_{R1} = \frac{(p_1 - w_1)}{\mu_{31}} \left\{ -\frac{1}{2}\beta\left[(q_3 - q_h)^2 + (q_3 - q_c)^2\right] + (D_0 - \alpha p_1 + \beta q_3)(q_3 - q_c) \right\} \tag{3}$$

and

$$\pi_{D1} = \frac{(w_1 - c)}{\mu_{31}} \left\{ -\frac{1}{2}\beta\left[(q_3 - q_h)^2 + (q_3 - q_c)^2\right] + (D_0 - \alpha p_1 + \beta q_3)(q_3 - q_c) \right\} \tag{4}$$

Finally, the overall decentralized supply chain profit π_{S1} is found by combining the individual profits of the retailer and the distributor given in (3) and (4), i.e., $\pi_{S1} = \pi_{R1} + \pi_{D1}$, thus

$$\pi_{S1} = \frac{(p_1 - c)}{\mu_{31}} \left\{ -\frac{1}{2}\beta\left[(q_3 - q_h)^2 + (q_3 - q_c)^2\right] + (D_0 - \alpha p_1 + \beta q_3)(q_3 - q_c) \right\} \tag{5}$$

Proposition 1 (Optimal Retailer and Distributor Prices without IoT) *The distributor optimal wholesale price and the retailer's optimal price are given by*

$$w_1^* = \frac{-\beta\left[(q_3 - q_h)^2 + (q_3 - q_c)^2\right] + 2(D_0 + \beta q_3)(q_3 - q_c)}{4\alpha(q_3 - q_c)} + \frac{c}{2} \tag{6}$$

$$p_1^* = \frac{-3\beta\left[(q_3 - q_h)^2 + (q_3 - q_c)^2\right] + 6(D_0 + \beta q_3)(q_3 - q_c)}{8\alpha(q_3 - q_c)} + \frac{c}{4}. \tag{7}$$

Proof Applying the first and second-order optimality conditions to the retailer's profit function given by (3) we find that

$$p_1 = \frac{-\beta\left[(q_3 - q_h)^2 + (q_3 - q_c)^2\right] + 2(D_0 + \beta q_3)(q_3 - q_c)}{4\alpha(q_3 - q_c)} + \frac{w_1}{2} \tag{8}$$

Substituting this value into the distributor's profit given by (4), the distributor finds the optimal value w_1 that maximizes its profit function, which is given by (6). Now Substituting (6) into (8) yields the optimal retailer's price given by (7). □

The optimal profit expressions for the retailer and distributor are given by the following proposition.

Proposition 2 (Optimal retailer and distributor profits without IoT) *The optimal profit expressions for the retailer, distributor and supply chain are given by:*

$$\pi_{R1}^* = \frac{\left[-\beta\left[(q_3-q_h)^2+(q_3-q_c)^2\right]+2(D_0+\beta q_3-\alpha c)(q_3-q_c)\right]^2}{64\alpha\mu_{31}(q_3-q_c)} \quad (9)$$

$$\pi_{D1}^* = \frac{\left[-\beta\left[(q_3-q_h)^2+(q_3-q_c)^2\right]+2(D_0+\beta q_3-\alpha c)(q_3-q_c)\right]^2}{32\alpha\mu_{31}(q_3-q_c)} \quad (10)$$

$$\pi_{S1}^* = \frac{3\left[-\beta\left[(q_3-q_h)^2+(q_3-q_c)^2\right]+2(D_0+\beta q_3-\alpha c)(q_3-q_c)\right]^2}{64\alpha\mu_{31}(q_3-q_c)} \quad (11)$$

Proof The optimal profit expressions are obtained by substituting p_1^* and w_1^* in the profit functions given by (3) and (4), respectively. The relationship between them is due to the linear nature of the demand function. □

4.2 With IoT

When the supply chain players invest in IoT infrastructure to monitor product quality, the quality level can be always detected even when visible changes do not occur. As a result, the quality is assumed to be a linearly decreasing function of time throughout the demand period at a constant unit retail price p_2 as mentioned previously.

With IoT data, the quality level is known at all points of time and the demand function at the retailer is given by

$$D(p_1, t) = D_0 - \alpha p_1 + \beta(q_3 - \mu_{31}t)$$

and the total demand is

$$D_2 = \frac{1}{\mu_{32}}\left[-\frac{1}{2}\beta(q_3-q_c)^2 + (D_0-\alpha p_2+\beta q_3)(q_3-q_c)\right].$$

The derivation of the model in this case is like that of the previous section, except that the demand function is given by (2) and the retailer incurs an additional fixed cost per cycle, I_r, that corresponds to the investment in IoT infrastructure.

The profit functions of the retailer, distributor, and supply chain are given by

$$\pi_{R2} = \frac{(p_2-w_2)}{\mu_{32}}\left\{-\frac{1}{2}\beta(q_3-q_c)^2 + (D_0-\alpha p_2+\beta q_3)(q_3-q_c)\right\} - I_r \quad (12)$$

$$\pi_{D2} = \frac{(w_2-c)}{\mu_{32}}\left\{-\frac{1}{2}\beta(q_3-q_c)^2 + (D_0-\alpha p_2+\beta q_3)(q_3-q_c)\right\} \quad (13)$$

$$\pi_{S2} = \frac{(p_1 - c)}{\mu_{32}} \left\{ -\frac{1}{2}\beta(q_3 - q_c)^2 + (D_0 - \alpha p_2 + \beta q_3)(q_3 - q_c) \right\} - I_r \qquad (14)$$

Following the same approach described in the previous section, we present the following propositions for optimal prices and profits.

Proposition 3 (Optimal Retailer and Distributor Prices with IoT) *The optimal prices that maximize the retailer's and distributor profits are*

$$p_2^* = \frac{6D_0 + 3\beta(q_3 + q_c)}{8\alpha} + \frac{c}{4} \qquad (15)$$

$$w_2^* = \frac{2D_0 + \beta(q_3 + q_c)}{4\alpha} + \frac{c}{2}. \qquad (16)$$

Proposition 4 (Optimal retailer and distributor profits with IoT) *The optimal profit expressions for the retailer, distributor and supply chain are given by:*

$$\pi_{R2}^* = \frac{(q_3 - q_c)[-\beta(q_3 - q_c) + 2(D_0 + \beta q_3 - \alpha c)]^2}{64\alpha\mu_{32}} - I_R$$

$$\pi_{D2}^* = \frac{(q_3 - q_c)[-\beta(q_3 - q_c) + 2(D_0 + \beta q_3 - \alpha c)]^2}{32\alpha\mu_{32}}$$

$$\pi_{S2}^* = \frac{3(q_3 - q_c)[-\beta(q_3 - q_c) + 2(D_0 + \beta q_3 - \alpha c)]^2}{64\alpha\mu_{32}} - I_R.$$

The proofs of the above propositions are like those of Proposition 1–2.

5 IoT impact on Reducing Food Waste

We numerically study the impact of IoT investment on food waste reduction. Inspired from the parameters used in (Chen et al. 2019), in Table 1, we show the values for the initial deterioration rate without IoT and with IoT, the initial quality at the retailer, the potential market size, the price sensitivity, the quality sensitivity, and the unit product cost.

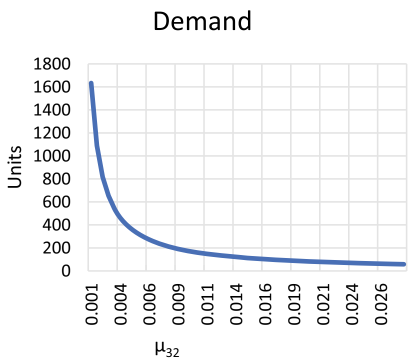
In Fig. 1, we show how demand changes depending on where IoT has been deployed. IoT impact on food waste is reflected through changes in demand after

Table 1 Initial parameter assignment

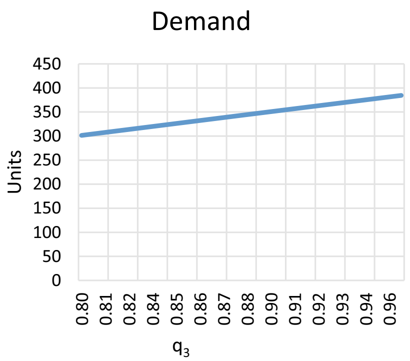
μ_{31} (/hr)	μ_{22} (/hr)	q_3	q_h	q_c	D_0 (units/hr)	α	β	c ($/unit)
0.007	0.004	0.95	0.60	0.30	15	1.8	1.8	5

an improvement in the deterioration rate μ_{32} when it is implemented at the retailer level only (Fig. 1a), an improvement in retailer initial quality q_3 when implemented at the distributor level only (Fig. 1b), or an improvement in both deterioration rate and initial retailer quality if IoT is implemented at both the distributor and retailer.

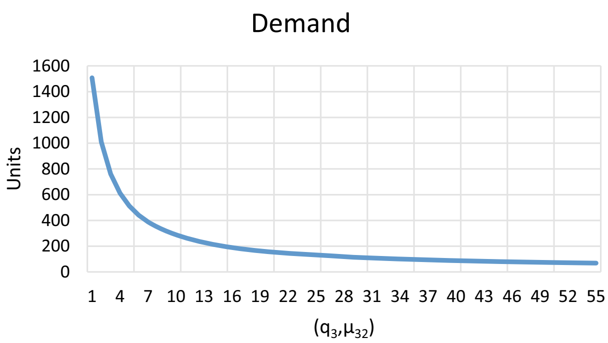
We note that in all cases the demand increases and therefore the food loss decreases. The behaviour of how demand changes are similar to those of the changes in profits. The benefit of IoT deployment has diminishing marginal benefits. i.e., there is a point beyond which additional investments in IoT do not lead to as much food waste reduction as the prior investment. Besides, based on the parameters used, and if only one party will invest in IoT, it should be the retailer as deploying the technology at the retailers can save more food waste as seen in Fig. 1a, b. We can see from Fig. 1a that the demand follows an iso-elastic pattern with respect to the deterioration rate when only the retailer invests in IoT. When only the distributor invests in IoT, we see in Fig. 1b that the demand is an increasing function of the initial quality. However, the demand does not vary significantly as it would if the retailer is the only investor in IoT. The demand increases the most, and so will the



(a) Retailer only.



(b) Distributor only.



(c) Retailer and distributor.

Fig. 1 Impact of IoT deployment on food loss reduction

reduction in food waste, when both the retailer and distributor invest in IoT as shown in Fig. 1c.

6 Conclusions

We have presented models to assess the impact of IoT on coordination and waste reduction in food supply chains. We provided analytical and numerical results. Our analysis reveals that IoT can coordinate the supply chain. We also show how IoT can lead to a reduction in food waste.

We believe that the models we presented in this paper will serve as a good starting point for investigating the impact of IoT on supply chains. As such it is natural that it will have some limitations and there are several ideas for extending our work. First, an extension of the discounting model may include competition where two retailers may invest in IoT and compete on prices and quality. Second, while we have modelled the impact of IoT investment implicitly through the deterioration rate, it will be useful to consider a direct approach where one would develop an investment function and find optimal investment levels. Third, in our model we used a deterministic demand function and it would be worthwhile investigating the impacts of demand uncertainty on the value of investing in IoT technology.

References

Bahroun Z, Ben-Daya M, Hassini E (2020) IoT Quality-controlled demand pricing model in food supply chains. In: Golinska-Dawson P, Tsai KM, Kosacka-Olejnik M (eds) Smart and sustainable supply chain and logistics—trends, challenges, methods and best practices. EcoProduction (Environmental issues in logistics and manufacturing). Springer, Cham. https://doi.org/10.1007/978-3-030-61947-3_26

Ben-Daya M, Hassini E, Bahroun Z (2019) Internet of things and supply chain management: a literature review. Int J Prod Res 57(15–16):4719–4742

Ben-Daya M, Hassini E, Bahroun Z, Banimfreg B (2021) The role of internet of things in food supply chain quality management: a review. Qual Manag J 28(1):17–40

Cicatiello C, Franco S, Pancino B, Blasi E, Falasconi L (2017) The dark side of retail food waste: evidences from in-store data. Resour Conserv Recycl 125:273–281

Chen X, Wu S, Wang X, Li D (2019) Optimal pricing strategy for the perishable food supply chain. Int J Prod Res 57(9):2755–2768

FAO (2012) Labour in FAO statistical yearbook 2012. https://bit.ly/3a1i5HZ

Ivanov D, Tang CS, Dolgui A, Battini D, Das A (2021) Researchers' perspectives on industry 4.0: multi-disciplinary analysis and opportunities for operations management. Int J Prod Res 59(7):2055–2078

Janssen L, Sauer J, Claus T, Nehls U (2018) Development and simulation analysis of a new perishable inventory model with a closing days constraint under non-stationary stochastic demand. Comput Ind Eng 118:9–22

Ma P, Wang H, Shang J (2013) Contract design for two-stage supply chain coordination: integrating manufacturer-quality and retailer-marketing efforts. Int J Prod Econ 146(2):745–755

Mallidis I, Sariannidis N, Vlachos D, Yakavenka V, Aifadopoulou G, Zopounidis K (2020a) Optimal inventory control policies for avoiding food waste. Oper Res 22: 685–701
Mallidis I, Vlachos D, Yakavenka V, Eleni Z (2020b) Development of a single period inventory planning model for perishable product redistribution. Ann Oper Res 294:697–713
Ozbilge A, Hassini E, Parlar M (2021) Donate more to earn more. Submitted for publication, DeGroote School of Business, McMaster University
Taleizadeh AA, Moshtagh MS, Moon I (2018) Pricing, product quality, and collection optimization in a decentralized closed-loop supply chain with different channel structures: game theoretical approach. J Clean Prod 189:406–431
Yavari M, Geraeli M (2019) Heuristic method for robust optimization model for green closed-loop supply chain network design of perishable goods. J Clean Prod 226:282–305

An Agent-Based Approach to Evaluate Freight Consolidation Center Strategy for Last Mile Deliveries in Jaipur City, India

Pankaj Kant and Sanjay Gupta

1 Introduction

The negative impacts of urban goods distribution for social, economic and externalities is an area of key concern in sustainable development of cities. The sustainability of urban goods transport is the key policy objective of various countries (OECD 2003). In recent decades there is a thrust in improving passenger transport in Indian cities but urban freight is still a neglected area in national and local policy discourse. Even the master plan development (MPD) exercise and comprehensive mobility plan (CMP) exercise by local development authorities of Indian cities do not address the critical concerns of urban freight issues and freight stakeholders (MoUD 2014).

Urban freight strategies are often selected without comprehensive information of their potential benefits in transport management plans (T.M.P) (DoT 2012). Sustainable transportation is essential for the overall sustainable development of cities due to its contribution to externalities, economic and social issues (Gudmundsson et al. 2015). Urban freight strategies and key performance indicators are helpful to local policy makers to reduce the negative impacts of urban goods distribution in context of sustainable development objectives (Litman 2019; Patier and Routhier 2008). Replication of freight stakeholders behaviours and attributes are essential and key to sustainability in city logistics domain (Dablanc et al. 2013).

Awareness regarding freight issues and evaluation for freight strategies needs to be addressed among all relevant urban freight stakeholders (Martin et al. 2012). Its tedious and time-consuming task to predict the outcomes of urban freight policies

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including financial implications (Browne and Allen 2011). The effect of urban freight transport can be quantified under various categories, and each category requires a different kind of freight strategy (Lindholm 2010). A research study concluded Seven groups of sustainable policy measures to mitigate the negative impact of urban freight and barriers in implementing freight strategies for the sustainability of urban freight transport (BESTUFS II 2006).

International best practices in sustainable urban freight strategies are available for local policy makers and other urban freight stakeholders (CIVITAS 2015). Divergent objectives of shippers and transporters act as a barrier in the implementation of urban freight strategies (Van Duin et al. 2018). A suitable framework is essential for selecting the freight strategies based on the requirements, behaviour and attributes of freight stakeholders for sustainability in urban freight sector (Sharma et al. 2017).

City logistics is a difficult domain for local policymakers due to of lack information and knowledge about urban freight. Among all available city logistics solutions, Urban Consolidation Centre as a logistics space strategy is an appreciated one (Faure et al. 2016). Urban consolidation centres (U.C.C.s) have a major role in solutions to reduce the impact of urban freight transport (Quak 2014). An urban consolidation centre (U.C.C.) is a logistics space strategy used in the periphery of cities for transshipment, load consolidation and selection of carriers for last-mile delivery (Browne et al. 2005).

The urban freight planning related aspects in the developing country context are not amply researched upon. There is almost negligible literature available on the freight stakeholder behaviour analysis and its relation with urban goods distribution strategies like logistics spaces and consolidation centre strategy in the Indian context.

Inputs from wholesalers, retailers, and transport operators in the modelling framework are missing in policy discourse by local policymakers in Indian cities to arrive at acceptable solutions as city logistics measures.

The next section of research presents a literature review related to consolidation centre strategy in urban goods distribution. Section 3: research methodology. Section 4: case city profile and commodity selection. Section 5: descriptive view of data set. Section 6: model validation. Section 7: Evaluation of urban consolidation centre strategy and Sect. 8 presents the conclusions and policy implications.

2 Literature Review

An urban consolidation centre (U.C.C.) can mitigate several urban freight issues like emissions, congestion, parking, road safety of inner roads and business deliveries. The success of the U.C.C. has several barriers like financial, social, cultural, and legal barriers. The most important related to U.C.C. is unclear business terms and low acceptability among private stakeholders. Acceptability for all freight stakeholders is key to the success of U.C.C. (Elvsaas 2020). The location of U.C.C. has been analyzed by the centre-of-gravity method to optimize freight deliveries in the seaside tourist resorts of the West Pomeranian Region of Poland. The research has applied the interview method for the analysis of the tourist traffic impact on deliveries in the selected area. The research study was concentrated on the aspects of transport issues and organizational assumptions. Two different optimum locations were proposed for summertime and after summertime (Kijewska et al. 2012).

A research study assesses the potential role of clean vehicles in association with U.C.C. to reduce the freight traffic and environmental impact in urban areas of London. A pilot was conducted for stationery and office supplies company to use electric tricycle for deliveries to customers from a micro-consolidation centre located in the delivery area. The results show the reduction in CO_2 emissions per parcel delivery by 14% and 55% respectively as a result of this delivery system. The pilot trial was successful in the context of transport, environmental and financial terms (Leonardi et al. 2012). Challenges and factors affecting the implementation of U.C.C. in Hague have been analyzed for the local municipality. Two factors that affect the implementation of U.C.C. were the allocation of the costs and benefits and the willingness of transport companies to cooperate. The municipality had a major role in bringing the costs and benefits together. The scientific theory could provide more accurate advice to local policymakers, but evaluations of U.C.C.s are often poorly documented (van Duin and Quak 2010).

A UCC is viable under some given conditions like the number of delivery parcels, the approach distance, and so the urban sprawl. The morphology of the city also influences the performance of U.C.C.s. Productivity of U.C.C. shall address fixed costs rather than variable costs. Location of U.C.C. and the number of U.C.C. required is needs to be evaluated before implementation. Finally, it is certainly useful to study the influence of demand and location on the viability of U.C.C (Faure et al. 2016).

Utilizing U.C.C. gives a chance to mitigate the negative effects of freight transport in urban areas. Research analysis of urban consolidation centres development in the Westpomeranian Region of Poland suggests that U.C.C. is a good solution enabling more effective functioning of tourist, recreational, health resort services and improvement in the quality of the services due to reduction in the noise and pollution in the tourist zones. Implementation of a U.C.C. requires adjusting regulations of entrepreneurs, wholesalers and distributors (Chwesiuk et al. 2010).

Results of Binnenstadservice.nl (B.S.S.) U.C.C. show positive results after its first year of service in Nijmegen. Due to the B.S.S. consolidation centre, the number of trucks and number of truck kilometres in the city centre decreased. The effects on inconvenience for residents, traffic safety and shopping environment are promising. The effects on local air quality are limited due to passenger and bus traffic in addition to freight traffic in the city. The fiscal deficit will be there in the second year of operation without local municipality support. The positive results of B.S.S. in Nijmegen give rise to B.S.S. franchise initiatives in other Dutch cities (van Rooijena and Quak 2010).

A framework for the classification of U.C.C. and initiatives was developed based on a survey of already adopted alternatives. The main cause for the inefficiencies of the U.C.C. is the lack of direct consultation between carriers and receivers in urban areas. Urban consolidation was never treated as a stand-alone concept. Finally, there is a need for the classification of consolidation-oriented measures and initiatives like physical and behavioural concepts (Verlindea et al. 2012).

The results of the U.C.C. of Belo Horizonte city show a significant improvement to all actors involved in the process, such as society, carriers and retailers. There was a reduction in the number of vehicles and a reduction of pollutant emission in the urban environment. In addition, the adoption of green vehicles can further improve environmental parameters (de Assis Correia et al. 2012). Research results from Sweden and Scotland suggest that freight policies in conjunction with stakeholders collaboration are key to support public-led urban consolidation centre (U.C.C.) developments. The key finding reveals that urban freight policies such as time window restrictions can support successful U.C.C.s; they cannot be considered in isolation by the local authority. A successful development of U.C.C. also requires a commitment to financially support for the medium-term (Zehra Akgün et al. 2019).

An agent-based simulation (ABMS) framework with receivers and carriers was applied to the city of Copenhagen for sustainable business models and the supporting role of administrative policies for the feasibility of U.C.C. Research results show that environmental improvement may be achieved through the use of a U.C.C. by reduction of trucks in urban areas by up to 60% and reducing emissions by about 70%. However, it is challenging to find schemes that are also financially sustainable. There is a need for committing carriers to use the U.C.C. for its success. The success of the U.C.C. is not possible without supporting measures and temporary subsidies to the carriers (van Heeswijk et al. 2019).

An agent-based modelling framework was developed for multiple stakeholders for the city logistics measure (U.C.C.). The model integrates multiple stakeholders, which can be used to analyze the city logistics solutions measures satisfying domain stakeholders. The modelling framework used a semantic model (ontology) and its validation by the participatory simulation game. The model uses city logistics ontology as a fundamental building block with events and additional behavioural attributes to capture real-world behaviour (Anand et al. 2019).

The literature review suggests that there is insignificant research on the application of agent-based modelling and simulation in the decision-making process of different stakeholders in a developing environment like India. Moreover, no attempt has been reported in demonstrating the use of ABMS for evaluating urban consolidation centre strategy in India. The present study provides the much-needed insight into the freight stakeholder behaviour towards scientifically arriving at sustainable urban goods distribution strategies like consolidation centre strategy using an agent-based modelling system (ABMS) modelling approach in a developing environment of India with the case city of Jaipur.

3 Methodology and Data Collection

3.1 Research Methodology

The basic fundamental block of ABMS is the state action charts of its agents (stakeholders). The stakeholder's interaction model uses agent-based modelling and simulation (ABMS) framework to evaluate the consolidation centre strategy in the case city with the help of KPIs. The proposed ABMS modelling framework for agents interaction is shown in Fig. 1. The consolidation centre strategy is tested once the ABMS model is calibrated and validated. The primary agents for this research study are administrators, wholesalers, retailers, carriers and loader/unloaders.

The proposed framework has two types of movement involved, one is the flow of information, and the other is the flow of actual goods movement. The information flow and sequence are depicted by the solid line, and the sequence of goods movement is shown by the dotted line in the proposed ABMS framework. The retailers place the weekly orders to the wholesaler via the message/call function. Wholesaler process the order received from retailer and call/message to transport carrier available at the parking area in the near vicinity of wholesaler. A carrier moves to the godown of the respective wholesaler after receiving the message from the wholesaler. Loaders start loading the carrier once it reaches godown. After loading, the carrier moves to the respective retailer in the city. Unloading of goods starts once the carrier is reached to the retailer. The carrier again moves back to the initial parking lot after the goods are delivered to the retailer and wait for his next consignment from the wholesaler. Transport carriers use the shortest routes option for route selection in delivering goods from wholesalers to retailers in existing time window scenarios

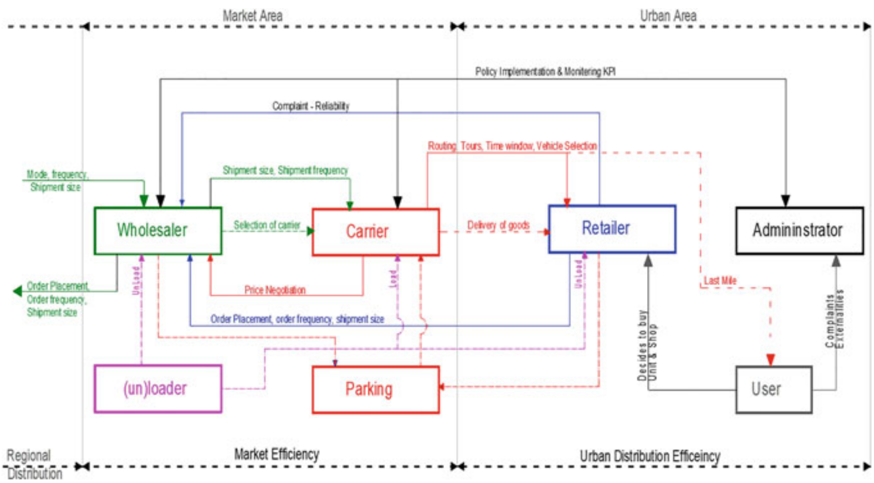


Fig. 1 Conceptual ABMS modelling framework for agents (*Source* Author)

Table 1 State action transition and functions for agents

Agents	State	Transition type or triggered by	Function
Retailers	Frequency of ordering goods (weekly)	Rate	Uniform
	Receiving goods	Message/call	
	Working hours (10 a.m.–9 p.m.) Monday to Saturday	Time out	Boolean
Wholesalers (distributor)	Shipping goods as per received orders	Message/call	Function of retailer orders
	Working hours (10 a.m.–6 p.m.) Monday to Saturday	Timeout	Boolean
Trucks/carriers	Got order from distributer	Msg. from the wholesaler	
	Loading (Hours)	Rate	Triangular
	Going to client (retailer)	Agent arrival	MSG/call
	Unloading	Rate	Triangular
	Going back to distributor	Agent arrival	M.S.G./call
	Route restriction (6 p.m.–8 p.m.)	Time out	

Source Author

and restrictions implemented in case-city by local administrators. The parking lot for the transport carrier and warehouses are situated in the wholesale market areas across commodities. The behaviour and interaction rules of identified agents for this research study are shown in Table 1.

Modelling assumptions adopted in the proposed ABMS research framework are the following.

- Capacitated vehicle routing problem with a time window (CVRPTW) is assumed for this research framework.
- All freight vehicles are initially assumed to be located at wholesale markets.
- The location of retailers for both wholesale markets is assumed to be located at the centroid of residential zones (total 92 zones) as per the comprehensive mobility plan of the case city. Model results for (92) retailers are expanded for the full population of building hardware and electronics goods retailers in Jaipur city.
- Tour routing and planning by transport carriers are not considered in the modelling.
- The model only captures the urban goods distribution from wholesalers to retailers as last-mile delivery.
- The ABMS model only simulates the transport model, not the total logistics cost model.

- The simulation time for the ABMS model is 90 days (12 weeks). Unit time setting for simulation experiment is per day.
- The ABMS model was validated by G.E.H. statistics with model counts and counts observed from cordon points traffic volume around the wholesale market.

AnyLogic 8.4 java-based student version software is used for ABMS modelling.

3.2 Data Collection

The primary establishment surveys were conducted in the case wholesale markets and retailer's premises. Face to face pen and pencil survey method was used for the establishment surveys to collect the information from wholesalers, retailers and origin-destinations surveys from transport operators. Manual traffic count of freight vehicles was conducted at market cordon points of wholesale markets to capture the total flow of incoming and outgoing goods vehicles. Transport carrier surveys were conducted in the wholesale market during the loading of goods, and transport operators survey at their offices in transport Nagar in Jaipur city. Table 2 shows the sample size collected by various sampling methods for this research study.

4 Case City Profile and Consolidation Space Selection

Jaipur city which is the capital city of the Rajasthan state in India is famous for its tourist attraction, stone work, textile, jewellery and its local architecture. Jaipur is also known as pink city in India. Jaipur city is well connected with rest of Indian Cities with road, rail and air transport. The total population of Jaipur city is 31 million (yr. 2011) and its total area is 2940 km^2. The primary land use of the Jaipur city is residential (45%). The commercial land use constitutes 6.7% and circulation is 16%. (Anand et al. 2016). There are around 12 wholesale markets in the Jaipur city involved in intra-city and inter-city goods distribution. Some of these of wholesale

Table 2 Data collection

	Establishment survey (wholesalers)	Establishment survey (retailers)	Truck driver survey
Sampling method	Stratified	Systematic	Stratified
Confidence level (%)	95	98	98
Population size	510	5100	Unknown
Sample size required	109	189	392
Sample size collected	110	200	550

Source Primary survey

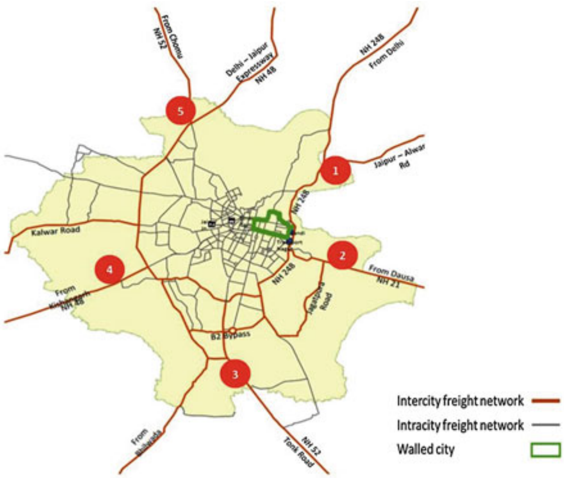
markets are situated in walled city of the city like textiles, furniture, iron market, food grain, chemical markets and electronics markets. Dairy and meat products and vegetable wholesale market on the periphery of Jaipur city. Building hardware & timber market is situated centre of city near Gopalpura bypass and stone market at Ajmer bypass. Fertilizer and chemical market is situated at Durgapura area in Jaipur city (Anand et al. 2016).

Building Hardware market (BH) and Electronics market (EM) were selected for the evaluation of freight consolidation centre strategy in Jaipur city. Goods distribution in the building hardware market is weigh based, whereas it is number and item-based in the Electronics market. Electronics market is situated in old city area and there is no scope of expansion for wholesalers due to rising demand in case city. Building hardware market is developed by local development authority to cater the need of construction industries in fast developing of Jaipur city and satellite towns.

Five consolidation spaces are identified for the relocation of the building hardware (Aatish) market (B.H.) and electronics (Jayanti) market (E.M.) as recommended by the comprehensive mobility plan of Jaipur city (Jaipur Development Authority 2019). Figure 2 shows the location of the new consolidation centre for wholesale market relocation. All these new locations are on the periphery of the city along with incoming highways in Jaipur city. These new locations are tested for the relocation of wholesale markets without changing the retailer's location in ABMS modelling framework for Jaipur city.

Five major highways connect Jaipur city for receiving goods by wholesalers from respective manufacturers. Kukas (1) area is located on the periphery of Jaipur city connected to Delhi city by national highway (NH) 48. Similarly, Kanuata (2) is located on NH 21 connected to Agra city, Chaksu (3) on NH 52 connected to Kota city, SEZ (4) on NH48 connected to Ahemdabad city and Harmada (5) on NH48/NH21 connected to Bikaner city at the periphery of Jaipur city.

Fig. 2 Location of consolidation centres



5 Descriptive Statistics of Data Set

Descriptive statistics of wholesalers attributes is shown in Table 3. The mean value of the shop area in the electronics market is higher than the building hardware market. Employment per 100 m^2 in the electronics market is higher than the building hardware market. Total tonnage handled, including incoming and outgoing tonnage per 100 m^2 in the building hardware market, is almost double of the electronics market. Total tonnage trips frequency, including incoming and outgoing trips per 100 m^2 in the building hardware market, is marginally lesser than the electronics market. Incoming freight trips in the building hardware market are almost double the electronics market. Outgoing trips in the electronics market are higher than building hardware market.

Descriptive statistics for retailers of building hardware and electronics goods retailers are presented in Table 4. The median value of employment is two people in most of the retail shops in the building hardware market, similar to electronics market retailers. The number of trips attracted (incoming trips frequency) to building hardware retailers has almost half compared to electronics goods retailers. The weekly tonnage attracted to building hardware retailers is much higher than the electronics goods retailers.

Descriptive statistics of transport operator attributes are shown in Table 5. There is a significant difference in haulage time in the case of L.C.V. and 4w commercial vehicles mode in both markets, suggesting a significant difference in distribution leads. Loading time is slightly higher than unloading for all modes in both markets. Idle time is almost similar in both markets for 3 W and 4 W, whereas, in the case of L.C.V., idle time is higher in the building hardware market compared to the electronics market. There is no significant difference in loading unloading cost in both markets for respective freight modes.

Table 3 Descriptive statistics of wholesalers

Indicators	Unit	Electronics market			Building H. market		
		Mean	Median	SD	Mean	Median	SD
Shop area	m^2	140.2	149.5	67.7	89.1	80	62.5
Employment	100/m^2	5	4	2.1	3.1	3	1.5
Incoming frequency	Weekly	4.1	4	1.4	9	9	2.7
Incoming tonnage	Weekly	14.1	15	3.04	27.6	23	15.5
Outgoing trips frequency	Weekly	22.1	23	4.1	14.9	15	3.2
Outgoing tonnage	Weekly	11.8	12	2.04	24.8	20	13.8
Average nos. of retailers	Per wholesaler	5.5			8.8		

Source Author

Table 4 Descriptive statistics of retailers

Indicators	Unit	Electronics			Building hardware		
		Mean	Median	SD	Mean	Median	SD
Shop area	m^2	77.19	70	59.7	94.5	83.6	66
Employment	$100/m^2$	2.85	2	1.64	3.07	2	1.9
Incoming trips	Trips/week	4.16	4	1.51	2.48	2	1.3
Incoming tonnage	Tons/week	5.22	5	3.42	8.99	7.5	2.8

Source Author

Table 5 Descriptive statistics of transport operators

Mode	Commodity	Haulage time (Hr)		Loading time (Hr)		Unloading time (Hr)		Idle time (Hr)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
3W	EM	0.7	0.2	0.3	0.05	0.27	0.06	0.95	0.15
	BH	0.7	0.4	0.6	0.20	0.51	0.07	0.9	0.17
4W	EM	0.7	0.2	0.4	0.08	0.34	0.09	1.15	0.16
	BH	0.8	0.3	0.6	0.17	0.49	0.15	1.13	0.20
LCV	EM	0.9	0.4	0.7	0.07	0.66	0.07	1.4	0.14
	BH	1.4	0.6	0.7	0.12	0.69	0.09	1.85	0.22

Source Authorb

5.1 *Cordon Point Traffic Volume Counts (T.V.C.)*

Traffic volume counts of motorized freight vehicles were observed at the cordon point of the building hardware market for nine hours. A total of 1256 freight vehicles were observed, out of which there were 313 3w commercial vehicles, 388 4w commercial vehicles, and 555 LCV, respectively observed in the T.V.C. survey. In the case of the electronics market, a total of 1030 freight vehicles are observed in the case of the building hardware goods distribution. There were 345 (3w) commercial vehicles, 362 (4w) commercial vehicles, and 323 LCV observed in the T.V.C. survey.

6 ABMS Model Validation Results

Table 6 shows the ABMS modelling and validation results for electronics and building hardware goods distribution in Jaipur city. A total of 1318 freight trips for all retailers were predicted by the ABMS model in Jaipur city. Total 1256 freight trips counts are observed from the cordon survey of building hardware wholesale market by commercial vehicles (3w, 4w and L.C.V.). In electronics goods distribution, the ABMS model predicts 940 freight trips for all retailers in Jaipur city. There is a

Table 6 ABMS model results and validation

	Building hardware	Electronics
Trips/Deliveries	Counts	Counts
Nos. of deliveries/day extrapolated for all retailers (M)	1318	940
Trips counts/day from the primary survey (C)	1256	1030
Trips variation (%)	4.9	−8.7
GEH	2.4	4.5

Source Author

variation of 4.9% from modal count (M) and observed count (C) in building hardware distribution. The model is over predicting the total freight deliveries by 4.9%. In the case of electronics goods distribution, there is a variation of -8.7%, and the model is under predicting the total freight deliveries by -8.7%. The G.E.H. statistic for model validation has a value of 2.4 in the case of building hardware distribution and 4.5 in electronics goods distribution. G.E.H. value less than 5 is acceptable for validation.

7 Evaluation of Consolidation Centre Locations

Table 7 shows the impact of new consolidation centres (strategy) with business as usual (B.A.U.) scenario evaluated for building hardware (B.H.) and electronics goods (E.M.) distribution in the case city. In the case of building hardware goods distribution, the *Kanauta* location is best suitable in terms of total V.K.T., which has observed a 34% increase in V.K.T. compared to the B.A.U. scenario and *Chaksu* is the least preferable location where only an 8% increase in V.K.T. has been observed. *Kanuata* is the best preferable location, followed by *Kukus* location for building hardware distribution for wholesalers due to increased business deliveries. It is also preferable for transport operators due increase in travel time and fleet efficiency to maximize their profit. An increase in V.K.T. for the *Kanuata* location will have a positive impact on emissions which is not desirable from an emission point of view. *Chaksu* location is most preferred in case emission is concerned for local policymakers due to minimum V.K.T. by transporters involved in building hardware distribution.

In the case of electronics goods distribution, it can be observed *Kukas followed by Chaksu* are the best preferable locations for t for transport operators to maximize their efficiency. In the case of building hardware, distribution transport operators can maximize the economic efficiency by an increase in V.K.T. and fleet usage, but wholesalers have a reduction in the number of business deliveries compared to the B.A.U. scenario and all five locations are not desirable locations for wholesalers of electronics goods distribution. Exiting location of wholesalers in Jaipur city is more desirable for wholesalers compared to new locations in Jaipur city. Chaksu (3)

Table 7 Impact of logistics space strategy on urban goods distribution (KPI per week)

Location	Commodity	VKT	% Chg (%)	TKT	% Chg (%)	T.T. (Hrs)	% Chg (%)	DLV (nos)	% Chg (%)	Fleet usage (%)	% Chg (%)
Atish Mkt	BAU (BH)	1737		4623		58		607		58	
Jayanti Mkt	BAU (EM)	1134		1343		57		439		49	
Kukas	BH	2268	31	3221	31	76	30	727	20	70	12
Kanauta	BH	2334	34	3314	35	77	33	740	22	72	14
Chaksu	BH	1878	8	2667	8	62	8	715	18	61	3
Sez	BH	2178	25	3093	26	73	25	721	19	68	10
Nh52/48	BH	2208	27	3135	27	74	27	718	18	68	10
Kukas	EM	1464	29	1734	29	73	28	408	−7	60	11
Kanauta	EM	1266	9	1500	12	64	12	403	−5	53	4
Chaksu	EM	1446	25	1620	21	68	20	412	−4	57	8
Sez	EM	1446	22	1710	27	72	26	407	−4	60	11
Nh52/21	EM	1200	5	1422	6	60	5	401	−5	51	2%

Source Author

location is best suited for wholesalers for maximum business deliveries. *NH52/48(5) location* is best suited if emissions are the priority of policy planners due to the least V.K.T. by freight carriers. The study results confirm a trade-off between stakeholders financial benefits and externalities associated with freight transport. It can also be observed from the results that a location for consolidation centres strategy has a different impact on key performance indicators across commodity distribution.

8 Conclusion

Urban freight strategies are vital decisions in the sustainability of urban goods distribution. This paper investigated the impacts of consolidation centre strategy on freight stakeholders involved in urban goods distribution across two commodities in Jaipur city. The impacts of consolidation centre space strategy are evaluated in the ABMS modelling framework with the help of key performance indicators of urban goods distribution.

The research results indicate that consolidation centre space strategy impacts vary across commodity distribution in urban areas and a single location for multiple commodities is not desirable across commodity distribution for heterogeneous freight stakeholders. Research results also show that there is a trade-off between the economic efficiency of urban freight stakeholders and externalities associated with freight transport in the selection of the location of consolidation centre spaces. Proposed research study framework can be extended for other urban commodities to develop the prepare freight mobility plan to assess the impacts on urban freight stakeholders. Due diligence is required in the evaluation of the location for consolidation centre space strategy according to the commodity or group of commodities in the master planning exercise in the context of Indian cities.

Wide spectrum of commodities for the evaluation of the consolidation centre spaces in urban areas needs to be evaluated in case of Indian cities. The logistics cost model needs to be integrated into the modelling framework for the evaluation of monetary impacts on freight stakeholders. A joint model for shipment size and mode choice could be explored in the ABMS modelling framework for the evaluation of freight strategies.

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References

Anand N, Van Duin R, Tavasszy L (2016) Framework for modelling multi-stakeholder city logistics domain using the agent-based modelling approach. Transp Res Proc 16:4–15

BESTUFS II (2006) Best urban freight solutions II. Retrieved March 21, 2018, from http://www.bestufs.net/download/BESTUFS_II/key_issuesII/BESTUFS_II_results_datacollection/BESTUFS_II_data_collection_synthesis_report.pdf

Browne M, Sweet M, Woodburn AG, Allen J (2005) Urban freight consolidation centres. University of Westminster, London

Browne M, Allen J (2011) Enhancing the sustainability of urban freight transport and logistics. Transp Commun Bull Asia Pac 80:80

CIVITAS (2015) civitas.eu. Retrieved 06 12, 2019, from 'Making urban freight logistics more sustainable', Civitas Policy Note, pp 1–63. http://www.eltis.org/resources/tools/civitas-policy-note-making-urban-freight-logistics-more-sustainable

Chwesiuk K, Kijewska K, Iwan S (2010) Urban consolidation centres for medium-size touristic cities in the Westpomeranian Region of Poland. Proc Soc Behav Sci 2:6264–6273

Comprehensive mobility plan Jaipur. Retrieved July 15, 2019, from http://transport.rajasthan.gov.in

Dablanc L, Giuliano G, Holliday K, O'Brien T (2013) Best practices in urban freight management: lessons from an international survey. TRB, Transp Res Rec (T.R.R.) 29–38

de Assis Correia V, de Oliveira LK, Guerra AL (2012) Economic and environmental analysis of an urban consolidation centre for Belo Horizonte city (Brazil). Proc Soc Behav Sci 39:770–782

Elvsaas M (2020) https://www.ntnu.edu/. Retrieved from https://www.ntnu.edu/documents/341714296/0/Nordt%C3%B8mme+presentation/146f1d52-27a0-4991-83dc-6db1482e65df

Faure L, Burlat P, Marquès G (2016). Evaluate the viability of urban consolidation centre with regards to urban morphology. Trans Res Proc 12:348–356

Gudmundsson H, Hall RP, Marsden G, Zietsman J (2015) Sustainable transportation—indicators, frameworks, and performance management. Samfundslitteratur, Frederiksberg

Jaipur development authority. Retrieved May 13, 2019, from http://jda.urban.rajasthan.gov.in/

Kijewska K, Iwan S, Kaczmarczyk T (2012). Technical and organizational assumptions of applying U.C.C.s to optimize freight deliveries in the seaside tourist resorts of the West Pomeranian Region of Poland. Proc Soc Behav Sci 39:592–606

Leonardi J, Browne M, Allen J (2012) Before-after assessment of a logistics trial with clean urban freight vehicles: a case study in London. Soc Behav Sci 39:146–147

Lindholm M (2010) A sustainable perspective on urban freight transport: factors affecting local authorities in the planning procedures. Proc Soc Behav Sci 2:6205–6216

Litman T (2019) developing indicators for sustainable and livable transport planning. Retrieved May 9, 2019, from www.vtpi.org/wellmeas.pdf

Martin R, Hegi P, Haefeli U, Matti D, Schultz B, Rütsche P (2012) Sustainable goods supply and transport in conurbations: freight strategies and guidelines. Proc Soc Behav Sci 39:116–133

MoUD (2014) https://smartnet.niua.org/. Retrieved March 2018, from https://smartnet.niua.org/sites/default/files/resources/National%20Urban%20Transport%20Policy.pdf

OECD (2003) Delivering the goods: 21St century challenges to urban goods transport. Retrieved April 12, 2019, from https://www.itf-oecd.org/sites/default/files/docs/03deliveringgoods.pdf

Patier D, Routhier J-L (2008) Hoe to improve the capacity of urban goods movement data. In: Annecy: 8th international conference on survey methods in transport

Quak H (2014) https://www.researchgate.net. Retrieved from https://www.researchgate.net/publication/254805169_Sustainability_of_Urban_Freight_Transport_Retail_Distribution_and_Local_Regulations_in_Cities

Sharma S, Shelton J, Warner V (2017) Methodologies and models for selection of optimal truck freight management strategies. In: Transportation research board (TRB)

U.S. DoT (2012) Assessing the effectiveness of transportation management plan (T.M.P.) strategies. Federal Highway Administration, Washington, DC 20590 van Duin JHR, Quak H (2010) New challenges for urban consolidation centres: a case study in The Hague. Proc Soc Behav Sci 2:6177–6188

Van Duin R, Slabbekoorn M, Tavasszy LA, Quak H (2018). Identifying Dominant Stakeholder Perspectives On Urban Freight Policies: A Q-Analysis On Urban Consolidation Centres In The Netherlands. Transport, 33(4), 867-880

van Heeswijk W, Larsen R, Larsen A (2019). An urban consolidation centre in the city of Copenhagen: a simulation study. Int J Sustain Transp 13(9):675–691

van Rooijena T, Quak H (2010) Local impacts of a new urban consolidation centre—the case of Binnenstadservice.nl. Proc Soc Behav Sci 2:5967–5979

Verlindea S, Macharis C, Witlox F (2012). How to consolidate urban flows of goods without setting up an urban consolidation centre? Proc Soc Behav Sci 39:687–701

Zehra Akgün E, Monios J, Fonzone A (2019) Supporting urban consolidation centres with urban freight transport policies: a comparative study of Scotland and Sweden. Int J Logistics Res Appl 2–21

A Proposed Framework for Designing Blockchain Solutions for Logistics in post-Covid Scenario and Future Pandemics

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1 Introduction

Logistics companies, that are participating in the distribution, storage, and movement of goods, have been widely affected by the Covid-19 pandemic and it is also exposed that traditional logistics is not adaptable, agile, and resilient enough to manage a pandemic or another widespread disaster. During the Covid-19 pandemic, it is essential for all countries to save human lives. Unfortunately, many countries are unable to provide a smooth supply of essential items such as food, medical diagnostics equipment, and medicine (Han et al. 2021; Singh et al. 2021a, b; Thompson & Anderson 2021). The reason for this problem is the traditional logistics systems. Because the traditional logistics system is highly reliable on the human interaction and the use of the latest technology is limited (Cigolini et al. 2004; Dunn 1995; Fleischmann et al. 2000). Moreover, logistics companies are facing many challenges in logistics activities such as transparency, traceability, visibility, immutability, auditing, trust (Dutta et al. 2020; Litke et al. 2019; Rejeb et al. 2020). These issues can be resolved by using emerging technologies such as blockchain, the internet of things (IoT), artificial intelligence, cloud computing, and machine learning by transforming traditional logistics into digital or smart logistics (Ahmad et al. 2021; Chen and Ho, 2021; Su,

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2012; Wang and Sarkis 2021). Digital logistics infrastructure is required to improve the firm's logistics performance (Kersten et al. 2017). Blockchain technology is one of the most effective proposals for digital logistics networks because this technology has distinctive features; transparency, traceability, cybersecurity, real-time information sharing, and visibility which are highly crucial for the future of logistics (Aslam et al. 2021). This study is providing the initial framework for convergence of logistics with the help of blockchain technology. In doing so, this study highlights the major issues in traditional logistics and identifies the need for digital logistics. This study guides the logistics companies to understand the relationship between digital logistics and Blockchain technology as a solution for handling these pre-and-post-pandemic challenges and the future of logistics management.

For the remainder of the study, we distributed our study into three parts. Firstly, this study criticizes traditional logistics and its weaknesses. Secondly, describes smart logistics and highlights its advantages. Thirdly, this study develops the relationship between smart logistics and Blockchain technology as a solution for improving logistics performance. This paper is designed as per the following sections: Sect. 2 is based on a brief literature review and Sect. 3 explained the proposed framework. The discussion is expressed in Sect. 4. Section 5 is devoted to the conclusion, implication, and future recommendation.

2 Literature Review

2.1 Logistics Activities During Pandemic Covid-19

To prevent the spread of covid-19 few policies such as work-from-home, lockdowns, and social distancing are being used globally. Due to the implementation of safety protocols like lockdowns, and border closures, the logistics activities are mostly suspended. The operational efficiency was affected and it lead to the shortage of supply, delivery delays, and higher freight rates (Farooq et al. 2021). Moreover, the Covid-19 has hit the logistics businesses very hard as firms were not familiar with backup operations plans, many firms also lack the technology and had no proper information to follow the health guidelines e.g., disinfecting deliveries. Apart from this, logistics firms have contributed very well during Covid-19 and will be an important part of the economic recovery, however, need to upgrade the way logistics operations work, to handle the post-pandemic scenario and any similar problem in the future.

2.2 *Traditional Versus Digital Logistics Networks*

Logistics management is a key attribute of the supply chain management process, and it deals with the flow of products, information, and capital at the same time. The fundamental aim of logistics management is to deliver the right amount of material/product at the right time and right place (Ghoumrassi and Țigu 2017). Traditional logistics network is based on less integrated systems e.g., manually data input, lack of upgraded IT system, paper-based documents, and using follow up calls to track the delivery status, less agile and responsive, and poor flexibility, thus, these methods are less effective and efficient (Mears-Young and Jackson 1997; Ouyang et al. 2019; Zielske and Held 2021). Therefore, logistics organizations need to reform their functions for becoming highly integrated with providing better services in today's era, where the emerging technologies provide the main platform for the digital infrastructure for logistics companies (Oluyisola et al. 2021). The adoption of these technologies into logistics enhances the integration transform the logistics to agile and resilient this phenomenon lead to the emergence of a new concept called "digital logistics" or "smart logistics"(Burroughs and Burroughs 2020; Hofmann and Osterwalder 2017; Issaoui et al. 2021). Digital logistics provide smart tools and methods such as cloud-based data computing systems, end-to-end visibility, and traceability for planning and controlling logistics operations (Barykin et al. 2021; Issaoui et al. 2019; Moldabekova et al. 2021; Sergi et al. 2021). Digital logistics focus on more integrated techniques, and it allows the firms to adopt vertical integration (integrated with numinous IT systems inside the organization); horizontal integration (collaboration with inter-department), and end-to-end engineering integration (collaboration among product, machines, and stakeholders) (Bag et al. 2020). In the broader perspective, the investment of technology will allow the firm to reduced third-party logistics (3PL) services and labor costs using autonomous vehicles, drones, and robotic (Strandhagen et al. 2017).

2.3 *Blockchain for Logistics*

Logistics has been amidst a tech-driven revolution. In recently, logistics 4.0 widely discussed supply chain and logistics management. Logistics 4.0 is the combination of emerging technologies used to optimize logistics processes. These emerging technologies are based on the inclusion of artificial intelligence, machine learning, the internet of things (IoT), cloud computing, big data analytics, blockchain, and additive manufacturing or 3D printing (Koh et al. 2019; Qu et al. 2019; Singh et al. 2021a, b). Being an emerging technology, the Blockchain provides a decentralized platform for storing and transmitting information securely and more transparently. Due to the involvement of multiple activities such as various delivery points, inventory planning, delivery tracking, visibility of materials, and high level of data sharing are the major challenges for logistics companies (Chen et al. 2021). To cope with these challenges, blockchain has effective features to support the logistics operations such as cyber-security, real-time information system, reliability, transparency, visibility, and traceability or trackability (Aslam et al. 2021; Behnke and Janssen 2020; Cole et al. 2019; Helo and Hao 2019; Phadnis 2018). These Blockchain features help to reduce the leads time, improve Inter-Intra firm privacy, secure the financial/transaction information, improve the forecasting, better control on inventory, and effective utilization of firm resources (Hellani et al. 2021). Literature proposed serval theories allow the implementation of Blockchain technology into the supply chain and logistics management. These theories are the resource-based view (RBV), principal-agent theory (PAT), network theory (NT), and transaction-cost theory, also called transaction-cost analysis (TCA) (Treiblmaier 2018). Traditional logistics operations are fully connected via human physical interaction, and the covid-19 pandemic is not allowed this business style due to prevent the spread of the pandemic by implementing safety regulations like social distance and lockdowns. In the absence of technology, the logistics firms have no electronic visibility, traceability, and trackability of inventory as well as in-transit materials and it's created the biggest problem for logistics firms as well as many businesses due to unavailability of product information. Therefore, the logistics firm needs to upgrade its business structure and adopt the technology which is beneficial for the firm to uplift the logistics activities. Among other emerging technologies, blockchain is closely related to upgrading the logistics and supply chain operation because this technology application is its interface with the physical world. Additionally, it provides significant potential for improving information and communication at all levels of the logistics network.

3 Proposed Framework

In this study, we highlighted the major problem in traditional logistics networks, and these are negatively affecting the firm performance and market reputation. For the solution to these problems, we proposed the adoption of emerging technologies into logistics and update into a new domain as digital logistics. The literature suggests that the blockchain is one of the most effective and efficient technology for digital logistics because this technology has state-of-the-art features which are highly synchronized with logistics needs. Figure 1 expressed the transformation from traditional to digital logistics networks.

4 Discussion

Logistics is the main pillar of supply chain management, and the particular importance of logistics was realized during the recent covid-19 pandemic where delivery and the supply of many essential products were either cut or delayed. Traditional logistics have many problems which are expressed in Fig. 1. This paper proposed the

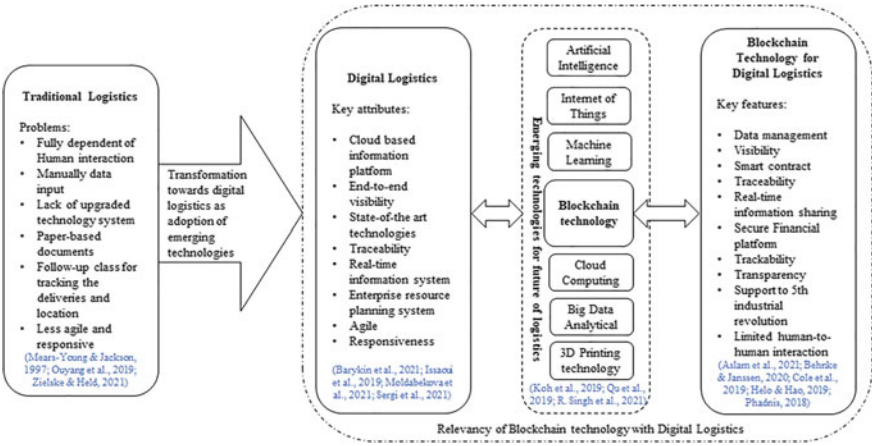

Fig. 1 Framework for transformation towards digital logistics using Blockchain

framework for the transformation towards digital logistics as adoption of emerging technologies. The reason behind this transformation is that digital logistics have an important attribute that is highly needed for 21st-century logistics and will be required for post-covid to recover the economy. This study provided a relationship among emerging technologies with digital logistics from literature. The adoption of all these emerging technologies is quite difficult because this concept for prior practices may be costly. This study proposed Blockchain technology for this adoption because this technology has serval key features such as traceability, trackability, real-time information sharing, secure financial platform, and transparency which are highly recommended for logistics networks. From the pandemic perspective, blockchain technology is the best solution for performed logistics activity with limited human-to-human interaction because blockchain provides a state-of-the-art technology structure for track and trace the inventory in few electronic clicks. On the other hand, blockchain has some advantages among other emerging technologies such as it provides the best security platform to support the next industrial revolution which is known as industry 5.0. Blockchain is also a useful security tool for the adoption of the Internet of things (IoT). Furthermore, the implementation of blockchain will provide generate a lot of data that can be used to re-design the warehouse and optimization the delivery choosing the best route for transportation.

5 Conclusion

This paper provides very interesting findings, firstly, this study provides the actual picture of where traditional logistics stand and highlighted its main problems. Secondly, this study develops the relevancy among emerging technologies and digital logistics and suggests that digital logistics is the solution to the pandemic and future challenges of logistics. Thirdly, among the serval emerging technology, this study recommends that the blockchain is the most relevant technology for digital logistics because blockchain has unique features which are highly recommended for digital logistics networks. Consequently, Blockchain technology is an important factor for the 5th industrial revolution or Industry 5.0 due to it provides highly secure information networks and supports the implementation of IoT. Moreover, this study also expressed that how traditional logistics are not suitable for pandemics and this study guides managers of logistics companies to understand the weakness of traditional logistics and the use of Blockchain to modernize the firm logistics function. This study guides the logistics companies to understand the relationship between digital logistics and Blockchain technology as a solution for handling this type of pandemic. It is very difficult to adopt all the latest emerging technologies of small and medium enterprises (SME's) as well as giants because it is very costly but due to the need for future of logistics firms should be evaluated their technology need and alliance with these technologies. The main limitation of this study is based on the literature only and could not be explained empirically. The real-time implementation of Blockchain technology for logistics can open a new horizon of research for handling the post-pandemic and future challenges of logistics networks.

References

Ahmad RW, Hasan H, Jayaraman R, Salah K, Omar M (2021) Blockchain applications and architectures for port operations and logistics management. In: Research in transportation business and management. https://doi.org/10.1016/j.rtbm.2021.100620

Aslam J, Saleem A, Khan NT, Kim YB (2021) Factors influencing blockchain adoption in supply chain management practices: a study based on the oil industry. J Innov Knowl 6(2):124–134. https://doi.org/10.1016/j.jik.2021.01.002

Bag S, Gupta S, Luo Z (2020) Examining the role of logistics 4.0 enabled dynamic capabilities on firm performance. Int J Logistics Manage 31(3):607–628. https://doi.org/10.1108/IJLM-11-2019-0311

Barykin SY, Kapustina IV, Kalinina OV, Dubolazov VA, Esquivel CAN, Alyarovna NE, Sharapaev P (2021) The sharing economy and digital logistics in retail chains: opportunities and threats. Acad Strateg Manag J 20(SpecialIssue2):1–14

Behnke K, Janssen MFWHA. (2020). Boundary conditions for traceability in food supply chains using blockchain technology. Int J Inf Manage 52(2019):101969. https://doi.org/10.1016/j.ijinfomgt.2019.05.025

Burroughs B, Burroughs WJ (2020) Digital logistics: enchantment in distribution channels. Technol Soc 62. https://doi.org/10.1016/j.techsoc.2020.101277

Chen M-C, Ho PH (2021) Exploring technology opportunities and evolution of IoT-related logistics services with text mining. Complex Intell Syst 0123456789. https://doi.org/10.1007/s40747-021-00453-3

Chen CL, Deng YY, Weng W, Zhou M, Sun H (2021) A blockchain-based intelligent anti-switch package in tracing logistics system. J Supercomput 77(7). https://doi.org/10.1007/s11227-020-03558-7

Cigolini R, Cozzi M, Perona M (2004) A new framework for supply chain management: conceptual model and empirical test. Int J Oper Prod Manag 24(1–2):7–41. https://doi.org/10.1108/01443570410510979
Cole R, Stevenson M, Aitken J (2019) Blockchain technology: implications for operations and supply chain management. Supply Chain Manag 24(4):469–483. https://doi.org/10.1108/SCM-09-2018-0309
Dunn SC (1995) Environmentally responsible logistics systems. Int J Phys Distrib Logist Manag 25(2):20–38. https://doi.org/10.1108/09600039510083925
Dutta P, Choi TM, Somani S, Butala R (2020) Blockchain technology in supply chain operations: applications, challenges and research opportunities. Transp Res Part E Logist Transp Rev 142(September):102067. https://doi.org/10.1016/j.tre.2020.102067
Farooq MU, Hussain A, Masood T, Habib MS (2021) Supply chain operations management in pandemics: a state-of-the-art review inspired by covid-19. Sustainability (Switzerland) 13(5):1–33. https://doi.org/10.3390/su13052504
Fleischmann M, Krikke HR, Dekker R, Flapper SDP (2000) A characterisation of logistics networks for product recovery. Omega 28(6):653–666. https://doi.org/10.1016/S0305-0483(00)00022-0
Ghoumrassi A, Ţigu G (2017) The impact of the logistics management in customer satisfaction. Proc Int Conf Bus Excel 11(1):292–301. https://doi.org/10.1515/picbe-2017-0031
Han J, Zhang X, He S, Jia P (2021) Can the coronavirus disease be transmitted from food? A review of evidence, risks, policies and knowledge gaps. Environ Chem Lett 19(1):5–16. https://doi.org/10.1007/s10311-020-01101-x
Hellani H, Sliman L, Samhat AE, Exposito E (2021) On blockchain integration with supply chain: overview on data transparency. Logistics 5(3):46. https://doi.org/10.3390/logistics5030046
Helo P, Hao Y (2019) Blockchains in operations and supply chains: a model and reference implementation. Comput Ind Eng 136(July):242–251. https://doi.org/10.1016/j.cie.2019.07.023
Hofmann E, Osterwalder F (2017) Third-party logistics providers in the digital age: towards a new competitive arena? Logistics 1(2):9. https://doi.org/10.3390/logistics1020009
Issaoui Y, Khiat A, Bahnasse A, Ouajji H (2019) Smart logistics: study of the application of blockchain technology. Proc Comput Sci 160(2018):266–271. https://doi.org/10.1016/j.procs.2019.09.467
Issaoui Y, Khiat A, Bahnasse A, Ouajji H (2021) Toward smart logistics: engineering insights and emerging trends. Arch Comput Methods Eng 28(4):3183–3210. https://doi.org/10.1007/s11831-020-09494-2
Kersten W, Blecker T, Ringle MC (2017) Digitalization in supply chain management and logistics. In: Proceedings of the Hamburg international conference of logistics (HICL). https://doi.org/10.15480/882.1442
Koh L, Orzes G, Jia F (2019) The fourth industrial revolution (Industry 4.0): technologies disruption on operations and supply chain management. Int J Oper Prod Manag 39(6):817–828. https://doi.org/10.1108/IJOPM-08-2019-788
Litke A, Anagnostopoulos D, Varvarigou T (2019) Blockchains for supply chain management: architectural elements and challenges towards a global scale deployment. Logistics 3(1):5. https://doi.org/10.3390/logistics3010005
Mears-Young B, Jackson MC (1997) Integrated logistics—call in the revolutionaries! Omega 25(6):605–618. https://doi.org/10.1016/S0305-0483(97)00032-7
Moldabekova A, Philipp R, Reimers HE, Alikozhayev B (2021) Digital technologies for improving logistics performance of countries. Transp Telecommun 22(2):207–216. https://doi.org/10.2478/ttj-2021-0016
Oluyisola OE, Bhalla S, Sgarbossa F, Strandhagen JO (2021) Designing and developing smart production planning and control systems in the industry 4.0 era: a methodology and case study. J Intell Manuf 0123456789. https://doi.org/10.1007/s10845-021-01808-w
Ouyang Q, Zheng J, Wang S (2019) Investigation of the construction of intelligent logistics system from traditional logistics model based on wireless network technology. Eurasip J Wirel Commun Netw 2019(1). https://doi.org/10.1186/s13638-018-1334-8

Phadnis S (2018) Internet of things and supply chains: framework for identifying oppertunities for improvement and its application. Emerg Technol Supply Chain Manag

Qu YJ, Ming XG, Liu ZW, Zhang XY, Hou ZT (2019) Smart manufacturing systems: state of the art and future trends. Int J Adv Manuf Technol 103(9–12):3751–3768. https://doi.org/10.1007/s00170-019-03754-7

Rejeb A, Keogh JG, Zailani S, Treiblmaier H, Rejeb K (2020) Blockchain technology in the food industry: a review of potentials, challenges and future research directions. Logistics 4(4):27. https://doi.org/10.3390/logistics4040027

Sergi I, Montanaro T, Benvenuto FL, Patrono L (2021) A smart and secure logistics system based on IoT and cloud technologies. Sensors 21(6). https://doi.org/10.3390/s21062231

Singh R, Gehlot A, Akram SV, Gupta LR, Jena MK, Prakash C, Singh S, Kumar R (2021a) Cloud manufacturing, internet of things-assisted manufacturing and 3D printing technology: reliable tools for sustainable construction. Sustainability (Switzerland) 13(13). https://doi.org/10.3390/su13137327

Singh S, Kumar R, Panchal R, Tiwari MK (2021b) Impact of COVID-19 on logistics systems and disruptions in food supply chain. Int J Prod Res 59(7):1993–2008. https://doi.org/10.1080/00207543.2020.1792000

Strandhagen JO, Vallandingham LR, Fragapane G, Strandhagen JW, Stangeland ABH, Sharma N (2017) Logistics 4.0 and emerging sustainable business models. Adv Manuf 5(4):359–369. https://doi.org/10.1007/s40436-017-0198-1

Sun C (2012) Application of RFID technology for logistics on internet of things. AASRI Proc 1:106–111. https://doi.org/10.1016/j.aasri.2012.06.019

Thompson DDP, Anderson R (2021) The COVID-19 response: considerations for future humanitarian supply chain and logistics management research. J Hum Logist Supply Chain Manag 11(2):157–175. https://doi.org/10.1108/JHLSCM-01-2021-0006

Treiblmaier H (2018) The impact of the blockchain on the supply chain: a theory-based research framework and a call for action. Supply Chain Manag 23(6):545–559. https://doi.org/10.1108/SCM-01-2018-0029

Wang Y, Sarkis J (2021) Emerging digitalisation technologies in freight transport and logistics: current trends and future directions. Transp Res Part E Logist Transp Rev 148(March). https://doi.org/10.1016/j.tre.2021.102291

Zielske M, Held T (2021) Application of agile methods in traditional logistics companies and logistics startups: results from a German Delphi Study. J Syst Softw 177:110950. https://doi.org/10.1016/j.jss.2021.110950

Application of Big Data Analytics in Modern Logistics Solutions

Jozef Fras and Waldemar Osmólski

1 Introduction

Changing market needs and concentration of the entire supply chain on the customer service level generate the need to constantly search for new solutions to improve logistics processes. This trend leads to a transformation of the currently used solutions, in the direction of intelligent supply chains. The use of modern technologies is aimed at improving logistics processes at the operational level by reducing lead times, minimizing bottlenecks and errors resulting from faulty information flow. The encroaching robotization, mobility and automation into logistics processes in our reality is a fact. Solutions using the latest achievements of electronics and robotics largely contribute to lowering the costs of functioning of enterprises, speeding up processes taking place in them or relieving people from tiresome and exhausting work. This also applies to mobile solutions in which data is retrieved and transferred in real time from mobile devices to enterprise IT systems, in particular based on 5G network capabilities. The pressure to automate is growing as companies look to reduce labor costs. Many companies that are currently considering, for example, relocating production to developed and economically stable countries may view automation as a means to remain competitive with rising labor costs.

Restructuring efforts in integrated supply chains are increasingly aided by Artificial Intelligence (AI). As in other industries, AI will fundamentally expand human performance in terms of reach, quality and speed by eliminating mundane and routine

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work. This approach allows logistics workers to focus on more meaningful issues and impactful work. Another very important aspect is the inability to utilize the large amount of data (Big Data) generated on a daily basis in integrated supply chains in the traditional way. Many logistics companies around the world are currently undergoing a digital transformation, moving away from legacy enterprise resource planning systems to advanced analytics, increased automation, and hardware and software robotics. This is helping the logistics industry to redefine today's behaviors and practices, taking actions from reactive to proactive, planning from predictive to predictive, and processes from manual to autonomous.

2 Big Data and Its Analysis

In order to answer the question: what really is Big Data and its analysis, we must know that Big Data generally refers to data that exceeds the typical storage, processing and computational capabilities of conventional databases and data analysis techniques. Most commonly, Big Data (Katal et al. 2013) is characterized as gigantic or highly complex data sets, encompassing resources larger than an exabyte in size (Chaouni Benabdellah 2016). On the other hand, Big Data describes how to collect, manage and analyze large amounts of data, associated with the so-called 3V's concept: Volume, Velocity, Variety (Mikavica 2015; Robak et al. 2013). This model has been supplemented over time with another component, Value, i.e., verification, evaluation. In the Polish language version, the Big Data model is defined as: Utilization, Inference, Enrichment, Verification. Currently, it is also noted that Big Data is nothing more than specific sets of information with a large volume, high variability and high diversity, requiring new forms of processing to support new decision-making and discovery of new phenomena, related to the optimization of various processes. However, to fully understand the impact and application of Big Data in supply chain analysis, we must first understand its nature and how it is collected. What is also important is the fact that the importance of Big Data does not boil down solely to how much data a company has, but most importantly how it is able to collect it, process it and on this basis draw the appropriate conclusions. They are the basis for making the right and fast decisions that enable dynamic development of any company. To be able to do that we need to pay special attention to 4 basic aspects related to data management:

- **Data must be accessible:** Organizations must make it easy and convenient for data owners at all levels to use data.
- **Data must be high quality:** Organizations are spending more time than ever before searching for duplicates, errors, omissions, conflicts and inconsistencies.
- **Data must be secure:** Organizations will need to strive for compliance and put strict data processes in place before using big data.
- **Data must be analyzed using the right tools and platforms:** Organizations must find the right technology that works within their existing ecosystems and meets their specific needs.

One of the most significant problems of Big Data is that it is often erroneous, outdated or incomplete. Therefore, an extremely large amount of time should be spent on their initial selection, eliminating errors and inaccuracies, resulting from the way they are obtained. These actions, in consequence, lead to the reduction of time allocated for the creation of innovative solutions (Chaouni Benabdellah 2016). Poor data quality can also lead to higher supply chain operating costs, which in turn is associated with lower efficiency and wasted resources (Mikavica 2015). Also, lack of sufficient knowledge by data analysts forces data to be entered manually, which in turn generates a higher probability of errors leading to disruptions in supply chains (Wang 2016). Another of the elements that can introduce dysfunctions in the proper functioning of supply chains is usually the lack of a functional and transparent user interface for analyzing Big Data (Taniguchia 2015), or the amount of available data. This can vary from region to region, for example, in small economies and rural areas, only a small amount of data may be available as opposed to metropolitan cities and urban areas (Chaouni Benabdellah 2016), which can have a significant impact on logistics and supply chain activities in these regions. To overcome the above difficulties, Big Data analytics should be carefully embedded in the operational realities of the supply chain (Sahin and Robinson 2002) using adequate human resources on both the analysis and operations side (Najafabadi et al. 2015). What is also important is that Big Data requires tools and methods that can be used to analyze and extract patterns from large-scale data (Katal et al. 2013). In other words, Big Data analytics is nothing but a complex process of examining big data to discover information—such as hidden patterns, correlations, market trends, and customer preferences that can help organizations make informed business decisions. It is also a form of advanced analytics that involves complex applications with elements such as predictive models and statistical algorithms. What is extremely important is that the logistics sector is ideally positioned to benefit from the technological and methodological advances of Big Data. Today, logistics operators manage huge flows of goods while creating gigantic data sets. As a result, there is an opportunity to eliminate the current divisions and high competition in the service market, enabling the creation of interoperable ecosystems, striving for the development of the Internet of Things (Osmólski et al. 2019). Many service providers are realizing that Big Data is a trend that is changing the face of the logistics industry. In a recent survey on supply chain trends, sixty percent of respondents said they plan to invest in Big Data analytics within the next five years.

3 Application Areas of Big Data Analysis in Supply Chains

In order to effectively leverage Big Data analytics applications, it becomes necessary to acquire clean and data from a variety of sources, which may include:

- social media data
- financial forecasts for enterprises

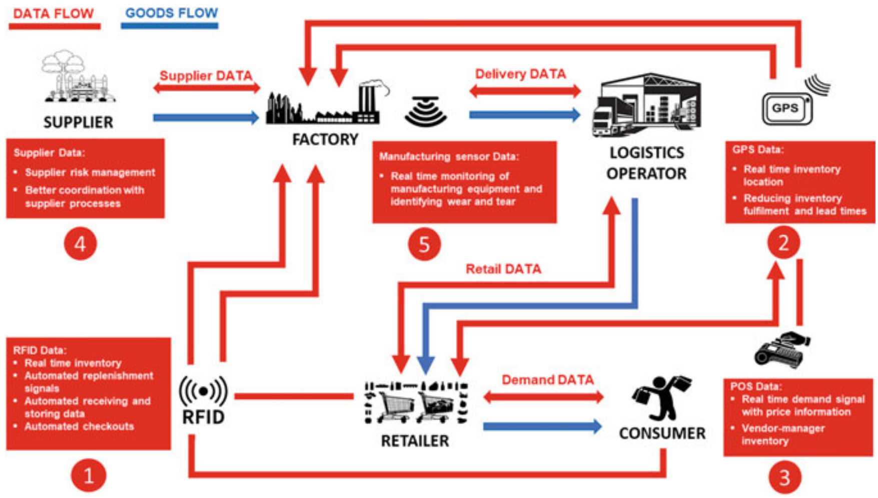

Fig. 1 Application areas for big data analytics in supply chains. *Source* Own elaboration

- traffic and weather data from sensors, monitors and forecasting systems installed in vehicles
- vehicle diagnostics, driving patterns and location information
- enterprise data from operating systems.

As we have seen, there are many sources from which analytical systems can be fed with the necessary information. All these data sources and skilful use of analyses created on their basis lead to full optimization of production and warehouse processes, optimization of inventory levels, delivery processes, verification of customer satisfaction level or increase in financial effectiveness of enterprises. All this happens thanks to cooperation and proper flow of information in integrated supply chains. An important issue at this point becomes the question of sources of obtaining relevant data, which are various types of sensors and devices installed in individual nodes of the supply chain. Figure 1 shows the 5 major nodes of the supply chain that are the main sources of Big Data generation.

Based on the data acquisition systems configured in this way, we are able to identify 5 main areas of use for Big Data analytics, which are.

3.1 Optimization of Transport Processes

Based on the use of Big Data analytics technology, through RFID tags, GPS devices, barcodes and more, logistics companies can track their vehicles in real time. These systems can capture real-time traffic data, road network data and fleet data, which entails the ability to optimize routes, planning and scheduling of deliveries. Based on such in-depth analytics, it becomes possible to predict possible accidents or bad weather conditions and track shipments and fleets from anywhere. Real-time delivery status updates are also offered to customers. Customers receive automatic notifications in case of delivery delays. While there are other use cases for Big Data in transportation, it's not about the scope of the analysis, but the depth of the analysis. The two basic requirements for good data analytics are data quantity and data quality. An organization must be able to capture hundreds of thousands of events and ensure their quality every time in order to make accurate predictions. It is also essential to have the ability to stream analytics and analytics in real-time, especially in time-sensitive data use cases. What is important is that it is critical for organizations to perform analytics in a timely manner to highlight the true value of data in transit.

This is where the application of artificial intelligence (AI), or machine learning (MI) to transportation processes comes to the rescue. Such a solution has been used by DHL in its Smart Truck solution or Cargonnex for transportation planning, among others. AI is also used in solutions for managing autonomous vehicles in both local distribution and linehaul. Such a solution, called platooning, was tested, among others, on the A9 freeway in Germany in cooperation between Schenker and MAN during the transport of goods in a convoy of trucks.

Another example is the use of AI in air freight transport. Timely shipments here are crucial to the economy, as they account for just 1% of global trade in terms of tonnage, but as much as 35% in terms of value. DHL has developed a predictive algorithm-based tool to predict delays during air freight. By analyzing 58 different internal data parameters, the software is able to predict weeks in advance what the expected average daily transit time is for planned connections. In addition, the solution is able to identify the most important factors affecting shipment delays.

3.2 *Optimization of Warehouse Processes*

Warehouse management in the traditional way, using legacy systems or ERP systems is already highly inefficient. Today, millions of customers are interested in receiving real-time updates on product orders, getting up-to-date knowledge of product availability before making a purchase decision, and have instant access to product manufacturing details. Moreover, customers can make purchases from anywhere in the world. With Big Data, you can understand how customer behavior is changing and what expectations they often have of manufacturers and supply chain managers. You can also gain detailed insights into the process of loading, moving, unloading and delivering goods. As a result, you can better plan routes and delivery schedules to increase safety and reduce operating costs for your business.

A very important path forward for logistics, especially warehouse logistics, is robotization, using not only AI solutions, but also Internet of Things and Industrial Internet of Things or Cloud Computing. According to the U.S. Association for Advancing Automation, robot orders in 2018 increased nearly 16% over 2017 to 28,400 units. The largest increase in automation was in the food sector last year.

Robot shipments to companies in the electronic components manufacturing industry increased by half, and by 13% in the metal manufacturing and processing industry. Intelligent robotic sorting is an efficient and fast solution for sorting letters, packages and even palletized shipments. UK-based Ocado has reduced the time it takes to prepare an order consisting of 50 lines from two hours to five minutes by using robots in the picking process. Ocado currently already has 2500 such robots. The Finnish ZenRobotics ZRR2 system, which uses a combination of embedded vision and machine learning algorithms, is used for sorting and collecting recyclables from moving conveyor belts. Autonomous AGVs have been used in warehouse processes and drones or vision technologies have been used in goods inventory. These are only a few examples confirming the use and development of the latest technologies in the area of logistics.

3.3 Inventory Management System Optimization

Stock management system is considered as one of the most essential elements of warehouse processes. Managing inventory in a seamless manner is not possible by using conventional forms such as analyzing historical inventory data or sales values. To operate effectively, retailers and supply chain managers need to obtain information about customer behavior, product turnover, store performance, supplier relationships, replenishment planning, etc. Inventory management must go beyond traditional methods such as analyzing historical sales and inventory data. Algorithms can explore patterns and relationships between various data elements and business decisions. This gives retailers unparalleled insight into consumer behavior, supplier relationships, product performance, offline and online store performance, replenishment planning and more. Among other things, connecting multiple outlets can provide essential information for forecasting optimal inventory levels. Real-time data gives companies the ability to predict future sales of products that have no previous sales history. Big Data provides valuable information that can help companies leverage related product details used to predict the sales potential of a new item, seasonal product or help uncover new merchandising opportunities. Also, machine learning and real-time data can help companies determine the average price for their products by quickly assessing multiple factors, including available supplies, costs, competitor prices and overall product value. Big Data also provides the ability to predict demand for specific products. Knowing which products are bestsellers and which are underperforming gives companies the ability to address any potential problems in real time. In particular, the real-time data obtained helps companies reduce the number of backlogged items. Big Data uses predictive analytics to anticipate consumer demand. These insights help improve planning and give manufacturers more peace of mind and confidence when communicating with customers. This is especially important in the financial aspect, where Big Data analytics can help create strategic alliances with product suppliers by providing important real-time information about orders, shipments and backlogs, so companies can gain valuable insights into productivity and financial health. Understanding how to use Big Data in supplier relationships can lead to better customer service and increased customer satisfaction.

As an example, e-commerce giant Walmart is among the large companies that use analytics to keep their warehouses running smoothly. The company is present in 27 countries and has an estimated 11,766 stores currently in operation, which requires a lot of maintenance of warehouses in these countries to ensure a smooth flow of goods to end users. The company relies on Big Data analytics to monitor merchandise flows and labor productivity in real-time at both stores and distribution centers. With a huge pool of data from all sources, it has the ability to accurately plan the delivery of specific assortments to the appropriate points. This is achieved by monitoring customer preferences, shopping patterns, which speeds up decision making on how to stock store shelves and display merchandise. Big Data also helps in obtaining detailed information on new products, discontinued products and specific brands that are in higher demand.

3.4 Predictive Maintenance of Machinery and Equipment

Predictive maintenance of machinery and equipment is based on IoT/IIoT sensors placed in the respective equipment systems of the monitored equipment. The Internet of Things collects data in real time and sends it back to a central system for monitoring the status of individual systems. The relevant software takes the monitoring data showing the regular operation of the system and automatically analyzes it to establish a baseline for proper functioning. The predictive maintenance system then uses machine learning to quickly process and analyze new data packets coming in from IoT sensors all the time, monitoring the condition of the devices based on anomalies and generating an alert when needed. Combining this data with static information such as maintenance schedules makes it easy to gain contextual insights into the status of monitored systems. Using predictive analytics based on the information captured, companies are able to identify patterns based on which they can predict deteriorating performance, inconsistencies and future failures. This allows them to keep their equipment in good functional condition, thereby increasing their productivity by avoiding costly downtime. What is also important to realize is that not all failure modes can be predicted by predictive maintenance techniques. Some failure modes may give no warning of impending failure, others may give some warning but not enough to avoid the consequences of failure, and for others the cost of detecting impending failure may outweigh the benefits. However, for all predictive maintenance programs, it is true that in order to create an effective failure prediction system, it is necessary to know the causes (modes) of failure to be avoided, as a kind of benchmark necessary to verify ongoing analyses. At this point, it is important to emphasize that for the prediction of failures against which systems must be protected, requiring the use of more advanced techniques (such as those that use complex data analysis and complex modeling techniques), it must be economically justified. In other words, advanced predictive technologies must be focused on the significant economic benefits of their use, not simply driven by technical need.

Predictive maintenance techniques have been used, among other things, to predict the failure of Typhoon fighter components. The failure rate of aircraft components varies with changing conditions due to the operating location and, therefore, the location of the air base. In total, about 2000 components on each aircraft are monitored for wear, with each verification generating a 40-megabyte output that becomes the input for the predictive model. This runs various iterations of the model to predict the impact of trends and environmental changes on the proper functioning of the tested components. Using this type of approach has enabled decisions to be made on whether to replace components before they fail, from an airbase or headquarters location based in the UK. As a result, aircraft uptime has improved significantly—for example, the downtime of an aircraft on the ground waiting for spare parts has improved from double digits to 4%. The expected benefits are a savings of $3.1 billion in maintenance over 25 years for 10 aircraft.

3.5 *Improve Customer Service*

In order for a company to be successful in an ever-changing marketplace, it becomes essential to know the exact needs of individual customers and, most importantly, to meet those needs in a way that allows the company to be recommended to future potential customers. Unfortunately, companies are not always able to grow their business and keep up with each individual customer, which very often leads to their partial loss. To be able to prevent this process in an effective way, Big Data analytics is starting to be used on a large scale, thus enabling insights into the needs of individual customers, learning about their preferences and habits. Big Data analytics provides logistics companies with the right set of data about their customers. The data collected from multiple customer-product interactions helps build statistical models that can accurately predict customer actions. With them, they can apply historical and predictive analytics models and understand how to create a sense of customer loyalty and improve their relationship with the company. In-depth analytics also help predict the emergence of potential problems and enable the organization to address them earlier. Such initiatives help improve performance in terms of building and deepening a sense of satisfaction among customers. What is also extremely important is that based on Big Data analytics, revenue growth can be accelerated through precise customer segmentation and targeted marketing efforts, increasing the company's sales potential.

Brand awareness is another way in which Big Data can have a significant impact on building a company's relationship with its customers. The Aberdeen Group's Data-Driven Retail study found that "data-driven retailers enjoy a 2.7 times greater annual increase in brand awareness (20.1% vs. 7.4%) compared to everyone else." The breadth of customer data insights allows marketers to present customized content when and where it is most effective for brand recognition and recall. Among other things, this also leads to more effective retention and acquisition of new customers. A McKinsey study found that "users who make heavy use of Big Data analytics tools to learn about customer behavior are 23 times more effective in their efforts than competitors who do not." Big Data can help companies leverage real-time data collected in cloud solutions. Big Data's ability to acquire, process and analyze real-time data quickly and accurately enough to take immediate and effective action cannot be matched by any other technology. This is critical when analyzing data from GPS, IoT sensors, website clicks or other data received in real-time. It provides business intelligence that results in time and cost savings by optimizing marketing efforts.

As an example of how Big Data can retain customers and their interests, let's look at Walmart. Walmart is building 40 (PB) Petabyte or 40 million Gigabyte of data in the cloud to track the endless number of products they ship worldwide. Whereas this retail giant in the old days had to wait days or months to know the status of their sales in a selected sector or area and then make adjustments accordingly, now they can do it instantly. This gives the achievement of a huge competitive advantage to the company.

4 Conclusions

Using Big Data in logistics can improve the efficiency of procurement, distribution and manufacturing networks. According to a recent study, 91.6% of Fortune 1000 companies are increasing investments related to Big Data and AI. This study clearly indicates that many companies have started using Big Data analytics, realizing the benefits it can provide and the impact it can have on their organizations. By providing real-time insights to solve ongoing problems, Big Data analytics can help improve warehousing, handling, transportation and other logistics processes within a company. Thus, logistics operators can gather vital information that is highly beneficial to a company's accountability, visibility and customer service. Logistics companies are aware of these opportunities and are trying to make decisions based more on accurate Big Data analysis, which the authors have clearly highlighted in the following article. In conclusion, we can state unequivocally that without accurate Big Data analysis, modern companies are unable to create a competitive advantage in the market, becoming, in part, outsiders slowly disappearing from the economic space. However, using the benefits of data solutions can, among other things:

1. **Create more effective marketing and sales**
   Big Data is increasingly being used for advanced consumer segmentation, automating product personalization, tailoring communications during the sales cycle or leveraging new sales opportunities.
2. **Increase the ability to forecast demand more accurately**
   Sales teams in today's enterprises now have access to vast and complex amounts of data from a variety of sources, including suppliers and customers. Advanced

analytics tools can be used to integrate data from multiple systems, and when combined with external factors such as weather forecasts, competitive behavior and pricing, will greatly enhance the ability to forecast demand.

3. **Help with route planning and traffic management**
   Big Data analytics is the ideal way to plan routes—avoiding congestion as much as possible—and having absolute control over routes or times.
4. **Reduce and optimize costs**
   Capturing transportation fleet data not only allows you to have more control over the information, but also to tailor it better. From there, it becomes easier to make decisions.
5. **Reduce environmental impact**
   Today, more and more companies are trying to control and develop strategies to reduce their "environmental footprint". These actions will be much more effective if they are developed in real time based on data obtained during the company's daily operations.
6. **Solve more complex distribution network problems**
   An increasingly complex distribution network consisting of suppliers, manufacturers, distributors, or logistics operators faces increasing challenges in managing the flow of goods, information, or changing demand patterns. Companies can deal with this complexity more easily than in the past by leveraging Big Data analytics, which provides the ability to solve highly complex problems by modeling results in more detailed scenarios than ever before.
7. **Develop better supply chain collaboration**
   Increased supply chain data should be seen as an opportunity to improve the management of more complex supplier networks and to develop better collaboration. Getting the most benefit from Big Data requires investment in technology, of course, but also a change in organizational culture. Employees in different departments of companies need to be involved in the process of determining which data is useful to them and which should be ignored. Recognizing and rewarding employees who can effectively use the analytical capabilities of the data collected is just as important as investing in the latest analytical techniques.

References

Chaouni Benabdellah A (2016) Big data for supply chain management: opportunities and challenges. Int J Sci Eng Res 7(11)

Katal A, Wazid M, Goudar RH (2013) Big data: issues, challenges, tools and good practices. In: IEEE sixth international conference on contemporary computing (IC3), pp 404–409

Mikavica B (2015) Big data: challenges and opportunities in logistics systems. In: 2nd logistics international conference, Serbia

Najafabadi MM, Villanustre F, Khoshgoftaar TM, Seliya N, Wald R, Muharemagic E (2015) Deep learning applications and challenges in big data analytics. Springer J Big Data 2(1)

Osmólski W, Voronina R, Koliński A (2019) Verification of the possibilities of applying the principles of the physical internet in economic practice, LogForum, Nr 1 rok 2019, Poznań, str. 7–17
Robak S, Franczyk B, Robak M (2013) Applying big data and linked data concepts in supply chains management. In: 2013 federated conference on computer science and information systems (FedCSIS), pp 1215–1221, 201
Sahin F, Robinson EP (2002) Flow coordination and information sharing in supply chains: review, implications, and directions for future research. Decis Sci 33(4):505–536
Taniguchia E (2015) New opportunities and challenges for city logistics. In: 9th international conference on city logistics, Canary Islands
Wang G (2016) Big data analytics in logistics and supply chain management: certain investigations for research and applications. Int J Prod Econ 98–110. http://www.elsevier.com

Case Study Validation of a Predictive Maintenance Implementation Framework

Marcel André Hoffmann

1 Introduction

Industrial companies are faced with many tasks in efficiency, sustainability, and customer requirements (Mack et al. 2015). To solve these multiple tasks, reliable processes in production and logistics are inevitable. In a strategy paper of the European Commission, smart and adaptive manufacturing systems play a crucial role in facing the challenges in supply chains (European Commission 2021). This also includes the adaption of smart solutions in the management of reliability and maintenance of production systems, accompanied by large amounts of data to be processed (Feng and Shanthikumar 2018).

The European Standard DIN EN 13306 divides maintenance strategies into four categories. In the **reactive** maintenance strategy, measures are only implemented after failure. This leads to more extended downtimes and no planning or forecasting opportunities. In a **time-based preventive** strategy, the useful lifetimes of parts are defined and documented in a maintenance schedule, and parts are replaced according to this plan. This strategy is characterized by higher maintenance activity and spare parts consumption since the maximum lifetime is usually not reached (Erbe et al. 2005). The **condition-based preventive** maintenance follows the concept of either constant or discrete observation of the object's condition state. The monitoring can be achieved by sensors or manual inspections (Prajapati et al. 2012).

Consequently, parts can be replaced before a breakdown occurs, and the wear reserve can be used to a high extension. The **predictive** maintenance (PdM) strategy extends the CBM, whereas a prognosis of the residual useful life (RUL) allows good planning opportunities for scheduling maintenance activities and

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deploying resources. Furthermore, this strategy aims to inhibit failures and, therefore, production downtimes (CEN 2017; Lei et al. 2018; Ansari et al. 2019).

Although PdM shows high potential in maintenance optimization, the number of implementations in the industrial environment is still comparatively low (Haarman et al. 2018). Therefore, Hoffmann and Lasch (2020) developed a roadmap for a structural implementation process of this maintenance strategy based on literature findings, which has not been applied yet. This paper aims to validate this framework based on a practical case study. The following research questions are considered:

RQ1: Are all relevant aspects included in the implementation framework of a predictive maintenance strategy?

RQ2: In which way and order are the proposed steps put into practice by a maintenance expert team?

The remainder of the article is structured as follows: Sect. 2 provides a short introduction to the roadmap of Hoffmann and Lasch (2020) and gives an overview of the proposed methodology of the validation study. Section 3 shows the practical realization of the analysis phase, Sect. 4 includes the decision-making process, and in Sect. 5, the implementation process is shown. A conclusion is drawn in Sect. 6.

2 Predictive Maintenance Implementation Framework and Validation Methodology

2.1 PdM Implementation Framework

The paper of Hoffmann and Lasch (2020) proposes a generic framework to implement a predictive maintenance strategy in industrial processes. Therefore, technical criteria of this maintenance strategy are considered as well as management-related tasks such as cost–benefit-considerations or decision-making support. The overall aim is to give a structured roadmap to the maintenance management on implementing PdM in an industrial environment that does not require extensive know-how and splits up this assignment into several packages of strategic and tactical tasks.

The general structure is divided into three phases: analysis, decision making, and implementation. This is accompanied by a feedback loop, as shown in Fig. 1. A detailed description of the process is given in chapters three to five.

2.2 Validation Methodology

Since the paper of Hoffmann and Lasch (2020) provides a literature-based theoretical framework for PdM implementation, a practical realization is missing as yet. This paper aims to research the feasibility of the given model to be applied in a practical

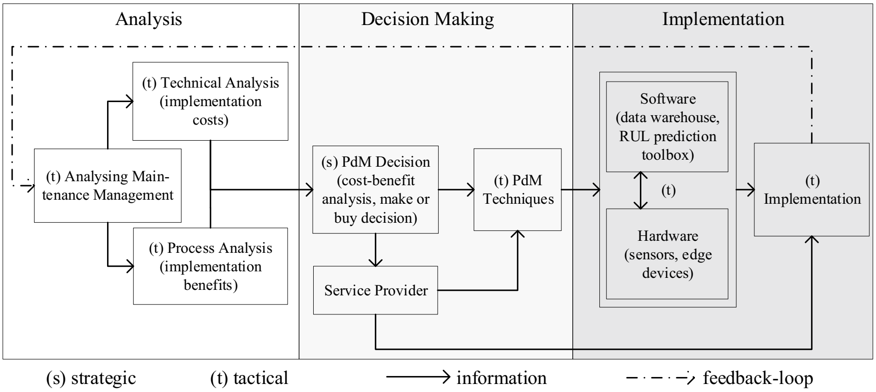

Fig. 1 PdM implementation roadmap according to Hoffmann and Lasch (2020)

industrial use case. Therefore, a co-validation based on Yin and McKay (2018) was conducted. The validation team consists of maintenance experts in an automotive industry company as model users and maintenance researchers. This approach was chosen to enable an interdisciplinary validation process and gain new findings for the model based on the practical implementation.

A case study evaluation approach based on the paper of Offermann et al. (2009) was chosen to validate the roadmap. Therefore, the analysis and decision-making phase was conducted in cooperation with the maintenance department of the mentioned automotive industry company. The validation of the implementation phase is based on a maintenance expert interview.

The considered assembly line consists of eleven maintenance objects shown in Table 3, whereas most perform joining processes. The remaining machines execute handling and testing processes. In the following, the proposed steps according to the roadmap of Hoffmann and Lasch (2020) are performed.

3 Analysis Phase

3.1 Maintenance Management

The initial step starts with the analysis of the existing maintenance management. Therefore, the current mix of applied maintenance strategies and their strategic roles, the structure of the maintenance costs, and failure causes are examined. Applied key performance indicators and the existing infrastructure of the information system are further evaluation criteria.

Own employees carry out most maintenance measures, and only a few of them are conducted by machine suppliers due to service contracts. The company follows a preventive time-based maintenance strategy. Therefore, a period of 90 min every week and one maintenance shift every month are scheduled. Maintenance activities are carried out based on a maintenance plan with fixed intervals and work instructions documented based on an ISO 9001 quality management certification.

The accounting department of the company records direct maintenance costs. One problem in this context is that those costs are assigned to working stations instead of classification to the single maintenance objects. The indirect maintenance costs are not captured. This is caused by the management's high priority of delivery reliability. Therefore, the maintenance intensity is high and parts are changed before reaching the wear limit. However, conclusions about the indirect maintenance costs can be partly drawn based on the machine downtimes documented by the maintenance management.

The failure causes are recorded in a detailed manner by the maintenance department. The mean time to repair (MTTR) and up- and downtime monitoring are currently the only implemented KPI considering the maintenance performance. The overall equipment effectiveness (OEE) is introduced as a relevant performance indicator.

The IT infrastructure is based on the SAP PM module. The in-house IT department develops specific solutions for plant condition monitoring. It should be noted that this condition monitoring captures the overall state (operating or down) of a machine but not maintenance-specific features such as vibration.

3.2 Process Analysis

The second step is process analysis, which aims to identify crucial steps within an industrial process that show high potential benefits for implementing PdM. In this context, the process configurations are of particular interest. Parallel and redundant production processes with several machines for the same purpose have a lower risk of a complete process shutdown than serial configurations, where unplanned downtimes can have devastating impacts on the process's reliability and safety. Further potentials of PdM are given at high storage costs for spare parts or production facilities, of which a failure has value-reducing impacts. High failure frequency, downtimes, and failure impacts on output and product quality are analyzed criteria within this step too.

Quantification of the analysis criteria as a sub-process is necessary to conduct the process analysis. Therefore, the expert team defines a weighting of the following features that are necessary for maintenance purposes.

The direct maintenance costs (MC) contain expenses for maintenance measures such as parts, personnel costs, and equipment, based on the accounting department's documentation. The failure frequency (FF) measures the number of failures of a machine per year, whereas the downtime (DO) includes the annual cumulated hours of downtime caused by machine failures. The criterion machine value (MV) measures the negative impacts of a failure on the overall object value.

Indirect maintenance costs are included in the analysis by considering the influence on the production output (IO) and product quality (IQ). There are no documented

Table 1 Weighted criteria process analysis

Nr.	Criteria	Weight in %
1	Maintenance cost (MC)	20
2	Failure frequency (FF)	30
3	Downtime (DO)	30
4	Machine value (MV)	5
5	Influence on output (IO)	5
6	Influence on quality (IQ)	10

values available for those criteria. Therefore, the expert team estimates the values based on their experience. The weights of the criteria are shown in Table 1.

In this case study, the team considers downtime and failure frequency as the most relevant criteria, whereas machine value, quality, and output are not of high priority. Based on the absolute values of each maintenance object's criteria, a scale is defined by the team, which allows for an assignment to a value from 1 to 10. An exemplary scale for the failure frequency is shown in Table 2. Similar scales exist for the remaining criteria, whereas a higher scale value represents a higher potential factor. As shown in Table 3, the scale values are weighted and summed up afterwards to calculate a value for the PdM potential within the process analysis.

Exemplary calculation of the potential factor of object 1:

$$= 2 * 0.2 + 10 * 0.3 + 7 * 0.3 + 8 * 0.05 + 8 * 0.05 + 8 * 0.1 = 7.1$$

Table 2 Exemplary scale for FF

Value from	to	Scale value
0.0	7	1
7.1	14	2
14.1	21	3
21.1	28	4
28.1	35	5
35,1	42	6
42.1	49	7
49.1	56	8
56.1	63	9
63.1	70	10

Table 3 Values for PdM potential

Criteria	Object type	MC	FF	DO	MV	IO	IQ	∑
Weight (%)		20	30	30	5	5	10	
Object 1	Welding	2	10	7	8	8	8	7.1
Object 2	Welding	1	5	3	8	8	7	4.1
Object 3	Welding	3	7	10	10	8	7	7.3
Object 4	Welding	2	7	10	10	5	6	6.9
Object 5	Welding	2	7	10	10	5	6	6.9
Object 6	Forming	1	1	1	4	10	4	1.9
Object 7	Welding	2	7	3	10	10	4	4.8
Object 8	Rework	1	1	1	2	9	5	1.9
Object 9	Handling robot	10	4	9	6	10	2	6.9
Object 10	Leak test	1	3	5	4	10	9	4.2
Object 11	Optical testing	1	1	1	8	1	10	2.3

3.3 Technical Analysis

The technical analysis concludes the analysis phase, aiming to determine the effort and cost of PdM implementation. If condition monitoring systems are already implemented at the maintenance object, an extension to a predictive system can be installed with comparatively low effort. Also, some existing sensors in the system might be used for PdM purposes. If those two prerequisites are not fulfilled, retrofitted sensors can compensate for that shortcoming. In this context, it must be analyzed whether such an installation of sensors and communication can be done with a moderate effort.

At first, the relevant criteria to estimate the effort of implementing PdM are defined. Usable sensor data (US), which enable RUL prediction, allow minimal implementation effort. If those are not available, sensor costs (SC) and the usable installation space (IS) must be considered. The data transfer (DT) expresses the efforts to extend the IT infrastructure for linking new sensors. Retrofitting (RF) contains necessary hardware changes to fit new sensors to an existing machine. Detecting measuring faults (MF) can be necessary when false signals are delivered due to interferences in the system or damaged sensors.

The priority and weights of the individual criteria are defined by the maintenance experts and shown in Table 4. In this case, the installation space and possible measurement faults are considered the most critical aspects. The scales are configured similar to those in Sect. 3.2, whereas a higher scale value represents a higher effort.

The evaluation considering the implementation effort for PdM of the eleven maintenance objects is done for every criterion and summed up similarly to the process analysis. The results can be seen in Table 5.

Table 4 Weighted criteria technical analysis

Nr.	Criteria	Weight in %
1	Usable sensors (US)	20
2	Sensor costs (SC)	5
3	Installation space (IS)	30
4	Data transfer (DT)	5
5	Retrofitting (RF)	10
6	Measuring faults (MF)	30

Table 5 Values for PdM implementation effort

Criteria	US	SC	IS	DT	RF	MF	$\sum$
Weight (%)	20	5	30	5	10	30	
Object 1	10	5	9	1	5	8	7.9
Object 2	10	5	9	1	9	1	6.2
Object 3	7	7	2	1	2	2	3.2
Object 4	10	3	5	1	6	6	6.1
Object 5	10	3	5	1	6	6	6.1
Object 6	10	5	3	1	3	10	6.5
Object 7	10	8	5	1	5	3	5.4
Object 8	10	5	5	1	3	10	7.1
Object 9	10	8	3	1	5	6	5.7
Object 10	10	5	3	1	3	10	6.5
Object 11	10	10	8	1	8	10	8.8

4 Decision-Making Phase

4.1 Decision-Making Matrix

The second phase addresses decision-making. Therefore a 3 × 3 decision support matrix is proposed by Hoffmann and Lasch (2020), in which the results of the process analysis (PdM potential) and technical analysis (implementation effort) are filled in. Depending on the category the maintenance object is assigned to, recommendations about implementing PdM are given based on a cost–benefit consideration. The calculated values for every maintenance object considering PdM potential (Sect. 3.2) and implementation effort (Sect. 3.3) are filled into the decision-making matrix in Fig. 2.

Maintenance object 3 shows a high potential for PdM with a comparatively low effort. Therefore, the implementation is highly recommended for this machine. The main reason is a high number of failures and long downtimes. Furthermore, a missing redundancy makes this machine crucial for the whole production process. On the

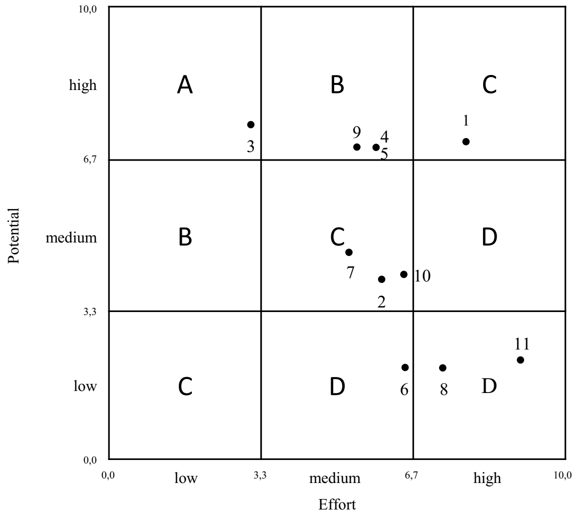

Fig. 2 Decision-Making matrix

other hand, necessary sensors for condition monitoring are already implemented, enabling a cost-efficient use of the already continuously measured values. The maintenance objects 4, 5, and 9 are assigned to class B, which implies an advisable implementation of PdM. The potential benefits are very high, but the effort is significantly higher than for the object in the first category. Machines 4 and 5 have a parallel configuration and can be described as redundant. However, they have a high failure frequency, and cost-intensive spare parts are necessary. Object 9 is a handling robot and, therefore, a critical part of the process since a breakdown can also lead to a complete shutdown.

A clear recommendation cannot be given about PdM implementation for those objects assigned to class C. However, a selective consideration is necessary to avoid overfitting. In this case study, maintenance objects 1, 2, 7, and 10 are classified in this category. Machine 1 shows high failure frequency and downtimes. Furthermore, a failure has comparatively high impacts on the output and product quality. Consequently, a PdM consideration seems useful for better process quality, but the implementation is not recommended in the first step under cost-considerations. The remaining objects of class C are characterized by medium potential and effort values, which leads to a lower priority for the PdM implementation.

Objects 6, 8, and 11 have an inconvenient effort-potential ratio and are therefore not suitable for monitoring by a predictive maintenance strategy since this would lead to adverse effects considering the overall maintenance costs. Following this decision-making process, the company's maintenance management decided to start a pilot project to implement PdM for objects 3 and 9.

4.2 Service Provider and PdM Techniques

A strategic decision about outsourcing specific PdM tasks is included in the decision-making phase. To gain further know-how in this field, the expert team makes a strategic decision against outsourcing maintenance tasks in this context. The management assesses that the existing maintenance team can execute all relevant maintenance measures since there is no significant change in operational maintenance tasks to be expected.

Following the proposed roadmap of Hoffmann and Lasch (2020), the decision about the RUL prediction method is to be made at this point of the process. Deviating from this recommendation, the maintenance team decides to postpone the decision about the PdM techniques to be used since the choice depends on the used software. The planning steps for this implementation pilot project are now explained based on the maintenance team expert interview.

5 Implementation Phase

5.1 Hardware Implementation

Within the third phase, the actual implementation is conducted. Therefore, the required software and hardware must be selected simultaneously for a secure and reliable data transfer and cannot be considered separately from each other.

The most critical task in hardware implementation is choosing the relevant features to be measured to ensure high data quality for condition monitoring. For those maintenance objects where sensors for condition monitoring are installed already (e.g., object 3), an evaluation is necessary whether the monitored features can be used for PdM purposes. To ensure this, a consultation with the machine manufacturer is required. This is also relevant for machines without any installed sensors for condition monitoring purposes yet to gain information about relevant thresholds that indicate the end of life for wearing parts and necessary maintenance measures. The company's sensor supplier and expert is consulted to assess which sensors to select for values to be measured and how to position them.

5.2 Software Implementation

Depending on the existing information system infrastructure and the extent of the expected amount of data, PdM tasks can either be implemented in an existing ERP system or cloud computing solutions combined with IoT-based sensors might be more suitable due to more scalable and flexible options.

In this particular case, two options are considered. The first variant is a predictive maintenance toolbox offered by the existing ERP system provider as an add-on. Therefore, pre-defined algorithms predict the RUL and schedule necessary maintenance measures. This variant reduces the effort of developing algorithms such as artificial intelligence solutions and can be implemented rapidly without extensive knowledge in data engineering.

The second variant contains an extensive in-house development of software for PdM purposes. This requires more effort in the field of data evaluation. Based on the framework of Lei et al. (2018), the process of health prognosis evaluation is split into four steps: data acquisition, health indicator construction, health state division, and RUL prediction. An own software solution requires superior know-how in feature engineering and the configuration of artificial intelligence algorithms frequently used for RUL prediction.

5.3 Implementation in Maintenance Management

A predictive strategy might require adaptions considering the operational targets and organizational structures. Therefore, the implementation phase is concluded by introducing this strategy into maintenance management. To realize the full potential of PdM, a holistic approach that considers production planning and purchasing claims is proposed.

Since the pilot project does not affect the whole production line, only minor changes are expected considering the maintenance management. The weekly timespan for maintenance activities is still used for inspections at the other objects. It is not clear yet, whether the maintenance measures for objects 3 and 9 are still executed in the monthly maintenance shift, or they can be done during the operation time due to the excellent planning opportunities based on the estimated RUL.

Regarding software-variant 1, synergies are expected by including other ERP modules such as production scheduling or material management, which can purchase needed spare parts according to the demand.

A feedback loop is planned to be installed to improve the implemented PdM strategy, aiming for constant optimization and adaptation of the maintenance processes. The feedback information will be embedded into the continual improvement process of the quality management system.

6 Conclusion

Many experts see a contribution of predictive maintenance to more efficient and reliable production processes in the industrial environment. However, the number of successful implementations is still low. Based on a practical case study and expert consultation, this article gives industrial companies a structured suggestion to start making their own experiences and gain know-how in the field of PdM.

The validation study shows that the underlying framework applies to a structured PdM implementation process with few adjustments to the initial version.

In the considered case, the analysis revealed two maintenance objects with high potential and moderate implementation effort, which are feasible for the maintenance management department to start a PdM pilot project.

Regarding RQ1, the expert team recommends implementing a sub-process for quantifying the analysis criteria in phase one. Besides this, the co-validation team sees all relevant criteria included in the framework to give a structured recommendation for action.

Regarding the execution and order of the proposed steps, the decision-making of the PdM techniques is recommended to be shift into the implementation phase since this is dependent on the used software solution, which answers RQ2.

The validation study is done with the limitation that the practical process is performed for the first two phases in the company, whereas the evaluation of the third phase is based on maintenance expert consultation. Further research in practical PdM implementation is still necessary to unfold the advantages for producing companies. Furthermore, plug-and-play solutions are required that offer practitioners the opportunity to get started without high effort.

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References

Ansari F, Glawar R, Nemeth T (2019) PriMa: a prescriptive maintenance model for cyber-physical production systems. Int J Comput Integr Manuf 32(4–5). Taylor & Francis. https://doi.org/10.1080/0951192X.2019.1571236

CEN (2017) DIN EN 13306: maintenance—maintenance terminology. Beuth Verlag, Berlin

Erbe H et al (2005) Infotronic technologies for e-maintenance regarding the cost aspects. In: IFAC proceedings volumes (IFAC-PapersOnline). IFAC. https://doi.org/10.3182/20050703-6-cz-1902.01384

European Commission (2021) Updating the 2020 new industrial strategy: building a stronger single market for Europe's recovery. https://ec.europa.eu/info/sites/default/files/communication-industrial-strategy-update-2020_en.pdf

Feng Q, Shanthikumar JG (2018) How research in production and operations management may evolve in the era of big data. Prod Oper Manag 27(9). https://doi.org/10.1111/poms.12836

Haarman M et al (2018) Beyond the hype: PdM 4.0 delivers results. Predictive Maintenance 4.0. https://www.pwc.de/de/industrielle-produktion/pwc-predictive-maintenance-4-0.pdf

Hoffmann MA, Lasch R (2020) Roadmap for a successful implementation of a predictive maintenance strategy. In: Smart and sustainable supply chain and logistics—trends, challenges, methods and best practices. EcoProduction (Environmental issues in logistics and manufacturing).https://doi.org/10.1007/978-3-030-61947-3_29

Lei Y et al (2018) Machinery health prognostics: a systematic review from data acquisition to RUL prediction. In: Mechanical systems and signal processing. Elsevier Ltd, p 104.https://doi.org/10.1016/j.ymssp.2017.11.016

Mack O et al (2015) Managing in a VUCA world.https://doi.org/10.1007/978-3-319-16889-0

Offermann P et al (2009) Outline of a design science research process. In: Proceedings of the 4th international conference on design science research in information systems and technology, DESRIST'09, June 2014. https://doi.org/10.1145/1555619.1555629

Prajapati A, Bechtel J, Ganesan S (2012) Condition based maintenance: a survey. J Qual Maint Eng 18(4). https://doi.org/10.1108/13552511211281552

Yin C, McKay A (2018) Model verification and validation strategies and methods: an application case study. In: ISCIIA and ITCA 2018—8th international symposium on computational intelligence and industrial applications and 12th China-Japan international workshop on information technology and control applications, May 2019

Modeling, Simulation and Optimization of Supply Chain, Production and Logistics Operations

The Simulation for the Ideal Optimum Site Model in the Actual Distance Method

Angela Yu Yen Chen and Yutaka Karasawa

1 Introduction

Our research is based on the real distance data for selecting optimum sites, there are five types are taken consideration, ① Ideal type optimum site (without consideration of available or unavailable locations), ② Present location plus α type optimum site (present center plus one to four optimum delivery sites), ③ Available location type optimum site, ④ Present location plus α available location type optimum site (present center plus one to four available optimum locations), and ⑤ Present location type only, moreover, subject to those types, we set up locations from one, two, three, four, to five places, for each type of the optimum sites selection model, there are 20 places of the optimum places are selected, the reason for a maximum of five locations is that the area only covers approximately 50 km in a small area of Japan, for integrating discussion to find the best solution for rational problem and real problem 1 (Fig. 1).

As this is a new research project, we tried to divide the region into 35 areas by zip code, but it did not really work, then we divided into 38 places for the delivery zone of the research, by measuring the actual distances between the distribution center and customer's place, so-called the map 38 places of the actual distance method.

The basic approach of the whole research is based on analyzing the master data from the distribution center, the area of the objects and analysis of delivery distribution properties in the map, the measurement of the center of gravity of the delivery

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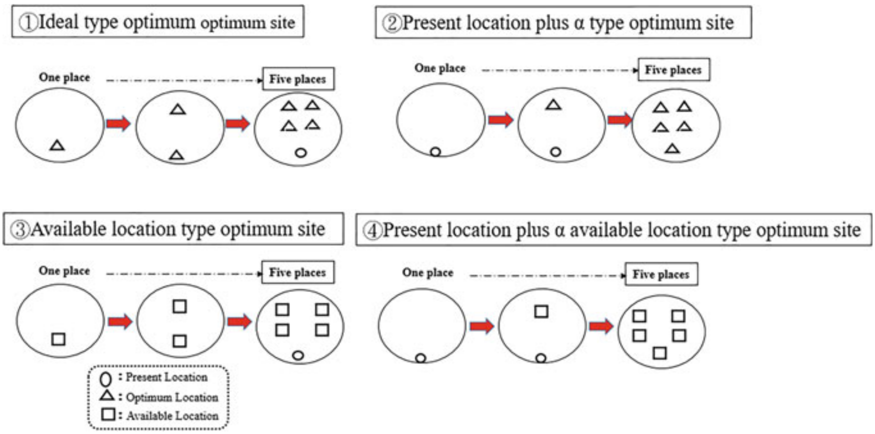

Fig. 1 Types of optimum locations simulations

zone and inspection of the error (the error inspection is carried out only for the approximation distance method), as shown in Fig. 2. The basic data for the simulation is the preparation for the distant table and ℓk (carrying one liter for one kilometer) table, the implement for the simulations of the optimum sites are based on the ideal type by actual distance method in the map (using the Google Maps Distance Matrix API), the dividing the cost for delivery centers are based on estimation the delivery cost and inventory cost and final evaluation for the optimum site of Σℓk, then our research continues inspecting for the optimum site, selecting the best order 2, as shown in Fig. 3.

2 Research Contents

2.1 Theory of Segmentation by City and Village

2.1.1 The Calculation of Gravity Points

The first step of the process of implementing simulation for an optimum site is to decide how to divide the area as shown in the Fig. 4. After trying to place 500 customers' addresses of one group by mapping, and making sure that there will be one portion of land without any disruption, such as rivers and mountains, and the range will not be too distant. However, some of the customers' master data did not meet the JIS (Japanese Industrial Standards) code on the map, moreover, some of the addresses could not be found in the areas, so we modified the mistyped and mapped again the area as 38 locations for selecting the optimum sites.

(1) Basic data :

① Number of customers: 13,012 households
② Number of deliveries: 19,018 bottles
③ Period, etc.: Data by delivery volume by daily delivery for 30 days
④ Delivery volume by product:
10L = 30 bottles, 20L = 8,193 bottles, 50L = 19,652 bottles
⑤ Total delivery amount: 1,146,760ℓ/30 days
⑥ Target area: Kita-Mikawa area (see map)
However, the difference in the number of delivery customers from the 38 area categories =>13,012-12,612 = 400. The reason for difference: There seems to be a difference depending on how you organize (address-based).

(2) Simulation and location types and types:

Location type	One Location	2 Locations	3 Locations	4 Locations	5 Locations
①Ideal type optimum location	OL1	OL2	OL3	OL4	OL5
②Present location plus α type	×	PLα2	PLα3	PLα4	PLα5
③Available type optimum location	AOL1	AOL2	AOL3	AOL4	AOL5
④Present location plus α available type	×	APLα2	APLα3	APLα4	APLα5

Remarks:
①PL : Present Location
②OL : Optimum Location
③AL : Available Location

Fig. 2 Master data and the types of simulation

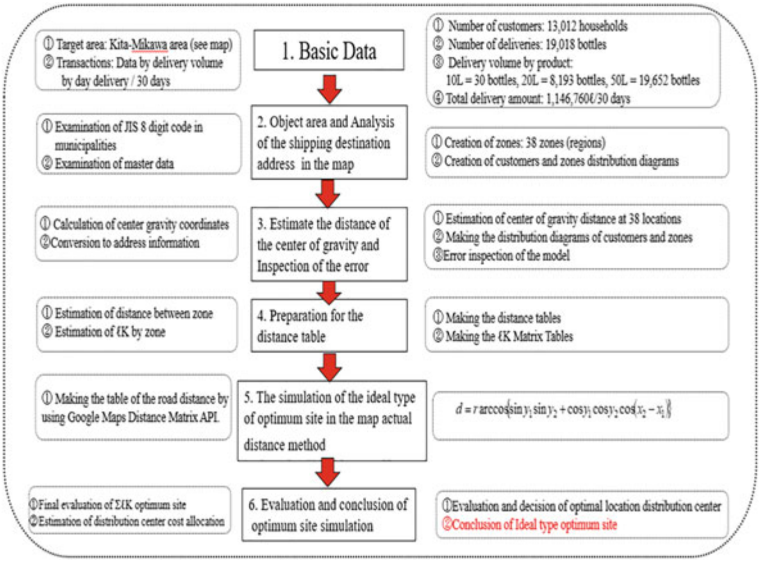

Fig. 3 The concept of research process

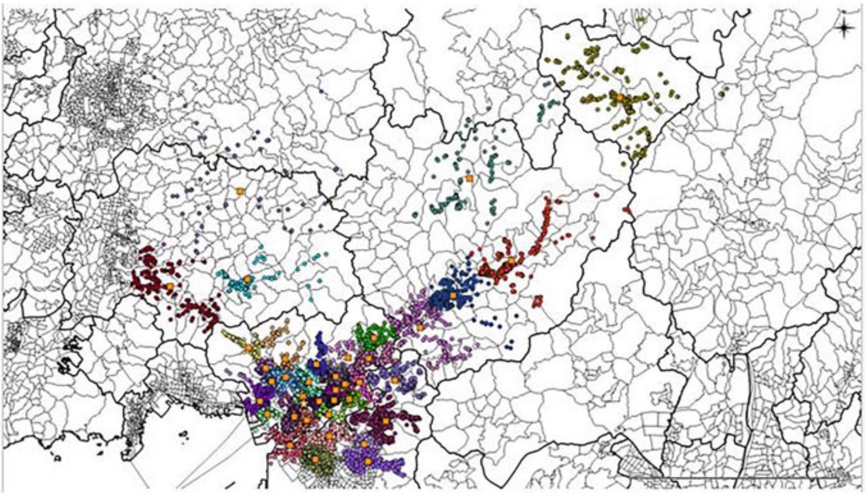

Fig. 4 The preparation of the customers' distribution map (*Remark* there is not any enclave within the land)

General speaking, taking the whole Japan areas, then you should divide the area by prefectures, since our research is only focused on the small area in Japan, so we group the areas by postcode for calculating the optimum sites.

We decided to use the Yahoo Open Local Platform (YOLP) system/software, implementing geocoding, with the information from 13,012 destinations by longitude and latitude, by taking the actual distance, though there were several incorrect data which were modified by hand. Since there are 2500 times per day limitation of using the Google Maps API. Therefore, the grouping was completed by mapping the customers' information, and each group included the information of longitude and latitude of the customers' addresses and delivery amount (ℓ) are introduced for the center of gravity coordinates (longitude and latitude).

The centers of gravity coordinates of each area are as follows:

$$x = \frac{\sum_{i=1}^{n} T_i x_i}{\sum_{i=1}^{n} T_i}, \; y = \frac{\sum_{i=1}^{n} T_i y_i}{\sum_{i=1}^{n} T_i}$$

Remarks:
x_i: longitude of customers' address
y_i: latitude of customers' address
T_i: delivery amount (ℓ)
n: customers' numbers in each area

2.1.2 The Considerations and the Quantity of Dividing into 38 Areas

Trying to set up a standard about 500 customers' addresses as one group by mapping, and making sure that there will be one group, even the road divided into two parts, and the size of the area not being too distant. However, some of the customers' master data did not meet the JIS (Japanese Industrial Standards) code on the map, moreover, from the code, some of the addresses could not be found in the areas, finally, we adjusted as 38 areas on the map, the detailed information of the 38 locations is shown in Table 1. Customers by cities, from P1 to P23 are Toyogawa-shi (city), from P24 to P30 are Toyahashi-shi, from P31 to P34 belongs to Sinsiro-shi, and Kita-sitara-gun is on P35, from P36 to P38 are Okazaki-shi, as shown in Figs. 5, 6 and 7. We also looked at the number of customers, and there are 13,012 households, with the total amount of delivery being 1,146,760 L, which included 30 bottles of 10 L size, 8193 bottles of 20 L size, and 19,652 bottles of 50 L size. After deciding the 38 locations the actual distance method is used for calculating the distance between the two places of these 38 areas, therefore, we used the master data to calculate the figure of the customers, the demanding amount, and the distance of each location. Finally, we produced a demand-distance table for simulation.

The solution of our research is to calculate the total cost (delivery fee plus center operation fee) from the master data to produce the ℓk (unit price for carrying one liter for one kilometer) and it is an appropriate tentative perspective from the model by each zone. Then, the delivery expenses were introduced, finally, to put those expenses into the delivery centers that were selected, then the simulation for the optimum sites were analyzed. There are one to five places for consideration, the base on the method of the present and unit price by zone, namely, to simulate by four types of the optimum site model and the present center.

2.2 Preparation of the Distant Table and ℓk Table

The method of preparing the distance matrix tables between the cities and villages, we used the actual distance and the approximate distance from the map, here we adopted the actual distance method for simulation, moreover, for preparing the ℓk matrix Table 4, which is based on the distance table of 38 areas, as shown in Table 2, then the basic document for simulation is completed, as shown in Table 3. General speaking, when it comes to selecting an optimum site model like a gravity model, people usually used the tk (tone/kilometer) matrix method to actually calculate the results of dividing, this research has more or less, 20 thousand customers scattered over the eastern part of the Aichi Prefecture and one western part of the Shizuoka prefecture in Japan. Therefore, we use the ℓk instead of the tk as the unit 3.

Table 1 T38 areas on the map

No.	Name of cities	No. of user
1	Toyokawa-shi	8065
2	Toyohashi-shi	2765
3	Sinshiro-shi	1380
4	Kitashitara-gun	374
5	Okazaki-shi	391
6	Toyota-shi	30
7	Hamamatsu-shi (Shizuoka)	7
Total		13,012

Location	Cities	No. of customers	Customers (%)	Delivery amount (ℓ)	Delivery amount (%)
P1	Toyokawa-shi ①	142	1.1	11,050	1.0
P2	Toyokawa-shi ②	667	5.1	54,370	4.7
P3	Toyokawa-shi ③	471	3.6	36,190	3.2
P4	Toyokawa-shi ④	346	2.7	30,390	2.7
P5	Toyokawa-shi ⑤	217	1.7	20,490	1.8
P6	Toyokawa-shi ⑥	129	1.0	9150	0.8
P7	Toyokawa-shi ⑦	519	4.0	44,140	3.8
P8	Toyokawa-shi ⑧	764	5.9	55,850	4.9
P9	Toyokawa-shi ⑨	316	2.4	25,050	2.2
P10	Toyokawa-shi ⑩	313	2.4	29,170	2.5
P11	Toyokawa-shi ⑪	290	2.2	27,280	2.4
P12	Toyokawa-shi ⑫	165	1.3	24,050	2.1
P13	Toyokawa-shi ⑬	183	1.4	14,850	1.3
P14	Toyokawa-shi ⑭	198	1.5	27,580	2.4
P15	Toyokawa-shi ⑮	415	3.2	38,070	3.3
P16	Toyokawa-shi ⑯	420	3.2	36,780	3.2
P17	Toyokawa-shi ⑰	212	1.6	18,540	1.6
P18	Toyokawa-shi ⑱	624	4.8	52,570	4.6
P19	Toyokawa-shi ⑲	259	2.0	19,450	1.7
P20	Toyokawa-shi ⑳	278	2.1	29,730	2.6
Location	Cities	No. of customers	Customers (%)	Delivery amount (ℓ)	Delivery amount (%)
P21	Toyokawa-shi ㉑	209	1.6	20,250	1.8
P22	Toyokawa-shi ㉒	661	5.1	51,010	4.4
P23	Toyokawa-shi ㉓	267	2.1	23,850	2.1
P24	Toyohashi-shi ①	299	2.3	23,900	2.1

(continued)

Table 1 (continued)

Location	Cities	No. of customers	Customers (%)	Delivery amount (ℓ)	Delivery amount (%)
P25	Toyohashi-shi ②	359	2.8	33,940	3.0
P26	Toyohashi-shi ③	276	2.1	32,600	2.8
P27	Toyohashi-shi ④	608	4.7	49,380	4.3
P28	Toyohashi-shi ⑤	398	3.1	39,060	3.4
P29	Toyohashi-shi ⑥	303	2.3	17,800	1.6
P30	Toyohashi-shi ⑦	522	4.0	63,980	5.6
P31	Sinshiro-shi ①	461	3.5	54,900	4.8
P32	Sinshiro-shi ②	360	2.8	36,950	3.2
P33	Sinshiro-shi ③	441	3.4	32,690	2.9
P34	Sinshiro-shi ④	142	1.1	5660	0.5
P35	Kitashitara-gun	357	2.7	15,070	1.3
P36	Okazaki-shi ①	233	1.8	23,830	2.1
P37	Okazaki-shi ②	126	1.0	9490	0.8%
P38	Okazaki-shi ③	62	0.5	7650	0.7
Total		13,012	100.0	1,146,760	100.0

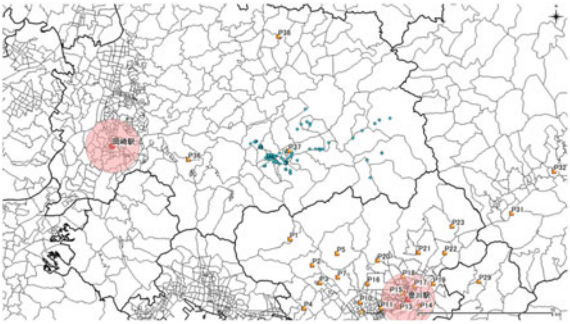

Fig. 5 P36 Okazaki-shi, 233 customers

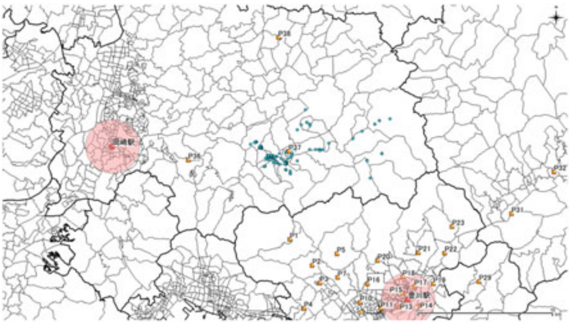

Fig. 6 P37 Okazaki-shi, 126 customers

Fig. 7 P38 Okazaki-shi, 62

The method of actual distance is taken from the Yahoo! Open Local Platform (YOLP) system/software, implementing geocoding,[1] with the information from 13,012 destinations by latitude and longitude, and there were several incorrect data which were modified by hand. Also, it was not possible to use the Google Maps API, since there is a limitation of 2500 times per day. Our research, therefore, decided to use YOLP at this time. As previously mentioned, the grouping was completed by mapping the customers' information, and each group included the information of the customers, and the latitude and longitude from the delivery amount (ℓ), and thereby calculated the gravity coordinates (latitude and longitude).

The method of approximate distance is to assume that the radius of the Earth, r = 6378.137 km (equatorial radius) is a ball shape, and the distance d is measured from spot A (latitude × 1, longitude y1) to spot B (latitude × 2, longitude y2), then the program is as follows;

$$d = r \arccos\{\sin y_1 \sin y_2 + \cos y_1 \cos y_2 \cos(x_2 - x_1)\}$$

Unfortunately, the Earth is an 「oval shape」, and consequently it caused a tolerance. Therefore, the method of drawing up the matrix distance between the two points of the cities should be considerate of both actual distance and approximate distance on the map (Fig. 8).

2.3 The Optimum Location Simulation

For finding a realistic solution for the horizontal optimum location simulation, we devised a new type of model so that we can support realistic management decisions and decision-making, not just using the number of conventional locations. In addition, the multi-step algorithm is based on a wide variety of algorithms such as

[1] Geocoding is the process of transforming a description of a location, such as a pair of coordinates, an address, or a name of a place, to a location on the earth's surface.

Table 2 Table of the actual distance method on the map for 38 areas (example)

Location		Arrival point	P1	P2	P3	P4	P5	P6
		Latitude	34.8629707	34.84561071	34.8337699	34.81672573	34.85331179	34.80561814
Start Point	Latitude	Longitude	137.30131	137.3194779	137.3255714	137.3128	137.3394865	137.3208462
P1	34.8629707	137.3013095	0	2.877	4.417	8.045	4.58	9.279
P2	34.84561071	137.3194779	2.877	0	1.955	4.885	3.509	5.478
P3	34.8337699	137.3255714	4.057	1.595	0	3.429	3.677	4.022
P4	34.81672573	137.3128	7.208	4.746	3.11	0	6.915	1.979
P5	34.85331179	137.3394865	4.806	3.076	3.251	7.059	0	7.567
P6	34.80561814	137.3208462	8.332	5.87	4.234	2.379	7.398	0
P7	34.83734598	137.3401707	5.617	2.791	2.239	5.406	2.195	5.915
P8	34.80326089	137.3489893	9.406	6.581	5.469	5.089	7.739	3.641
P9	34.8003621	137.3620273	9.676	6.851	5.693	5.684	8.009	4.236
P10	34.82064251	137.3580456	8.52	5.694	4.725	6.071	4.786	6.579
P11	34.81644871	137.3749543	9.928	7.102	6.576	7.922	6.146	6.589
P12	34.80506781	137.3851106	12.144	9.319	8.146	9.697	8.541	7.149
P13	34.81754503	137.3906428	10.825	7.999	8.927	10.273	7.464	7.596
P14	34.81837196	137.4069214	14.861	12.035	10.862	12.414	8.759	9.865
P15	34.82642438	137.3925224	11.585	7.922	7.988	9.334	6.987	9.843
P16	34.83316028	137.3642903	8.491	4.828	4.894	6.24	3.893	6.749
P17	34.83125618	137.402365	13.11	8.851	8.917	10.263	8.512	10.771
P18	34.83767594	137.3928127	11.811	7.651	7.717	9.063	7.213	9.571
P19	34.83295012	137.4176642	14.632	12.058	10.604	11.95	10.034	11.668

(continued)

Table 2 (continued)

Location		Arrival point	P1	P2	P3	P4	P5	P6
		Latitude	34.8629707	34.84561071	34.8337699	34.81672573	34.85331179	34.80561814
Start Point	Latitude	Longitude	137.30131	137.3194779	137.3255714	137.3128	137.3394865	137.3208462
P20	34.84866582	137.3725186	9.076	5.972	5.419	7.62	4.478	8.128
P21	34.8539671	137.4057124	13.294	10.6	10.048	12.248	8.696	12.756
P22	34.853703	137.4269815	15.261	12.567	12.014	14.215	10.663	14.723
P23	34.87139649	137.4329877	15.911	13.217	12.665	14.865	11.313	15.373
P24	34.77821126	137.3444784	13.56	9.272	7.634	6.335	10.604	4.887
P25	34.78638958	137.3855037	12.668	9.843	8.67	10.221	11	7.625
P26	34.77912055	137.4222122	17.757	14.931	13.758	15.31	13.511	12.714
P27	34.79929553	137.4449543	18.749	15.924	14.751	16.302	15.923	13.706
P28	34.76418687	137.4264511	17.802	14.976	13.803	15.355	16.134	12.759
P29	34.83445434	137.4547471	19.045	18.39	17.217	18.769	14.447	16.173
P30	34.76605784	137.3712467	15.086	12.26	11.087	9.741	13.418	8.293
P31	34.87994115	137.4812778	21.92	19.226	18.674	20.874	17.322	21.383
P32	34.90793958	137.5159418	25.74	23.046	22.494	24.694	21.142	25.202
P33	34.93778212	137.5777741	33.815	31.121	30.569	32.769	29.217	33.277
P34	35.00936674	137.5339967	49.003	46.309	45.757	47.957	44.405	48.465
P35	35.07888126	137.6921871	59.772	57.077	56.525	58.725	55.173	59.234
P36	34.91646628	137.2189389	10.237	13.145	14.74	17.926	14.136	19.159

(continued)

Table 2 (continued)

Location		Arrival point	P1	P2	P3	P4	P5	P6
		Latitude	34.8629707	34.84561071	34.8337699	34.81672573	34.85331179	34.80561814
Start Point	Latitude	Longitude	137.30131	137.3194779	137.3255714	137.3128	137.3394865	137.3208462
P37	34.92218539	137.3005012	10.905	13.812	15.407	18.593	14.526	19.826
P38	34.99872367	137.2921787	24.531	27.439	29.034	32.22	28.153	33.453

Location		Arrival point	P7	P8	P9	P10	P11	P12	P13
		Latitude	34.83734598	34.80326089	34.8003621	34.82064251	34.81644871	34.80506781	34.81754503
Start point	Latitude	Longitude	137.3401707	137.3489893	137.3620273	137.3580456	137.3749543	137.3851106	137.3906428
P1	34.8629707	137.3013095	5.411	9.214	9.393	8.17	9.302	12.061	10.852
P2	34.84561071	137.3194779	2.791	6.594	6.773	5.55	6.682	9.441	8.232
P3	34.8337699	137.3255714	1.92	5.152	5.331	4.237	6.206	7.999	8.209
P4	34.81672573	137.3128	5.168	5.089	7.034	5.941	7.91	9.703	9.913
P5	34.85331179	137.3394865	2.195	7.089	7.222	5.03	6.162	8.755	7.712
P6	34.80561814	137.3208462	5.651	3.641	4.236	5.219	6.618	7.188	7.596
P7	34.83734598	137.3401707	0	5.437	5.942	3.378	4.51	7.103	6.06
P8	34.80326089	137.3489893	5.293	0	2.013	3.107	3.355	5.087	5.297
P9	34.8003621	137.3620273	5.563	2.013	0	3.527	2.874	3.147	3.555
P10	34.82064251	137.3580456	3.04	3.118	2.887	0	2.421	4.237	4.448
P11	34.81644871	137.3749543	4.51	3.355	2.903	2.097	0	1.888	2.039
P12	34.80506781	137.3851106	6.795	4.85	3.108	4.001	1.701	0	2.352

(continued)

Table 2 (continued)

Location		Arrival point	P7	P8	P9	P10	P11	P12	P13
		Latitude	34.83734598	34.80326089	34.8003621	34.82064251	34.81644871	34.80506781	34.81754503
Start point	Latitude	Longitude	137.3401707	137.3489893	137.3620273	137.3580456	137.3749543	137.3851106	137.3906428
P13	34.81754503	137.3906428	5.827	5.373	3.555	4.448	1.784	2.066	0
P14	34.81837196	137.4069214	7.123	7.567	5.825	6.717	4.376	3.054	2.29
P15	34.82642438	137.3925224	5.578	5.819	5.132	4.393	2.757	3.643	1.671
P16	34.83316028	137.3642903	2.484	4.615	4.384	1.694	2.414	4.303	3.964
P17	34.83125618	137.402365	6.507	6.627	5.658	5.792	3.565	4.413	2.368
P18	34.83767594	137.3928127	5.307	7.513	6.114	4.592	3.225	5.939	2.824
P19	34.83295012	137.4176642	9.714	9.37	7.627	8.52	6.179	4.857	4.534
P20	34.84866582	137.3725186	3.627	6.997	6.766	4.076	4.744	6.632	5.76
P21	34.8539671	137.4057124	8.255	12.278	9.138	7.804	6.438	8.215	5.756
P22	34.853703	137.4269815	10.222	12.395	10.653	8.694	7.372	7.883	7.56
P23	34.87139649	137.4329877	10.873	14.895	12.709	11.282	10.441	9.939	9.616
P24	34.77821126	137.3444784	8.857	4.8	4.028	7.173	6.558	6.087	7.201
P25	34.78638958	137.3855037	8.555	5.402	3.65	6.332	3.987	2.548	4.677
P26	34.77912055	137.4222122	12.799	10.491	8.738	10.005	7.663	6.342	6.449
P27	34.79929553	137.4449543	13.792	11.483	9.731	10.998	8.656	7.334	7.034
P28	34.76418687	137.4264511	13.688	10.536	8.783	11.371	9.029	7.707	7.815
P29	34.83445434	137.4547471	14.127	13.95	12.197	13.464	11.122	9.8	9.5

(continued)

Table 2 (continued)

Location		Arrival point	P7	P8	P9	P10	P11	P12	P13
		Latitude	34.83734598	34.80326089	34.8003621	34.82064251	34.81644871	34.80506781	34.81754503
Start point	Latitude	Longitude	137.3401707	137.3489893	137.3620273	137.3580456	137.3749543	137.3851106	137.3906428
P30	34.76605784	137.3712467	10.972	6.2	6.067	8.749	6.996	5.558	7.687
P31	34.87994115	137.4812778	16.882	18.579	16.837	15.31	15.388	14.067	13.744
P32	34.90793958	137.5159418	20.702	23.601	21.859	21.112	17.554	19.089	18.766
P33	34.93778212	137.5777741	28.777	30.321	28.578	27.572	27.13	25.808	25.485
P34	35.00936674	137.5339967	43.965	47.987	46.758	44.374	43.533	43.987	43.664
P35	35.07888126	137.6921871	54.733	56.277	54.535	53.529	53.086	51.764	51.442
P36	34.91646628	137.2189389	15.291	19.094	19.273	18.05	19.182	21.941	20.732
P37	34.92218539	137.3005012	16.566	19.762	19.94	18.717	19.849	22.609	21.399
P38	34.99872367	137.2921787	30.193	33.388	33.567	32.344	33.476	36.235	35.026
Location		Arrival point	P14	P15	P16	P17	P18	P19	P20
		Latitude	34.818372	34.82642438	34.83316028	34.83125618	34.83767594	34.83295012	34.84866582
Start point	Latitude	Longitude	137.406921	137.3925224	137.3642903	137.402365	137.3928127	137.4176642	137.3725186
P1	34.8629707	137.3013095	11.965	10.896	7.917	13.012	11.803	14.505	9.01
P2	34.84561071	137.3194779	9.346	8.276	5.297	10.541	9.331	12.033	6.116
P3	34.8337699	137.3255714	10.8	7.815	4.368	10.081	8.871	11.573	5.655
P4	34.81672573	137.3128	12.504	9.491	6.513	10.324	9.411	11.904	8.062
P5	34.85331179	137.3394865	8.826	7.317	3.893	8.587	7.377	10.079	4.584

(continued)

Table 2 (continued)

Location		Arrival point	P14	P15	P16	P17	P18	P19	P20
		Latitude	34.818372	34.82642438	34.83316028	34.83125618	34.83767594	34.83295012	34.84866582
Start point	Latitude	Longitude	137.406921	137.3925224	137.3642903	137.402365	137.3928127	137.4176642	137.3725186
P6	34.80561814	137.3208462	9.773	8.932	6.996	9.699	9.894	11.357	8.545
P7	34.83734598	137.3401707	7.173	6.104	3.125	8.369	7.159	9.861	3.943
P8	34.80326089	137.3489893	7.55	6.184	4.601	6.755	7.499	9.134	6.983
P9	34.8003621	137.3620273	5.732	4.891	5.163	5.658	6.114	7.316	7.545
P10	34.82064251	137.3580456	6.906	4.825	1.639	5.64	4.537	8.49	4.021
P11	34.81644871	137.3749543	4.606	2.852	2.414	3.692	3.222	5.325	4.143
P12	34.80506781	137.3851106	3.453	3.689	4.115	5.292	5.087	5.764	5.843
P13	34.81754503	137.3906428	2.341	1.601	3.732	2.368	2.824	3.723	5.143
P14	34.81837196	137.4069214	0	2.56	5.027	2.719	3.407	3.077	6.459
P15	34.82642438	137.3925224	2.423	0	3.169	1.414	1.725	3.371	3.655
P16	34.83316028	137.3642903	5.078	3.5	0	4.037	2.898	5.392	2.382
P17	34.83125618	137.402365	2.647	1.344	4.098	0	1.418	1.651	4.469
P18	34.83767594	137.3928127	3.458	1.799	2.898	1.329	0	2.683	3.17
P19	34.83295012	137.4176642	3.091	2.906	5.786	1.651	3.077	0	6.584
P20	34.84866582	137.3725186	6.509	3.896	2.382	4.38	3.17	5.735	0
P21	34.8539671	137.4057124	6.449	4.732	6.111	4.11	3.505	4.788	5.096
P22	34.853703	137.4269815	6.117	5.884	7	4.629	4.292	3.13	6.775

(continued)

Table 2 (continued)

Location		Arrival point	P14	P15	P16	P17	P18	P19	P20
		Latitude	34.818372	34.82642438	34.83316028	34.83125618	34.83767594	34.83295012	34.84866582
Start point	Latitude	Longitude	137.406921	137.3925224	137.3642903	137.402365	137.3928127	137.4176642	137.3725186
P23	34.87139649	137.4329877	8.173	8.735	9.589	6.93	7.509	5.633	8.879
P24	34.77821126	137.3444784	8.672	8.537	8.755	9.783	10.501	10.256	11.137
P25	34.78638958	137.3855037	4.938	6.014	6.401	6.897	7.615	9.094	8.129
P26	34.77912055	137.4222122	7.124	7.785	9.779	8.818	9.895	8.352	12.947
P27	34.79929553	137.4449543	5.294	6.814	9.281	6.693	8.967	6.041	12.473
P28	34.76418687	137.4264511	8.49	9.151	11.145	10.184	11.261	10.455	14.313
P29	34.83445434	137.4547471	7.76	7.319	10.199	6.064	7.491	4.565	10.997
P30	34.76605784	137.3712467	7.948	9.023	10.28	9.907	10.625	12.104	12.662
P31	34.87994115	137.4812778	12.301	12.116	13.616	10.86	10.908	9.361	13.392
P32	34.90793958	137.5159418	17.323	17.138	19.418	15.883	14.475	14.383	18.708
P33	34.93778212	137.5777741	24.042	23.857	25.879	22.602	23.17	21.103	25.654
P34	35.00936674	137.5339967	42.221	41.828	42.681	40.781	40.601	39.282	41.971
P35	35.07888126	137.6921871	49.998	49.814	51.835	48.558	49.127	47.059	51.61
P36	34.91646628	137.2189389	21.846	21.298	17.874	22.568	21.358	24.06	18.566
P37	34.92218539	137.3005012	22.513	21.689	18.265	22.959	21.749	24.451	18.956
P38ˇ	34.99872367	137.2921787	36.14	35.316	31.892	36.585	35.376	38.078	32.583

(continued)

Table 2 (continued)

Location		Arrival point	P21	P22	P23	P24	P25	P26
		Latitude	34.8539671	34.853703	34.87139649	34.77821126	34.78638958	34.77912055
Start point	Latitude	Longitude	137.4057124	137.4269815	137.4329877	137.3444784	137.3855037	137.4222122
P1	34.8629707	137.3013095	12.958	14.639	15.618	12.3	12.462	17.846
P2	34.84561071	137.3194779	10.486	12.168	13.147	9.266	9.843	15.226
P3	34.8337699	137.3255714	10.026	11.707	12.686	7.81	8.4	13.783
P4	34.81672573	137.3128	12.433	14.115	15.093	6.331	10.104	15.487
P5	34.85331179	137.3394865	8.532	10.214	11.192	10.588	10.291	13.505
P6	34.80561814	137.3208462	12.916	14.598	15.576	4.883	7.557	12.782
P7	34.83734598	137.3401707	8.314	9.996	10.974	8.936	9.011	11.853
P8	34.80326089	137.3489893	10.712	12.112	14.19	4.796	5.549	10.813
P9	34.8003621	137.3620273	10.791	10.294	12.398	3.806	3.516	8.741
P10	34.82064251	137.3580456	7.75	8.642	11.228	6.95	5.956	9.964
P11	34.81644871	137.3749543	6.608	8.304	10.612	6.195	3.987	7.614
P12	34.80506781	137.3851106	9.24	10.79	10.846	5.409	2.842	6.048
P13	34.81754503	137.3906428	6.21	6.701	9.007	6.847	4.57	6.449
P14	34.81837196	137.4069214	6.553	6.056	8.16	9.652	4.938	6.565
P15	34.82642438	137.3925224	5.111	6.35	7.786	8.424	6.148	8.457

(continued)

Table 2 (continued)

Location		Arrival point	P21	P22	P23	P24	P25	P26
		Latitude	34.8539671	34.853703	34.87139649	34.77821126	34.78638958	34.77912055
Start point	Latitude	Longitude	137.4057124	137.4269815	137.4329877	137.3444784	137.3855037	137.4222122
P16	34.83316028	137.3642903	6.111	7.003	9.589	8.444	6.401	9.757
P17	34.83125618	137.402365	4.271	4.629	6.528	9.484	6.917	8.681
P18	34.83767594	137.3928127	3.505	4.295	7.509	9.406	8.443	9.492
P19	34.83295012	137.4176642	4.729	3.13	5.98	9.928	9.094	8.673
P20	34.84866582	137.3725186	5.096	6.778	7.933	11.149	8.731	11.553
P21	34.8539671	137.4057124	0	2.803	5.58	13.286	10.719	12.422
P22	34.853703	137.4269815	2.986	0	3.107	12.954	12.182	11.761
P23	34.87139649	137.4329877	5.58	3.107	0	15.01	14.111	13.69
P24	34.77821126	137.3444784	13.731	13.234	15.338	0	4.971	9.554
P25	34.78638958	137.3855037	12.27	11.683	14.534	5.637	0	6.304
P26	34.77912055	137.4222122	12.265	10.942	13.115	9.854	6.304	0
P27	34.79929553	137.4449543	10.618	8.63	10.539	12.648	7.934	3.453
P28	34.76418687	137.4264511	13.631	13.045	14.853	9.558	6.233	2.016
P29	34.83445434	137.4547471	9.142	6.258	8.065	15.114	10.4	9.316
P30	34.76605784	137.3712467	15.28	14.693	17.543	4.287	3.516	5.924
P31	34.87994115	137.4812778	10.106	7.394	6.071	22.182	17.469	16.298
P32	34.90793958	137.5159418	15.41	12.416	9.637	27.205	22.491	21.088

(continued)

Table 2 (continued)

Location		Arrival point	P21	P22	P23	P24	P25	P26
		Latitude	34.8539671	34.853703	34.87139649	34.77821126	34.78638958	34.77912055
Start point	Latitude	Longitude	137.4057124	137.4269815	137.4329877	137.3444784	137.3855037	137.4222122
P33	34.93778212	137.5777741	21.864	19.135	18.24	33.924	29.21	27.807
P34	35.00936674	137.5339967	38.673	37.315	34.861	52.103	47.389	45.987
P35	35.07888126	137.6921871	47.821	45.092	44.196	59.88	55.167	53.764
P36	34.91646628	137.2189389	22.513	24.195	25.174	22.18	22.343	27.726
P37	34.92218539	137.3005012	23.366	25.316	25.983	22.847	23.01	28.393
P38ˇ	34.99872367	137.2921787	36.531	38.212	39.191	36.474	36.637	42.02
Location		Arrival point	P27	P28	P29	P30	P31	P32
		Latitude	34.7992955	34.76418687	34.83445434	34.76605784	34.87994115	34.90793958
Start point	Latitude	Longitude	137.444954	137.4264511	137.4547471	137.3712467	137.4812778	137.5159418
P1	34.8629707	137.3013095	16.169	17.289	19.316	15.179	22.215	25.447
P2	34.84561071	137.3194779	13.549	14.669	16.845	12.56	19.209	22.976
P3	34.8337699	137.3255714	14.471	13.227	16.385	10.863	18.748	22.515
P4	34.81672573	137.3128	16.175	14.931	16.716	9.384	21.156	24.923
P5	34.85331179	137.3394865	15.968	15.118	14.891	13.009	17.789	21.022
P6	34.80561814	137.3208462	13.738	12.384	16.173	7.936	21.639	25.406
P7	34.83734598	137.3401707	11.377	13.838	14.673	11.728	17.037	20.804
P8	34.80326089	137.3489893	11.769	10.376	14.205	5.935	18.343	23.366

(continued)

Table 2 (continued)

Location		Arrival point	P27	P28	P29	P30	P31	P32
		Latitude	34.7992955	34.76418687	34.83445434	34.76605784	34.87994115	34.90793958
Start point	Latitude	Longitude	137.444954	137.4264511	137.4547471	137.3712467	137.4812778	137.5159418
P9	34.8003621	137.3620273	9.697	8.343	12.132	5.378	16.526	21.548
P10	34.82064251	137.3580456	10.92	10.783	13.355	8.673	16.217	21.057
P11	34.81644871	137.3749543	8.571	8.98	11.006	7.296	14.535	19.557
P12	34.80506781	137.3851106	7.04	7.414	9.476	6.152	16.134	21.157
P13	34.81754503	137.3906428	6.544	7.815	8.534	7.88	12.932	17.955
P14	34.81837196	137.4069214	5.375	7.931	7.667	8.248	14.469	19.491
P15	34.82642438	137.3925224	6.626	9.823	8.183	9.457	12.581	17.603
P16	34.83316028	137.3642903	9.281	11.123	10.203	10.17	14.578	19.418
P17	34.83125618	137.402365	6.698	10.047	6.462	10.227	10.86	15.883
P18	34.83767594	137.3928127	7.763	10.858	7.495	11.753	11.87	14.552
P19	34.83295012	137.4176642	6.041	10.455	4.963	12.403	9.361	14.383
P20	34.84866582	137.3725186	10.815	12.919	10.546	12.552	14.353	17.763
P21	34.8539671	137.4057124	9.79	14.204	8.734	14.029	10.378	13.061
P22	34.853703	137.4269815	9.128	13.543	6.188	15.491	7.832	12.854
P23	34.87139649	137.4329877	11.058	15.472	7.994	17.42	6.498	9.637
P24	34.77821126	137.3444784	12.672	9.095	15.108	3.934	21.766	26.788
P25	34.78638958	137.3855037	7.934	5.926	10.37	3.816	17.028	22.05

(continued)

Table 2 (continued)

Location		Arrival point	P27	P28	P29	P30	P31	P32
		Latitude	34.7992955	34.76418687	34.83445434	34.76605784	34.87994115	34.90793958
Start point	Latitude	Longitude	137.444954	137.4264511	137.4547471	137.3712467	137.4812778	137.5159418
P26	34.77912055	137.4222122	3.396	2.016	8.533	6.355	15.087	21.032
P27	34.79929553	137.4449543	0	5.042	5.957	9.437	12.511	18.456
P28	34.76418687	137.4264511	5.041	0	10.271	6.058	16.825	22.77
P29	34.83445434	137.4547471	6.683	11.395	0	13.709	10.037	15.059
P30	34.76605784	137.3712467	8.975	5.465	13.379	0	20.037	25.06
P31	34.87994115	137.4812778	13.666	18.377	9.966	20.778	0	5.869
P32	34.90793958	137.5159418	18.456	23.167	15.304	25.8	5.869	0
P33	34.93778212	137.5777741	25.175	29.886	22.023	32.519	12.588	7.56
P34	35.00936674	137.5339967	43.354	48.066	40.202	50.699	30.768	23.717
P35	35.07888126	137.6921871	51.131	55.843	47.979	58.476	38.545	33.71
P36	34.91646628	137.2189389	29.95	27.169	28.872	25.06	31.77	35.003
P37	34.92218539	137.3005012	30.34	27.837	29.263	25.727	32.045	35.812
P38ˇ	34.99872367	137.2921787	43.967	41.463	42.889	39.354	47.22	47.903

Location		Arrival point	P33	P34	P35	P36	P37	P38
		Latitude	34.93778212	35.00936674	35.07888126	34.91646628	34.92218539	34.99872367
Start point	Latitude	Longitude	137.5777741	137.5339967	137.6921871	137.2189389	137.3005012	137.2921787
P1	34.8629707	137.3013095	31.868	48.093	59.51	10.17	11.075	24.492

(continued)

Table 2 (continued)

Location		Arrival point	P33	P34	P35	P36	P37	P38
		Latitude	34.93778212	35.00936674	35.07888126	34.91646628	34.92218539	34.99872367
Start point	Latitude	Longitude	137.5777741	137.5339967	137.6921871	137.2189389	137.3005012	137.2921787
P2	34.84561071	137.3194779	29.397	45.622	57.039	13.173	14.455	27.495
P3	34.8337699	137.3255714	28.936	45.161	56.578	14.425	15.707	28.747
P4	34.81672573	137.3128	31.344	47.568	58.986	17.496	18.778	31.818
P5	34.85331179	137.3394865	27.443	43.667	55.085	14.148	14.729	28.469
P6	34.80561814	137.3208462	31.827	48.051	59.469	18.62	19.902	32.942
P7	34.83734598	137.3401707	27.225	43.449	54.867	16.134	16.716	30.456
P8	34.80326089	137.3489893	30.085	46.665	56.073	19.109	20.391	33.431
P9	34.8003621	137.3620273	28.267	46.446	54.255	19.379	20.661	33.701
P10	34.82064251	137.3580456	27.478	43.703	53.947	18.725	19.307	33.047
P11	34.81644871	137.3749543	26.276	43.087	52.265	20.086	20.667	34.407
P12	34.80506781	137.3851106	27.876	46.055	53.864	21.847	23.129	36.169
P13	34.81754503	137.3906428	24.674	42.853	50.662	21.403	21.985	35.725
P14	34.81837196	137.4069214	26.21	44.39	52.198	22.698	23.28	37.02
P15	34.82642438	137.3925224	24.322	41.59	50.311	20.926	21.508	35.248
P16	34.83316028	137.3642903	25.839	42.064	52.307	17.832	18.414	32.154
P17	34.83125618	137.402365	22.602	40.781	48.59	22.451	24.379	36.773
P18	34.83767594	137.3928127	23.611	39.984	49.599	21.152	23.08	35.474

(continued)

Table 2 (continued)

Location		Arrival point	P33	P34	P35	P36	P37	P38
		Latitude	34.93778212	35.00936674	35.07888126	34.91646628	34.92218539	34.99872367
Start point	Latitude	Longitude	137.5777741	137.5339967	137.6921871	137.2189389	137.3005012	137.2921787
P19	34.83295012	137.4176642	21.103	39.282	47.091	23.973	25.901	38.295
P20	34.84866582	137.3725186	24.184	40.408	52.083	18.417	18.999	32.739
P21	34.8539671	137.4057124	22.119	38.055	48.108	22.635	23.366	36.957
P22	34.853703	137.4269815	19.573	37.753	45.561	24.602	25.333	38.924
P23	34.87139649	137.4329877	18.24	33.806	44.228	25.252	25.983	39.574
P24	34.77821126	137.3444784	33.507	51.687	59.495	23.263	24.545	37.584
P25	34.78638958	137.3855037	28.769	46.949	54.757	22.371	23.653	36.693
P26	34.77912055	137.4222122	27.751	45.93	53.739	27.459	28.741	41.781
P27	34.79929553	137.4449543	25.175	43.354	51.163	29.862	31.79	44.184
P28	34.76418687	137.4264511	29.489	47.668	55.477	27.505	28.786	41.826
P29	34.83445434	137.4547471	21.778	39.957	47.766	28.386	30.314	42.708
P30	34.76605784	137.3712467	31.779	49.958	57.767	24.788	26.07	39.11
P31	34.87994115	137.4812778	12.588	30.768	38.576	31.261	31.992	43.568
P32	34.90793958	137.5159418	7.591	23.749	33.738	35.081	35.812	44.405
P33	34.93778212	137.5777741	0	17.288	27.466	43.156	43.887	50.826
P34	35.00936674	137.5339967	17.288	0	34.445	53.898	47.177	44.281
P35	35.07888126	137.6921871	27.469	34.445	0	69.113	69.843	65.06

(continued)

Table 2 (continued)

Location		Arrival point	P33	P34	P35	P36	P37	P38
		Latitude	34.93778212	35.00936674	35.07888126	34.91646628	34.92218539	34.99872367
Start point	Latitude	Longitude	137.5777741	137.5339967	137.6921871	137.2189389	137.3005012	137.2921787
P36	34.91646628	137.2189389	41.424	57.146	69.066	0	10.269	16.391
P37	34.92218539	137.3005012	42.233	46.225	69.875	10.115	0	17.615
P38ˇ	34.99872367	137.2921787	54.324	44.281	65.06	16.382	17.615	0

Table 3 The ℓk Matrix table of the actual distance method on the map for 38 areas (example) (Unit:ℓkm)

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1	0	31790.85	48807.85	88897.25	50609	102533	59791.55	101814.7	103792.7	90278.5
P2	156422.5	0	106293.4	265597.5	190784.3	297838.9	151746.7	358515.8	368248	301753.5
P3	146822.8	57723.05	0	124095.5	133070.6	145556.2	69484.8	186450.9	192928.9	153337
P4	219051.1	144230.9	94512.9	0	210146.9	60141.81	157055.5	154654.7	213763.3	180547
P5	98474.94	63027.24	66612.99	144638.9	0	155047.8	44975.55	145253.6	147978.8	103064.7
P6	76237.8	53710.5	38741.1	21767.85	67691.7	0	51706.65	33315.15	38759.4	47753.85
P7	247934.4	123194.7	98829.46	238620.8	96887.3	261088.1	0	239989.2	262279.9	149104.9
P8	525325.1	367548.9	305443.7	284220.7	432223.2	203349.9	295614.1	0	112426.1	173526
P9	242383.8	171617.6	142609.7	142384.2	200625.5	106111.8	139353.2	50425.65	0	88351.35
P10	248528.4	166094	137828.3	177091.1	139607.6	191909.4	88676.8	90952.06	84213.79	0
P11	270835.8	193742.6	179393.3	216112.2	167662.9	179747.9	123032.8	91524.4	79193.84	57206.16
P12	292063.2	224122	195911.3	233212.9	205411.1	171933.5	163419.8	116642.5	74747.4	96224.05
P13	160751.3	118785.2	132566	152554.1	110840.4	112800.6	86530.95	79789.05	52791.75	66052.8
P14	409866.4	331925.3	299574	342378.1	241573.2	272076.7	196452.3	208697.9	160653.5	185254.9
P15	441041	301590.5	304103.2	355345.4	265995.1	374723	212354.5	221529.3	195375.2	167241.5
P16	312299	177573.8	180001.3	229507.2	143184.5	248228.2	91361.52	169739.7	161243.5	62305.32
P17	243059.4	164097.5	165321.2	190276	157812.5	199694.3	120639.8	122864.6	104899.3	107383.7
P18	620904.3	402213.1	405682.7	476441.9	379187.4	503147.5	278989	394958.4	321413	241401.4
P19	284592.4	234528.1	206247.8	232427.5	195161.3	226942.6	188937.3	182246.5	148345.2	165714
P20	269829.5	177547.6	161106.9	226542.6	133130.9	241645.4	107830.7	208020.8	201153.2	121179.5
P21	269203.5	214650	203472	248022	176094	258309	167163.8	248629.5	185044.5	158031

(continued)

Table 3 (continued)

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P22	778463.6	641042.7	612834.1	725107.2	543919.6	751020.2	521424.2	632269	543409.5	443480.9
P23	379477.4	315225.5	302060.3	354530.3	269815.1	366646.1	259321.1	355245.8	303109.7	269075.7
P24	324084	221600.8	182452.6	151406.5	253435.6	116799.3	211682.3	114720	96269.2	171434.7
P25	429951.9	334071.4	294259.8	346900.7	373340	258792.5	290356.7	183343.9	123881	214908.1
P26	578878.2	486750.6	448510.8	499106	440458.6	414476.4	417247.4	342006.6	284858.8	326163
P27	925825.6	786327.1	728404.4	804992.8	786277.7	676802.3	681049	567030.5	480516.8	543081.2
P28	695346.1	584962.6	539145.2	599766.3	630194	498366.5	534653.3	411536.2	343064	444151.3
P29	339001	327342	306462.6	334088.2	257156.6	287879.4	251460.6	248310	217106.6	239659.2
P30	965202.3	784394.8	709346.3	623229.2	858483.6	530586.1	701988.6	396676	388166.7	559761
P31	1203408	1055507	1025203	1145983	950977.8	1173927	926821.8	1019987	924351.3	840519
P32	951093	851549.7	831153.3	912443.3	781196.9	931213.9	764938.9	872057	807690.1	780088.4
P33	1105412	1017345	999300.6	1071219	955103.7	1087825	940720.1	991193.5	934214.8	901328.7
P34	277357	262108.9	258984.6	271436.6	251332.3	274311.9	248841.9	271606.4	264650.3	251156.8
P35	900764	860150.4	851831.8	884985.8	831457.1	892656.4	824826.3	848094.4	821842.5	806682
P36	243947.7	313245.4	351254.2	427176.6	336860.9	456559	364384.5	455010	459275.6	430131.5
P37	103488.5	131075.9	146212.4	176447.6	137851.7	188148.7	157211.3	187541.4	189230.6	177624.3
P38	187662.2	209908.4	222110.1	246483	215370.5	255915.5	230976.5	255418.2	256787.6	247431.6
	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
P1	102787.1	133274.1	119914.6	132213.3	120400.8	87482.85	143782.6	130423.2	160280.3	99560.5
P2	363300.3	513307.2	447573.8	508142	449966.1	287997.9	573114.2	507326.5	654234.2	332526.9
P3	224595.1	289483.8	297083.7	390852	282824.9	158077.9	364831.4	321041.5	418826.9	204654.5

(continued)

Table 3 (continued)

	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
P4	240384.9	294874.2	301256.1	379996.6	288431.5	197930.1	313746.4	286000.3	361762.6	245004.2
P5	126259.4	179390	158018.9	180844.7	149925.3	79767.57	175947.6	151154.7	206518.7	93926.16
P6	60554.7	65770.2	69503.4	89422.95	81727.8	64013.4	88745.85	90530.1	103916.6	78186.75
P7	199071.4	313526.4	267488.4	316616.2	269430.6	137937.5	369407.7	315998.3	435264.5	174044
P8	187376.8	284109	295837.5	421667.5	345376.4	256965.9	377266.8	418819.2	510133.9	390000.6
P9	71993.7	78832.35	89052.75	143586.6	122519.6	129333.2	141732.9	153155.7	183265.8	189002.3
P10	70620.57	123593.3	129748.2	201448	140745.3	47809.63	164518.8	132344.3	247653.3	117292.6
P11	0	51504.64	55623.92	125651.7	77802.56	65853.92	100717.8	87896.16	145266	113021
P12	40909.05	0	56565.6	83044.65	88720.45	98965.75	127272.6	122342.4	138624.2	140524.2
P13	26492.4	30680.1	0	34763.85	23774.85	55420.2	35164.8	41936.4	55286.55	76373.55
P14	120690.1	84229.32	63158.2	0	70604.8	138644.7	74990.02	93965.06	84863.66	178139.2
P15	104959	138689	63614.97	92243.61	0	120643.8	53830.98	65670.75	128334	139145.9
P16	88786.92	158264.3	145795.9	186768.8	128730	0	148480.9	106588.4	198317.8	87609.96
P17	66095.1	81817.02	43902.72	49075.38	24917.76	75976.92	0	26289.72	30609.54	82855.26
P18	169538.3	312213.2	148457.7	181787.1	94573.43	152347.9	69865.53	0	141045.3	166646.9
P19	120181.6	94468.65	88186.3	60119.95	56521.7	1 12537.7	32111.95	59847.65	0	128058.8
P20	141039.1	197169.4	171244.8	193512.6	115828.1	70816.86	130217.4	94244.1	170501.6	0
P21	130369.5	166353.8	116559	130592.3	95823	123747.8	83227.5	70976.25	96957	103194
P22	376045.7	402111.8	385635.6	312028.2	300142.8	357070	236125.3	218934.9	159661.3	345592.8
P23	249017.9	237045.2	229341.6	194926.1	208329.8	228697.7	165280.5	179089.7	134347.1	21 1764.2
P24	156736.2	145479.3	172103.9	207260.8	204034.3	209244.5	233813.7	250973.9	245118.4	266174.3

(continued)

Table 3 (continued)

	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
P25	135318.8	86479.12	158737.4	167595.7	204115.2	217249.9	234084.2	258453.1	308650.4	275898.3
P26	249813.8	206749.2	210237.4	232242.4	253791	318795.4	287466.8	322577	272275.2	422072.2
P27	427433.3	362152.9	347338.9	261417.7	336475.3	458295.8	330500.3	442790.5	298304.6	615916.7
P28	352672.7	301035.4	305253.9	331619.4	357438.1	435323.7	397787	439854.7	408372.3	559065.8
P29	197971.6	174440	169100	138128	130278.2	181542.2	107939.2	133339.8	81257	195746.6
P30	447604.1	355600.8	491814.3	508513	577291.5	657714.4	633849.9	679787.5	774413.9	810114.8
P31	844801.2	772278.3	754545.6	675324.9	665168.4	747518.4	596214	598849.2	513918.9	735220.8
P32	648620.3	705338.6	693403.7	640084.9	633249.1	717495.1	586876.9	534851.3	531451.9	691260.6
P33	886879.7	843663.5	833104.7	785933	779885.3	845984.5	738859.4	757427.3	689857.1	838629.3
P34	246396.8	248966.4	247138.2	238970.9	236746.5	241574.5	230820.5	229801.7	222336.1	237555.9
P35	800006	780083.5	775230.9	753469.9	750697	781153.5	731769.1	740343.9	709179.1	777762.7
P36	457107.1	522854	494043.6	520590.2	507531.3	425937.4	537795.4	508961.1	573349.8	442427.8
P37	188367	214559.4	203076.5	213648.4	205828.6	173334.9	217880.9	206398	232040	179892.4
P38	256091.4	277197.8	267948.9	276471	270167.4	243973.8	279875.3	270626.4	291296.7	249260
	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30
P1	143185.9	161761	172578.9	135915	137705.1	197198.3	178667.5	191043.5	213441.8	167728
P2	570123.8	661574.2	714802.4	503792.4	535163.9	827837.6	736659.1	797553.5	915862.7	682887.2
P3	362840.9	423676.3	459106.3	282643.9	303996	498806.8	523705.5	478685.1	592973.2	393132
P4	377838.9	428954.9	458676.3	192399.1	307060.6	470649.9	491558.3	453753.1	507999.2	285179.8
P5	174820.7	209284.9	229324.1	216948.1	210862.6	276717.5	327184.3	309767.8	305116.6	266554.4
P6	118181.4	133571.7	142520.4	44679.45	69146.55	116955.3	125702.7	113313.6	147983	72614.4

(continued)

Table 3 (continued)

	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30
P7	366980	441223.4	484392.4	394435	397745.5	523191.4	502180.8	610809.3	647666.2	517673.9
P8	598265.2	676455.2	792511.5	267856.6	309911.7	603906.1	657298.7	579499.6	793349.3	331469.8
P9	270314.6	257864.7	310569.9	95340.3	88075.8	218962.1	242909.9	208992.2	303906.6	134718.9
P10	226067.5	252087.1	327520.8	202731.5	173736.5	290649.9	318536.4	314540.1	389565.4	252991.4
P11	180266.2	226533.1	289495.4	168999.6	108765.4	207709.9	233816.9	244974.4	300243.7	199034.9
P12	222222	259499.5	260846.3	130086.5	68350.1	145454.4	169312	178306.7	227897.8	147955.6
P13	92218.5	99509.85	133754	101678	67864.5	95767.65	97178.4	11 6052.8	126729.9	117018
P14	180731.7	167024.5	225052.8	266202.2	136190	181062.7	148242.5	218737	211455.9	227479.8
P15	194575.8	241744.5	296413	320701.7	234054.4	321958	252251.8	373961.6	311526.8	360028
P16	224762.6	257570.3	352683.4	310570.3	235428.8	358862.5	341355.2	409103.9	375266.3	374052.6
P17	79184.34	85821.66	121029.1	175833.4	128241.2	160945.7	124180.9	186271.4	119805.5	189608.6
P18	184257.9	225788.2	394748.1	494473.4	443848.5	498994.4	408100.9	570805.1	394012.2	617855.2
P19	91979.05	60878.5	116311	193099.6	176878.3	168689.9	1 17497.5	203349.8	96530.35	241238.4
P20	151504.1	201509.9	235848.1	331459.8	259572.6	343470.7	321530	384081.9	313532.6	373171
P21	0	56760.75	112995	269041.5	217059.8	251545.5	198247.5	287631	176863.5	284087.3
P22	152315.9	0	158488.1	660783.5	621403.8	599928.6	465619.3	690828.4	315649.9	790195.9
P23	133083	74101.95	0	357988.5	336547.4	326506.5	263733.3	369007.2	190656.9	415467
P24	328170.9	316292.6	366578.2	0	118806.9	228340.6	302860.8	217370.5	361081.2	94022.6
P25	416443.8	396521	493284	191319.8	0	213957.8	269280	201128.4	351957.8	129515
P26	399839	356709.2	427549	321240.4	205510.4	0	1 10709.6	65721.6	278175.8	207173
P27	524316.8	426149.4	520415.8	624558.2	391780.9	170509.1	0	248974	294156.7	465999.1

(continued)

Table 3 (continued)

	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30
P28	532426.9	509537.7	580158.2	373335.5	243461	78744.96	196901.5	0	401185.3	236625.5
P29	162727.6	111392.4	143557	269029.2	185120	165824.8	118957.4	202831	0	244020.2
P30	977614.4	940058.1	1122401	274282.3	224953.7	379017.5	574220.5	349650.7	855988.4	0
P31	554819.4	405930.6	333297.9	1217792	959048.1	894760.2	750263.4	1008897	547133.4	1140712
P32	569399.5	458771.2	356087.2	1005225	831042.5	779201.6	681949.2	856020.7	565482.8	953310
P33	714734.2	625523.2	596265.6	1108976	954874.9	909010.8	822970.8	976973.3	719931.9	1063046
P34	218889.2	211202.9	197313.3	294903	268221.7	260286.4	245383.6	272053.6	227543.3	286956.3
P35	720662.5	679536.4	666033.7	902391.6	831366.7	810223.5	770544.2	841554	723043.5	881233.3
P36	536484.8	576566.9	599896.4	528549.4	532433.7	660710.6	713708.5	647437.3	688019.8	597179.8
P37	221743.3	240248.8	246578.7	216818	218364.9	269449.6	287926.6	264173.1	277705.9	244149.2
P38	279462.2	292321.8	299811.2	279026.1	280273.1	321453	336347.6	317192	328100.9	301058.1

	P31	P32	P33	P34	P35	P36	P37	P38
P1	245475.8	2811 89.4	352141.4	531427.7	657585.5	112378.5	122378.8	270636.6
P2	1044393	1249205	1598315	2480468	3101210	716216	785918.4	1494903
P3	678490.1	814817.9	1047194	1634377	2047558	522040.8	568436.3	1040354
P4	642930.8	757410	952544.2	1445592	1792585	531703.4	570663.4	966949
P5	364496.6	430740.8	562307.1	894736.8	1128692	289892.5	301797.2	583329.8
P6	197996.9	232464.9	291217.1	439666.7	544141.4	170373	182103.3	301419.3
P7	752013.2	918288.6	1201712	1917839	2421829	712154.8	737844.2	1344328
P8	1024457	1304991	1680247	2606240	3131677	1067238	1138837	1867121
P9	413976.3	539777.4	708088.4	1163472	1359088	485444	517558.1	844210.1

(continued)

Table 3 (continued)

	P31	P32	P33	P34	P35	P36	P37	P38
P10	473049.9	614232.7	801533.3	1274817	1573634	546208.3	563185.2	963981
P11	396514.8	533515	716809.3	1175413	1425789	547946.1	563795.8	938623
P12	388022.7	508825.9	670417.8	1107623	1295429	525420.4	556252.5	869864.5
P13	192040.2	266631.8	366408.9	636367.1	752330.7	317834.6	326477.3	530516.3
P14	399055	537561.8	722871.8	1224276	1439621	626010.8	642062.4	1021012
P15	478958.7	670146.2	925938.5	1583331	1915340	796652.8	818809.6	1341891
P16	536178.8	714194	950358.4	1547114	1923851	655861	677266.9	1182624
P17	201344.4	294470.8	419041.1	756079.7	900858.6	416241.5	451986.7	681771.4
P18	624005.9	764998.6	1241230	2101959	2607419	1111961	1213316	1864868
P19	182071.5	279749.4	410453.4	764034.9	915920	466274.9	503774.5	744837.8
P20	426714.7	528094	718990.3	1201330	1548428	547537.4	564840.3	973330.5
P21	210154.5	264485.3	447909.8	770613.8	974187	458358.8	473161.5	748379.3
P22	399510.3	655682.5	998418.7	1925781	2324067	1254948	1292236	1985513
P23	154977.3	229842.5	435024	806273.1	1054838	602260.2	619694.6	943839.9
P24	520207.4	640233.2	800817.3	1235319	1421931	555985.7	586625.5	898257.6
P25	577930.3	748377	976419.9	1593449	1858453	759271.7	802782.8	1245360
P26	491836.2	685643.2	904682.6	1497318	1751891	895163.4	936956.6	1362061
P27	617793.2	911357.3	1243142	2140821	2526429	1474586	1569790	2181806
P28	657184.5	889396.2	1151840	1861912	2166932	1074345	1124381	1633724
P29	178658.6	268050.2	387648.4	711234.6	850234.8	505270.8	539589.2	760202.4
P30	1281967	1603339	2033220	3196313	3695933	1585936	1667959	2502258

(continued)

Table 3 (continued)

	P31	P32	P33	P34	P35	P36	P37	P38
P31	0	322208.1	691081.2	1689163	2117822	1716229	1756361	2391883
P32	216859.6	0	280487.5	877525.6	1246619	1296243	1323253	1640765
P33	411501.7	247136.4	0	565144.7	897863.5	1410770	1434666	1661502
P34	174146.9	134238.2	97850.08	0	194958.7	305062.7	267021.8	250630.5
P35	580873.2	508009.7	413957.8	519086.2	0	1041533	1052534	980454.2
P36	757079.1	834121.5	987133.9	1361789	1645843	0	244710.3	390597.5
P37	304107.1	339855.9	400791.2	438675.3	663113.8	95991.35	0	167166.4
P38	361233	366458	415578.6	338749.7	497709	125322.3	134754.8	0

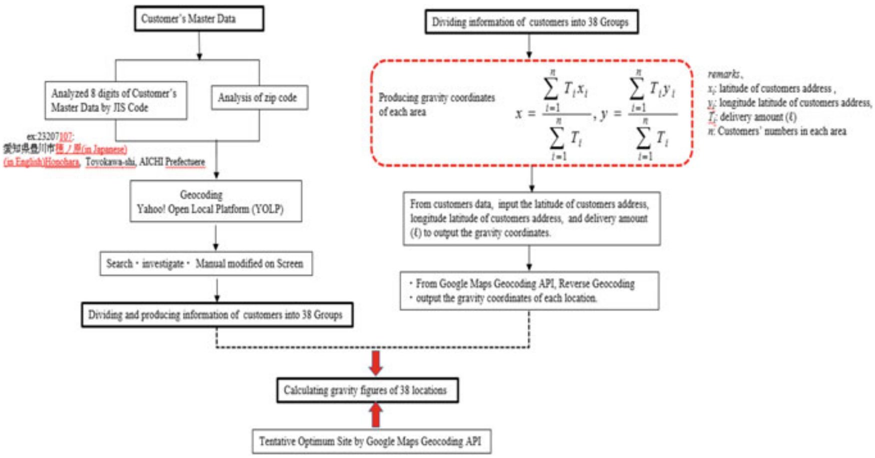

Fig. 8 Process of selecting optimum sites

optimal solutions and approximate solutions, but the Gravity Model is generally the main one-step horizontal optimal location simulation tool. However, in this research, there are 20 thousand delivery customers must be grouped and the distance of the center of gravity must be estimated, and a simple location model that applies mapping graph theory is applied to represent its validity. We adopted a method of verification using a gravitational model (Gravity Model), using the Gravity Model to show which area is the best for establishing a delivery center, with the lowest cost for the firm, and knowing how important the optimum site selection affects the company's management and strategy. However, this paper is only focused on the actual distance method, in the near future, we will produce the paper for the method of approximate distance.

3 The Results of the Simulation for the Ideal Optimum Site Type in the Actual Distance of 38 Places Mapping

Our research is introducing from longitude and latitude for selecting the ideal type of optimum sites, generally speaking, the simulation of one phase of multi points model uses the following gravity models:

$$f(C) = \sum_{i=1}^{n} \{T(P_i) \min K(P_i, C_j)\} \tag{1}$$

$$Cj \in C = \{C_1, C_2, \ldots, C_m\} \in P = \{P_1, P_2, \ldots, P_n\} \tag{2}$$

However, T(Pi) is the demanding amount in the area Pi, and K(Pi, Cj) is the distance between the area Pi and the delivery center Cj. At this moment, the objective function f (C) is the minimum, namely, it becomes the min f (C), which the group C puts the most optimum delivery centers together. For instance, when we search for the most optimum delivery centers of two places from the whole area, first of all, choosing the two candidate places $C' = \{C'1, C'2\}$ of the delivery centers from the P, and also making the P as a yardstick for the shortest distance, to allocate it for either delivery center candidate area, we divided P into network N′1, N′2 (but $N'1 \cup N'2 = P$) of the delivery destination area affiliated with each candidate delivery center area, at this moment, C’1belong to ($\in$)N′1, C′2 belong to ($\in$)N′2 and C′1 and C′2 are respectively the optimum sites in the network of N′1, N′2, When it is equivalent to the center of gravity, C′1 and C′2 are respectively the optimum delivery centers in the N′1 and N′2.

Regarding the above all with all of the combination of the C′ (nC2 ways), and attempting repeatedly, to find out the optimum delivery centers C = {C1, C2}by the combination of the minimized ΣTK. Even the number of the optimum delivery centers m is increasing, it can be accepted by similar logic.

The summary from the 38 map areas with the actual distance method, for the simulation of ideal type optimum sites are for the one place is 9,576,888ℓk, for the two places are 7,342,602ℓk, for the three places are 6,251,990ℓk, for the four places are 5,291,167ℓk and for the five places are 4,614,433ℓk, those results ignored the characters of the inventory fee and delivery fee, as shown in Table 4.

3.1 Simulation of 38 Locations for the Ideal Type of Optimum Sites

We analyzed the 38 map areas with the actual distance method of the Ideal type, from one to five places to be the delivery centers, the calculation time of the Ideal type optimum sites from one to five places are 0.73 ms, 2.50 ms, 21.95 ms, 220.49 ms, and 1,732.2 ms, as shown in Fig. 9, 10, 11, 12 and 13. The longest running time for the Ideal type of optimum sites was taken 1732.2 ms.

3.2 Available Locations

There are four types of simulations are included in the simulation model, and one to five places of optimum locations are, the Plus α type means the present center plus one to four optimum locations, The Available type means the location is able to be a delivery center by Japanese Law, the Ideal type means any area where there is an Ideal place to set up a delivery center. There are five locations that are

Table 4 The summary of ideal type of the optimum sites in actual distance of 38 map areas

Locations	Delivery center		$\sum \ell K$	Calculate time (ms)
	Centers	Address		
1 Location	P11	20, 4 Chome, Minamioodoori, Toyogawa-shi, Aichi-ken	9,576,888	0.73
2 Locations	P11	20, 4 Chome, Minamioodoori, Toyogawa-shi, Aichi-ken	5,901,167	2.5
	P32	100, Tomizawa, Sinshiro-shi, Aichi-ken	1,441,435	
	Subtotal		7,342,602	
3 Locations	P2	46, Sinchou, Goyu-cho, Toyogawa-shi, Aichi-ken	1,127,907	21.95
	P11	20, 4 Chome, Minamioodoori, Toyogawa-shi, Aichi-ken	3,682,648	
	P32	100, Tomizawa, Sinshiro-shi, Aichi-ken	1,441,435	
	Subtotal		6,251,990	
4 Locations	P3	30, Toyonari, Koumachi, Toyogawa-shi, Aichi-ken	1,803,880	220.49
	P18	19, Hashimoto, Sanzougo-Cho, Toyogawa-shi, Aichi-ken	1,433,466	
	P26	14–4, 3-Chome, Ushikawadoori, Toyohashi-shi, Aichi-ken	842,229	
	P32	100, Tomizawa, Sinshiro-shi, Aichi-ken	1,211,592	
	Subtotal		5,291,167	
5 Locations	P2	46, Sinchou, Goyu-cho, Toyogawa-shi, Aichi-ken	1,074,196	1732.2
	P9	43, Nishiura, Kosakaimachi, Toyogawa-shi, Aichi-ken	609,491	
	P18	19, Hashimoto, Sanzougo-Cho, Toyogawa-shi, Aichi-ken	1,090,883	
	P26	14–4, 3-Chome, Ushikawadoori, Toyohashi-shi, Aichi-ken	628,272	
	P32	100, Tomizawa, Sinshiro-shi, Aichi-ken	1,211,592	
	Sub total		4,614,433	
Total			23,500,193	1,978

Remarks
1. The P11 center is near the present delivery center P9. Therefore, the present delivery center is the optimum site, too. The present Delivery Center's address is included on P9 area
2. MS Stands for Micro Second

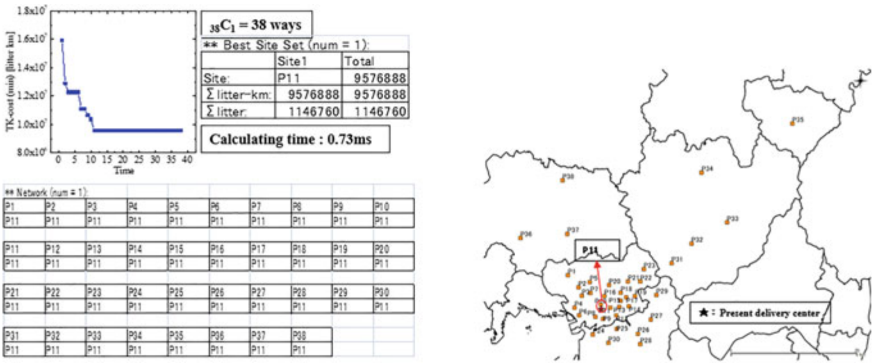

Fig. 9 One location for the ideal type of optimum sites

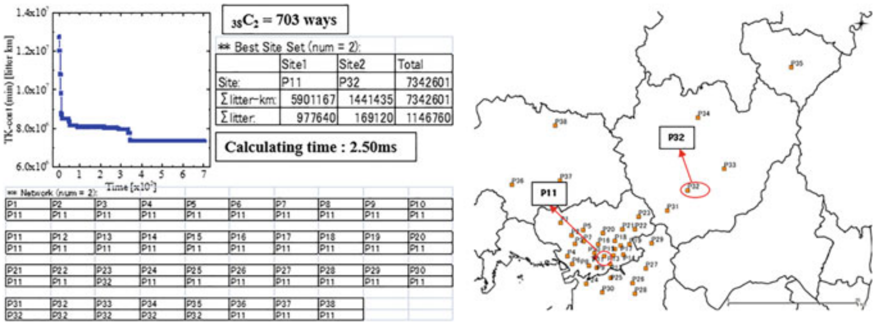

Fig. 10 Two locations for the ideal type of optimum sites

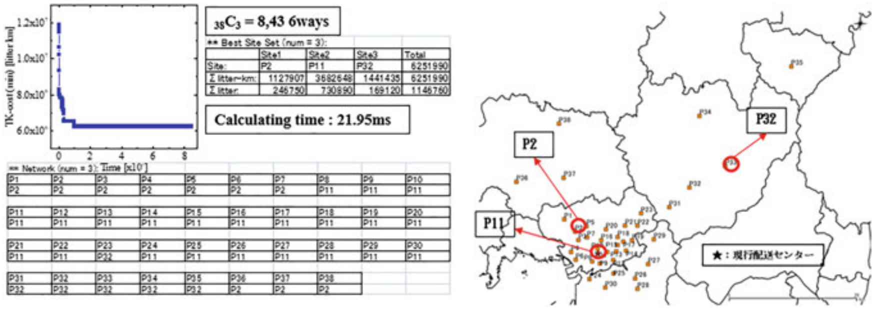

Fig. 11 Three locations for the ideal type of optimum sites

unavailable in our research, such as P14 (Location: Toyokawa-shi, Householder: 198 customers, Delivery Amount: 27,580ℓ), as shown in Fig. 14, and P15 (Location: Toyokawa-shi, Householder: 415 customers, Delivery Amount: 38,070ℓ) as shown in Fig. 15, P17 (Location: Toyokawa-shi, Householder: 212 customers, Delivery

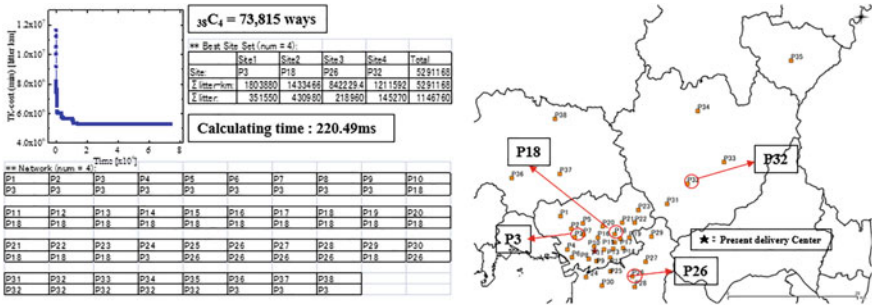

Fig. 12 Four locations for the ideal type of optimum sites

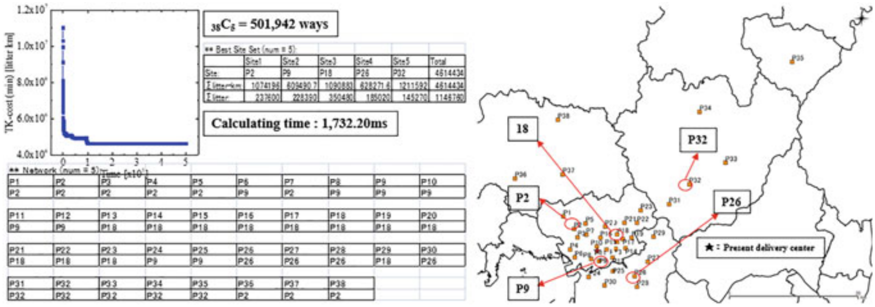

Fig. 13 Five locations for the ideal type of optimum sites

Amount: 18,540ℓ), P18 (Location: Toyokawa-shi, Householder: 624 customers, Delivery Amount: 52,570ℓ), and P30 (Location: Toyohashi-shi, Householder: 522 customers, Delivery Amount: 63,980ℓ), these places are near the Toyogawa Station, where the r = 200 km is not allowed to establish a dangerous goods delivery center, like gas. Even though, this paper is only focused on the Ideal type optimum sites in the actual distance method.

3.3 Summary of Optimum Site

In the 38 mapping actual distance method, there are five patterns of optimum sites in the Ideal type. It is true that the density of the customers is higher in the cities than those that are scattered in the suburbs. It is easy to estimate the optimum sites, between an overcrowded area and an underpopulated area of customer distribution, when actually, with the result of our simulations, there are only two places, one is in the overcrowded area, and the other is in the underpopulated area (Fig. 3). From

Fig. 14 Location P14

Fig. 15 Location P15

the result of the calculation, we picked the optimum sites for the minimum total liter-kilometer ($\Sigma\ell$k) places (Table 5).

3.4 Expenses for Delivery Center

There is a storage fee and a delivery fee for each delivery center, the former is the expense for inventory, calculated by the liter base, the latter is for expenses of the delivery goods, calculated by the liter and kilometer base. To allocate the Actual Distance Method to the 38 areas map actual distance. Usually, when we calculate the optimum inventory on the SKU (Stock Keeping Unit) base, the items of allocating shelves, such as a product or service, and all attributes associated with the working staff, equipment, and the frequency of storage and shipping times, and so on. Our research is based on the master data, to allocate $\Sigma\ell$ to produce the inventory fee. The present $\Sigma\ell$k calculated the delivery fee. Usually, the delivery fee is calculated for each optimum center by the delivery routes, which should be estimated by a

Table 5 ℓk of 38 area map actual distance method

Area	Location	Destination	10L (U)	20L (U)	50L (U)	Demands (L)
P1	Mukaidani, Nagasawamachi, Toyogawa-shi, Aichi-ken	142	1	28	113	11,050
P2	46, Sinchou, Goyu-cho, Toyogawa-shi, Aichi-ken	667	0	245	422	54,370
P3	30, Toyonari, Koumachi, Toyogawa-shi, Aichi-ken	471	1	103	367	36,190
P4	11–53, Otuyama, Hiroishi, Mito-cho, Toyogawa-shi, Aichi-ken	346	0	89	257	30,390
P5	23, Komaba, Hiraomachi, Toyogawa-shi, Aichi-ken	217	0	41	176	20,490
P6	154, Oumazenden, Mitocho, Toyogawa-shi, Aichi-ken	129	0	30	99	9150
P7	100, Hongou, Yahatacho, Toyogawa-shi, Aichi-ken	519	0	136	383	44,140
P8	350–261, Minamiyamasinden, Inacho, Toyogawa-shi, Aichi-ken	764	0	201	563	55,850
P9	43, Nishiura, Kosakaimachi, Toyogawa-shi, Aichi-ken	316	1	73	242	25,050
P10	10–5, 6 Chome, Zoushi, Toyogawa-shi, Aichi-ken	313	0	65	248	29,170
P11	20, 4 Chome, Minamioodoori, Toyogawa-shi, Aichi-ken	290	0	55	236	27,280
P12	41, Shiroshita, Ushikubomachi, Toyogawa-shi, Aichi-ken	165	0	37	128	24,050
P13	84–31, Shidou, Furuzyucho, Toyogawa-shi, Aichi-ken	183	0	42	141	14,850
P14	49, Shimonishiura, Miyaharacho, Toyogawa-shi, Aichi-ken	198	0	51	147	27,580
P15	67–1 2 Chome,, Sakuragidoori, Toyogawa-shi, Aichi-ken	415	0	124	291	38,070
P16	2-Chome, Honohara, Toyogawa-shi, Aichi-ken	420	2	100	318	36,780
P17	2, 1-Chome, Shinyutakamachi, Toyogawa-shi, Aichi-ken	212	0	60	152	18,540
P18	19, Hashimoto, Sanzougo-Cho, Toyogawa-shi, Aichi-ken	624	0	170	454	52,570
P19	43, Teramae, Asouda-Cho, Toyogawa-shi, Aichi-ken	259	0	54	205	19,450
P20	84, 2-Chome, Misenryou, Toyogawa-shi, Aichi-ken	278	0	71	207	29,730
P21	301, Shimonawate, Ookimachi, Toyogawa-shi, Aichi-ken	209	0	53	156	20,250

(continued)

Table 5 (continued)

Area	Location	Destination	10L (U)	20L (U)	50L (U)	Demands (L)
P22	137, Zyooshinkiri, Ikkucho, Toyogawa-shi, Aichi-ken	661	0	151	510	51,010
P23	13–6, Warita, Uenagayama-Cho, Toyogawa-shi, Aichi-ken	267	0	87	181	23,850
P24	41–3, Kadou, Maeshibamachi, Toyohashi-shi, Aichi-ken	299	1	87	211	23,900
P25	55, Ikan, Shimojicho, Toyohashi-shi, Aichi-ken	359	0	91	268	33,940
P26	14–4, 3-Chome, Ushikawadoori, Toyohashi-shi, Aichi-ken	276	0	63	213	32,600
P27	22, Oota, Ishimakihoncho, Toyohashi-shi, Aichi-ken	608	1	197	410	49,380
P28	146, Iharacho, Toyohashi-shi, Aichi-ken	398	0	97	301	39,060
P29	74 Koutubo, Ishimakinishikawacho, Toyohashi-shi, Aichi-ken	303	0	112	191	17,800
P30	102, Araki, Hanadacho, Toyohashi-shi, Aichi-ken	522	0	144	378	63,980
P31	Ichisukitanakagawara, Sinshiro-shi, Aichi-ken	461	0	91	370	54,900
P32	100, Tomizawa, Sinshiro-shi, Aichi-ken	360	0	73	287	36,950
P33	2–4, Nagashinohiyake, Sinshiro-shi, Aichi-ken	441	0	131	310	32,690
P34	Tadajishionosawa, Sinshiro-shi, Aichi-ken	142	2	100	40	5660
P35	Nakashitara, Toueicho, Kitasitara-gun, Aichi-ken	357	16	222	119	15,070
P36	12–15, Harayama, Okazaki-shi, Aichi-ken	233	0	42	191	23,830
P37	105, Harashinden, Kashiyamacho, Okazaki-shi, Aichi-ken	126	0	38	88	9490
P38	Chuicho, Okazaki-shi, Aichi-ken	62	0	17	45	7650

Area	10L (L)	20L (L)	50L (L)	10L (Bottle)	20L (Bottle)	50L (Bottle)	距離 (km)				
							P1	P2	P3	P4	P5
P1	60	1340	9650	6	67	193	0.00	2.88	4.42	8.05	4.58
P2	0	15,520	38,850	0	776	777	2.88	0.00	1.96	4.89	3.51

(continued)

Table 5 (continued)

Area	10L (L)	20L (L)	50L (L)	10L (Bottle)	20L (Bottle)	50L (Bottle)	距離 (km)				
							P1	P2	P3	P4	P5
P3	10	5580	30,600	1	279	612	4.06	1.60	0.00	3.43	3.68
P4	0	4740	25,650	0	237	513	7.21	4.75	3.11	0.00	6.92
P5	0	2340	18,150	0	117	363	4.81	3.08	3.25	7.06	0.00
P6	0	1300	7850	0	65	157	8.33	5.87	4.23	2.38	7.40
P7	0	7140	37,000	0	357	740	5.62	2.79	2.24	5.41	2.20
P8	0	8200	47,650	0	410	953	9.41	6.58	5.47	5.09	7.74
P9	10	3140	21,900	1	157	438	9.68	6.85	5.69	5.68	8.01
P10	0	3420	25,750	0	171	515	8.52	5.69	4.73	6.07	4.79
P11	0	2880	24,400	0	144	488	9.93	7.10	6.58	7.92	6.15
P12	0	1800	22,250	0	90	445	12.14	9.32	8.15	9.70	8.54
P13	0	1900	12,950	0	95	259	10.83	8.00	8.93	10.27	7.46
P14	0	2480	25,100	0	124	502	14.86	12.04	10.86	12.41	8.76
P15	0	5120	32,950	0	256	659	11.59	7.92	7.99	9.33	6.99
P16	20	4660	32,100	2	233	642	8.49	4.83	4.89	6.24	3.89
P17	0	3140	15,400	0	157	308	13.11	8.85	8.92	10.26	8.51
P18	0	7720	44,850	0	386	897	11.81	7.65	7.72	9.06	7.21
P19	0	2700	16,750	0	135	335	14.63	12.06	10.60	11.95	10.03
P20	0	3480	26,250	0	174	525	9.08	5.97	5.42	7.62	4.48
P21	0	2600	17,650	0	130	353	13.29	10.60	10.05	12.25	8.70
P22	0	6760	44,250	0	338	885	15.26	12.57	12.01	14.22	10.66
P23	0	3500	20,350	0	175	407	15.91	13.22	12.67	14.87	11.31

(continued)

Table 5 (continued)

Area	10L (L)	20L (L)	50L (L)	10L (Bottle)	20L (Bottle)	50L (Bottle)	距離 (km)				
							P1	P2	P3	P4	P5
P24	10	4840	19,050	1	242	381	13.56	9.27	7.63	6.34	10.60
P25	0	3840	30,100	0	192	602	12.67	9.84	8.67	10.22	11.00
P26	0	3400	29,200	0	170	584	17.76	14.93	13.76	15.31	13.51
P27	10	8120	41,250	1	406	825	18.75	15.92	14.75	16.30	15.92
P28	0	4460	34,600	0	223	692	17.80	14.98	13.80	15.36	16.13
P29	0	4100	13,700	0	205	274	19.05	18.39	17.22	18.77	14.45
P30	0	6780	57,200	0	339	1144	15.09	12.26	11.09	9.74	13.42
P31	0	4600	50,300	0	230	1006	21.92	19.23	18.67	20.87	17.32
P32	0	3200	33,750	0	160	675	25.74	23.05	22.49	24.69	21.14
P33	0	4940	27,750	0	247	555	33.82	31.12	30.57	32.77	29.22
P34	20	2640	3000	2	132	60	49.00	46.31	45.76	47.96	44.41
P35	160	5760	9150	16	288	183	59.77	57.08	56.53	58.73	55.17
P36	0	2780	21,050	0	139	421	10.24	13.15	14.74	17.93	14.14
P37	0	1940	7550	0	97	151	10.91	13.81	15.41	18.59	14.53
P38	0	1000	6650	0	50	133	24.53	27.44	29.03	32.22	28.15

Area	距離 (km)										
	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
P1	9.28	5.41	9.21	9.39	8.17	9.30	12.06	10.85	11.97	10.90	7.92
P2	5.48	2.79	6.59	6.77	5.55	6.68	9.44	8.23	9.35	8.28	5.30
P3	4.02	1.92	5.15	5.33	4.24	6.21	8.00	8.21	10.80	7.82	4.37
P4	1.98	5.17	5.09	7.03	5.94	7.91	9.70	9.91	12.50	9.49	6.51

(continued)

Table 5 (continued)

Area	距離 (km)										
	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
P5	7.57	2.20	7.09	7.22	5.03	6.16	8.76	7.71	8.83	7.32	3.89
P6	0.00	5.65	3.64	4.24	5.22	6.62	7.19	7.60	9.77	8.93	7.00
P7	5.92	0.00	5.44	5.94	3.38	4.51	7.10	6.06	7.17	6.10	3.13
P8	3.64	5.29	0.00	2.01	3.11	3.36	5.09	5.30	7.55	6.18	4.60
P9	4.24	5.56	2.01	0.00	3.53	2.87	3.15	3.56	5.73	4.89	5.16
P10	6.58	3.04	3.12	2.89	0.00	2.42	4.24	4.45	6.91	4.83	1.64
P11	6.59	4.51	3.36	2.90	2.10	0.00	1.89	2.04	4.61	2.85	2.41
P12	7.15	6.80	4.85	3.11	4.00	1.70	0.00	2.35	3.45	3.69	4.12
P13	7.60	5.83	5.37	3.56	4.45	1.78	2.07	0.00	2.34	1.60	3.73
P14	9.87	7.12	7.57	5.83	6.72	4.38	3.05	2.29	0.00	2.56	5.03
P15	9.84	5.58	5.82	5.13	4.39	2.76	3.64	1.67	2.42	0.00	3.17
P16	6.75	2.48	4.62	4.38	1.69	2.41	4.30	3.96	5.08	3.50	0.00
P17	10.77	6.51	6.63	5.66	5.79	3.57	4.41	2.37	2.65	1.34	4.10
P18	9.57	5.31	7.51	6.11	4.59	3.23	5.94	2.82	3.46	1.80	2.90
P19	11.67	9.71	9.37	7.63	8.52	6.18	4.86	4.53	3.09	2.91	5.79
P20	8.13	3.63	7.00	6.77	4.08	4.74	6.63	5.76	6.51	3.90	2.38
P21	12.76	8.26	12.28	9.14	7.80	6.44	8.22	5.76	6.45	4.73	6.11
P22	14.72	10.22	12.40	10.65	8.69	7.37	7.88	7.56	6.12	5.88	7.00
P23	15.37	10.87	14.90	12.71	11.28	10.44	9.94	9.62	8.17	8.74	9.59
P24	4.89	8.86	4.80	4.03	7.17	6.56	6.09	7.20	8.67	8.54	8.76
P25	7.63	8.56	5.40	3.65	6.33	3.99	2.55	4.68	4.94	6.01	6.40

(continued)

Table 5 (continued)

Area	距離 (km)										
	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
P26	12.71	12.80	10.49	8.74	10.01	7.66	6.34	6.45	7.12	7.79	9.78
P27	13.71	13.79	11.48	9.73	11.00	8.66	7.33	7.03	5.29	6.81	9.28
P28	12.76	13.69	10.54	8.78	11.37	9.03	7.71	7.82	8.49	9.15	11.15
P29	16.17	14.13	13.95	12.20	13.46	11.12	9.80	9.50	7.76	7.32	10.20
P30	8.29	10.97	6.20	6.07	8.75	7.00	5.56	7.69	7.95	9.02	10.28
P31	21.38	16.88	18.58	16.84	15.31	15.39	14.07	13.74	12.30	12.12	13.62
P32	25.20	20.70	23.60	21.86	21.11	17.55	19.09	18.77	17.32	17.14	19.42
P33	33.28	28.78	30.32	28.58	27.57	27.13	25.81	25.49	24.04	23.86	25.88
P34	48.47	43.97	47.99	46.76	44.37	43.53	43.99	43.66	42.22	41.83	42.68
P35	59.23	54.73	56.28	54.54	53.53	53.09	51.76	51.44	50.00	49.81	51.84
P36	19.16	15.29	19.09	19.27	18.05	19.18	21.94	20.73	21.85	21.30	17.87
P37	19.83	16.57	19.76	19.94	18.72	19.85	22.61	21.40	22.51	21.69	18.27
P38	33.45	30.19	33.39	33.57	32.34	33.48	36.24	35.03	36.14	35.32	31.89
Area	距離 (km)										
	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27
P1	13.01	11.80	14.51	9.01	12.96	14.64	15.62	12.30	12.46	17.85	16.17
P2	10.54	9.33	12.03	6.12	10.49	12.17	13.15	9.27	9.84	15.23	13.55
P3	10.08	8.87	11.57	5.66	10.03	11.71	12.69	7.81	8.40	13.78	14.47
P4	10.32	9.41	11.90	8.06	12.43	14.12	15.09	6.33	10.10	15.49	16.18
P5	8.59	7.38	10.08	4.58	8.53	10.21	11.19	10.59	10.29	13.51	15.97
P6	9.70	9.89	11.36	8.55	12.92	14.60	15.58	4.88	7.56	12.78	13.74

(continued)

Table 5 (continued)

Area	距離 (km)										
	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27
P7	8.37	7.16	9.86	3.94	8.31	10.00	10.97	8.94	9.01	11.85	11.38
P8	6.76	7.50	9.13	6.98	10.71	12.11	14.19	4.80	5.55	10.81	11.77
P9	5.66	6.11	7.32	7.55	10.79	10.29	12.40	3.81	3.52	8.74	9.70
P10	5.64	4.54	8.49	4.02	7.75	8.64	11.23	6.95	5.96	9.96	10.92
P11	3.69	3.22	5.33	4.14	6.61	8.30	10.61	6.20	3.99	7.61	8.57
P12	5.29	5.09	5.76	5.84	9.24	10.79	10.85	5.41	2.84	6.05	7.04
P13	2.37	2.82	3.72	5.14	6.21	6.70	9.01	6.85	4.57	6.45	6.54
P14	2.72	3.41	3.08	6.46	6.55	6.06	8.16	9.65	4.94	6.57	5.38
P15	1.41	1.73	3.37	3.66	5.11	6.35	7.79	8.42	6.15	8.46	6.63
P16	4.04	2.90	5.39	2.38	6.11	7.00	9.59	8.44	6.40	9.76	9.28
P17	0.00	1.42	1.65	4.47	4.27	4.63	6.53	9.48	6.92	8.68	6.70
P18	1.33	0.00	2.68	3.17	3.51	4.30	7.51	9.41	8.44	9.49	7.76
P19	1.65	3.08	0.00	6.58	4.73	3.13	5.98	9.93	9.09	8.67	6.04
P20	4.38	3.17	5.74	0.00	5.10	6.78	7.93	11.15	8.73	11.55	10.82
P21	4.11	3.51	4.79	5.10	0.00	2.80	5.58	13.29	10.72	12.42	9.79
P22	4.63	4.29	3.13	6.78	2.99	0.00	3.11	12.95	12.18	11.76	9.13
P23	6.93	7.51	5.63	8.88	5.58	3.11	0.00	15.01	14.11	13.69	11.06
P24	9.78	10.50	10.26	11.14	13.73	13.23	15.34	0.00	4.97	9.55	12.67
P25	6.90	7.62	9.09	8.13	12.27	11.68	14.53	5.64	0.00	6.30	7.93
P26	8.82	9.90	8.35	12.95	12.27	10.94	13.12	9.85	6.30	0.00	3.40
P27	6.69	8.97	6.04	12.47	10.62	8.63	10.54	12.65	7.93	3.45	0.00

(continued)

Table 5 (continued)

Area	距離 (km)										
	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27
P28	10.18	11.26	10.46	14.31	13.63	13.05	14.85	9.56	6.23	2.02	5.04
P29	6.06	7.49	4.57	11.00	9.14	6.26	8.07	15.11	10.40	9.32	6.68
P30	9.91	10.63	12.10	12.66	15.28	14.69	17.54	4.29	3.52	5.92	8.98
P31	10.86	10.91	9.36	13.39	10.11	7.39	6.07	22.18	17.47	16.30	13.67
P32	15.88	14.48	14.38	18.71	15.41	12.42	9.64	27.21	22.49	21.09	18.46
P33	22.60	23.17	21.10	25.65	21.86	19.14	18.24	33.92	29.21	27.81	25.18
P34	40.78	40.60	39.28	41.97	38.67	37.32	34.86	52.10	47.39	45.99	43.35
P35	48.56	49.13	47.06	51.61	47.82	45.09	44.20	59.88	55.17	53.76	51.13
P36	22.57	21.36	24.06	18.57	22.51	24.20	25.17	22.18	22.34	27.73	29.95
P37	22.96	21.75	24.45	18.96	23.37	25.32	25.98	22.85	23.01	28.39	30.34
P38	36.59	35.38	38.08	32.58	36.53	38.21	39.19	36.47	36.64	42.02	43.97
Area	距離 (km)										
	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
P1	17.29	19.32	15.18	22.22	25.45	31.87	48.09	59.51	10.17	11.08	24.49
P2	14.67	16.85	12.56	19.21	22.98	29.40	45.62	57.04	13.17	14.46	27.50
P3	13.23	16.39	10.86	18.75	22.52	28.94	45.16	56.58	14.43	15.71	28.75
P4	14.93	16.72	9.38	21.16	24.92	31.34	47.57	58.99	17.50	18.78	31.82
P5	15.12	14.89	13.01	17.79	21.02	27.44	43.67	55.09	14.15	14.73	28.47
P6	12.38	16.17	7.94	21.64	25.41	31.83	48.05	59.47	18.62	19.90	32.94
P7	13.84	14.67	11.73	17.04	20.80	27.23	43.45	54.87	16.13	16.72	30.46
P8	10.38	14.21	5.94	18.34	23.37	30.09	46.67	56.07	19.11	20.39	33.43

(continued)

Table 5 (continued)

Area	距離 (km)										
	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
P9	8.34	12.13	5.38	16.53	21.55	28.27	46.45	54.26	19.38	20.66	33.70
P10	10.78	13.36	8.67	16.22	21.06	27.48	43.70	53.95	18.73	19.31	33.05
P11	8.98	11.01	7.30	14.54	19.56	26.28	43.09	52.27	20.09	20.67	34.41
P12	7.41	9.48	6.15	16.13	21.16	27.88	46.06	53.86	21.85	23.13	36.17
P13	7.82	8.53	7.88	12.93	17.96	24.67	42.85	50.66	21.40	21.99	35.73
P14	7.93	7.67	8.25	14.47	19.49	26.21	44.39	52.20	22.70	23.28	37.02
P15	9.82	8.18	9.46	12.58	17.60	24.32	41.59	50.31	20.93	21.51	35.25
P16	11.12	10.20	10.17	14.58	19.42	25.84	42.06	52.31	17.83	18.41	32.15
P17	10.05	6.46	10.23	10.86	15.88	22.60	40.78	48.59	22.45	24.38	36.77
P18	10.86	7.50	11.75	11.87	14.55	23.61	39.98	49.60	21.15	23.08	35.47
P19	10.46	4.96	12.40	9.36	14.38	21.10	39.28	47.09	23.97	25.90	38.30
P20	12.92	10.55	12.55	14.35	17.76	24.18	40.41	52.08	18.42	19.00	32.74
P21	14.20	8.73	14.03	10.38	13.06	22.12	38.06	48.11	22.64	23.37	36.96
P22	13.54	6.19	15.49	7.83	12.85	19.57	37.75	45.56	24.60	25.33	38.92
P23	15.47	7.99	17.42	6.50	9.64	18.24	33.81	44.23	25.25	25.98	39.57
P24	9.10	15.11	3.93	21.77	26.79	33.51	51.69	59.50	23.26	24.55	37.58
P25	5.93	10.37	3.82	17.03	22.05	28.77	46.95	54.76	22.37	23.65	36.69
P26	2.02	8.53	6.36	15.09	21.03	27.75	45.93	53.74	27.46	28.74	41.78
P27	5.04	5.96	9.44	12.51	18.46	25.18	43.35	51.16	29.86	31.79	44.18
P28	0.00	10.27	6.06	16.83	22.77	29.49	47.67	55.48	27.51	28.79	41.83
P29	11.40	0.00	13.71	10.04	15.06	21.78	39.96	47.77	28.39	30.31	42.71

(continued)

Table 5 (continued)

Area	距離 (km)										
	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38
P30	5.47	13.38	0.00	20.04	25.06	31.78	49.96	57.77	24.79	26.07	39.11
P31	18.38	9.97	20.78	0.00	5.87	12.59	30.77	38.58	31.26	31.99	43.57
P32	23.17	15.30	25.80	5.87	0.00	7.59	23.75	33.74	35.08	35.81	44.41
P33	29.89	22.02	32.52	12.59	7.56	0.00	17.29	27.47	43.16	43.89	50.83
P34	48.07	40.20	50.70	30.77	23.72	17.29	0.00	34.45	53.90	47.18	44.28
P35	55.84	47.98	58.48	38.55	33.71	27.47	34.45	0.00	69.11	69.84	65.06
P36	27.17	28.87	25.06	31.77	35.00	41.42	57.15	69.07	0.00	10.27	16.39
P37	27.84	29.26	25.73	32.05	35.81	42.23	46.23	69.88	10.12	0.00	17.62
P38	41.46	42.89	39.35	47.22	47.90	54.32	44.28	65.06	16.38	17.62	0.00

simulation of the optimum route, here, we estimated from $\Sigma\ell k$ to produce the direct delivery cost.

We analyzed the 38 map areas with the actual distance method with the Ideal type, from one to five places to be the delivery centers. The yardstick of selecting the optimum sites is the cost minimum strategies, which is to allocate the delivery fee and inventory fee of the delivery center. Namely, the optimum sites mean to allocate the total expenses into the inventory fee and delivery fee from one to five places to choose the minimum cost center, which is referred to as the so-called optimum delivery center. The process is to allocate the inventory fee and delivery fee to each center, then to make a ranking for each center from the total cost to choose the most minimum one.

On the other hand, if the district area of one place is common, then the Ideal type five optimum delivery centers sites are P2, P9, P18, P26 and P32. The result of the one location optimum site of a delivery center, the Ideal type has P11, the P11 site is near the present delivery center P9. Therefore, the present center is the optimum site, too. Due to the fact that the unavailable areas are small, the present delivery center is P9 which is near Toyogawa city. Finally, all the P2 and P26 of five locations optimum sites are overlapped. This is the balance for two places, such as P11 and P9 that are in an overcrowded area, and P32 and P33 that are in an underpopulated area. The Ideal type five locations of optimum sites is $\Sigma\ell k$4,614,433 (Table 6), this numerical data is only calculated on the ℓk base, and it should be aware that this does not mean the cost minimum. However, when we discuss the optimum sites, it means the minimum cost for the firm.

4 Examination

Regarding all of delivery centers where were simulated in $\Sigma\ell K$, and deciding for the layout of warehouse and scale, for calculating a storage cost, including the operational cost, moreover, about all delivery centers, we estimate the average delivery charges, setting a delivery route and simulating, and working out the all delivery-related delivery expenses, it is necessary for calculating the storage costs of each centers. In our study, we also select the optimum sites based on the amount of money-based, after calculating the cost (Table 7). As a results, the three places of delivery centers became the first place conclusively, and, as for the economical expectation effect, it is clear for reducing the current cost about 30%.

5 Conclusion

Our research is significant supporting systems for the real decision making of the enterprises, the proposal of a moderate price in a small area for a distribution center in Japan, the distribution center has adopted a mono price policy for the delivery

Table 6 Present $\Sigma\ell k$ calculate delivery fee for ideal type of delivery center in 38 actual distance

Centers			$\Sigma\ell k$	Compare to present $\Sigma\ell k$%	Delivery fee
One location	P11	First	9,576,888	80.1	15,000,206
Subtotal			9,576,888	80.1	15,000,206
Two locations	P11	First	5,901,167	49.3	9,242,953
	P32	Second	1,441,435	12.1	2,257,709
Subtotal			7,342,602	61.4	11,500,661
Three locations	P2	First	1,127,907	9.4	1,766,632
	P11	Second	3,682,648	30.8	5,768,103
	P32	Third	1,441,435	12.1	2,257,709
Subtotal			6,251,990	52.3	9,792,444
Four locations	P3	First	1,803,880	15.1	2,825,403
	P18	Second	1,433,466	12.0	2,245,227
	P26	Third	842,229	7.0	1,319,177
	P32	Fourth	1,211,592	10.1	1,897,707
Subtotal			5,291,167	44.2	8,287,514
Five locations	P2	First	1,074,196	9.0	1,682,505
	P9	Second	609,491	5.1	954,641
	P18	Third	1,090,883	9.1	1,708,642
	P26	Fourth	628,272	5.3	984,058
	P32	Fifth	1,211,592	10.1	1,897,707
Subtotal			4,614,434	38.6	7,227,553
Total			33,077,081	276.5	51,808,379

Remark 1 Delivery fee $=(\Sigma\ell k \div 11{,}961{,}020) \times 18{,}734{,}454$
Remark 2 Present delivery center's address is included on P9 area

Table 7 Simulation results for the ideal type of optimum sites on 38 map locations

① The ℓk Simulation Results of Map 38 Real Distance Ideal Type of Optimum Sites

Method	Items	Map 38 Real Distance Method
1 Ideal Type of Optimum Location	Optimum number of locations	5
	Location details	P2, P9, P18, P28, P32
	$\Sigma\ell K$	4,614,433
	Rank	1

② The Final Simulation Results of Map 38 Real Distance Ideal Type of Optimum Sites

Method	Items	Map 38 Real Distance Method
1 Ideal Type of Optimum Location	Optimum number of locations	3
	Location details	P2, P11, P32
	Amount	14,927,509
	Rank	1

Current 21,191,018Yen
▲6,263,09 Yen
▲29.6%

pricing of its products, although with contradiction over the years and in other aspects, with a delivery price to end users that has been substantially increasing, especially because of the cost which has grown due to the increased fuel charges. As a result, a reevaluation of the delivery price setting has been urgently required at this time by top management and a research project. Therefore, establishing the acceptable delivery price setting method has now started. A new price setting project is required to take into considerations several factors, including the new price setting theory, innovative price setting concept, contribution to the whole company's business activities, and so on. In order to justify and evaluate the newly proposed price, market price method, tariff price, cost plus α method, and so on, respectively.

This research is focused on how the optimum site will affect the delivery unit price in tentative research. Our simulation for an optimum site selection proposal was analyzed on the computer to get final solution, multi-location type of optimal distribution site selection as well as optimum site selection to get gravity points by zone based, instead of using the simulation model easily, we incorporate the wisdom that accorded in a model and a system practically, that was able to make introducing the points clearly.

It is unexpected joy, if our research can contribute to a young researcher for a bridge function between the theory and the practice. We also apologize for cutting the details from relations of the space.

References

Chen AYY, Karasawa Y, Aiura N, Suzuki K, Wakabayashi K (2014) Literature study overseas on SCM strategy with a state art SCM strategy model. In: Golinska P (ed) Logistics operations, supply chain management and sustainability. Springer, pp 201–226

Chen AYY, Sato T, Karasawa Y, Wakabayashi K, Toyotani J (2016a) A basic research on a delivery cost settings to end users supported by the optimum site selection model. Indonesia, ICLS. 47

Chen AYY, Sato T, Karasawa Y, Wakabayashi K, Toyotani J (2016b) A practical on optimum site selection in real world. Indonesia, ICLS, 77

Chen AYY, Sato T, Karasawa Y, Toyotani J, Wakabayashi K (2016c) A basic research on a delivery cost. In: Proceedings of 19th Nihon logistics system association, pp 136–138

Solving a Location-Allocation-Sizing Problem Using Differential Evolution Algorithm: A Case Study of Agricultural Water Resources in North-Eastern Thailand

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1 Introduction

Drought is one of the global problems that tend to increase in priority every year. The United Nations has revealed that many regions of the world have encountered severe aridity due to climate change. In 2020, water scarcity affected more than one billion people worldwide (United Nations 2020). There are three categories of drought, namely, meteorological, hydrological, and agricultural drought (Li et al. 2021). Agricultural drought has mainly affected crop production, which contributes to food security, social economy, and stability (Zhang et al. 2021a, b).

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https://doi.org/10.1007/978-3-031-15412-6_7

Thailand is a country located in the tropical area of Southeast Asia. The proportion of land used for agriculture is 46.56%. Moreover, farmers make up 38% of Thailand's population. Therefore, aridity has inevitably affected the agricultural productivity of Thailand. The overall crop area in Thailand is equal to 23.8 billion square meters, and 43% of the country's crop areas are in the north-eastern region (Ministry of Agriculture and Cooperatives of Thailand 2020). Ubon Ratchathani, one of the large areas in the region, has more than 8.56 billion square meters of cropland. The population size of Ubon Ratchathani is 1,686,571 people, and 48.37% are in the agricultural sector (National Statistics Organization of Thailand 2021). The Water Crisis Prevention Centre of Thailand (2021) reported that 534,201 m^2 in Ubon Ratchathani face a medium to high risk of aridity.

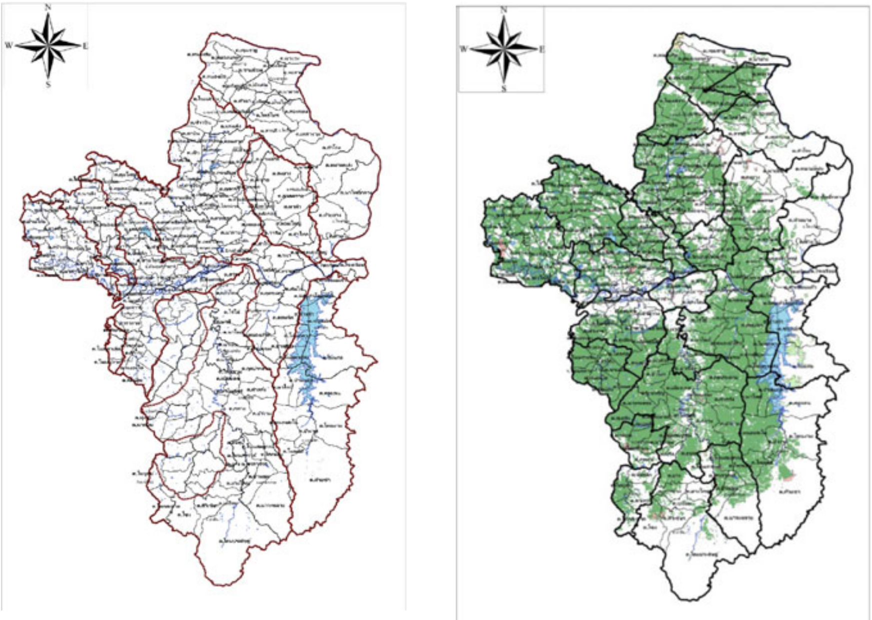
Thailand's government has supported many projects to help farmers keep water on their lands. However, the appropriate location and size of the reservoirs need to be considered. Determining the optimal size and location of agricultural reservoirs will mitigate the aridity problem and reduce the government's budget for drought compensation. Thus, the objective of this research is to find the optimal solution for both the location and size of agricultural water reservoirs in Ubon Ratchathani.

Location problems, known as facility location problems, are classic problems in the field of operations research. Inappropriate location decisions increase capital costs and affect customer satisfaction. Alfred Weber (1909) was the first researcher to publish research on solving the warehouse location problem. After his publication, many location-related problems were published in several research areas for facilities such as factories, distribution centers, fire stations, etc. (Moellmann and Thomas 2019; Yao et al. 2019; Zhang et al. 2021a, b).

Later, the facility location problem was extended to combinatorial problems, including location-routing, location-inventory, location-allocation, etc. The objective of the facility location-allocation problem (FLP) is to find the optimal subset from a given set of candidate facilities and allocate demand nodes to the proper facilities (Chandra et al. 2021). In addition, location-sizing is also a combinatorial problem widely used in many applications, such as distributed generators in micro-grids (Kizito et al. 2021), emergency medical service stations (Liu et al. 2019), and warehouses (Kalfakakou and Tsouros 2001).

However, water irrigation problems have normally been the solution to agricultural drought problems. Many researchers have tried to solve the aridity problem using irrigation techniques (Li et al. 2020; Haavisto et al. 2019; Naghdi et al. 2021; Xiea et al. 2018). In addition, Luís and Cabral (2021) applied the Geographical Information System (GIS) with Analytic Hierarchical Process (AHP) to select appropriate locations for small dams/reservoirs in Mozambique and found that only 7% of areas were suitable for the construction of small dams.

In this research, the location-allocation-sizing problem was introduced. A real case study in Ubon Ratchathani province was used to compare the effectiveness of the proposed algorithms. There are 219 subdistricts in Ubon Ratchathani province, each of which was not only a candidate node for the construction of an agricultural water reservoir but also a demand node for receiving water from a constructed reservoir (Fig. 1).



(a) Basin map (b) Cropland map

Fig. 1 Map of subdistricts and land used in Ubon Ratchathani province

Data collected from each node consisted of x and y coordinates, the height above sea level, and the average crop water requirements. Estimated construction costs for water reservoirs, irrigation systems, and water receiving systems were calculated following the criteria for calculating median prices of irrigation construction (Comptroller General's Department 2017). There are three sizes of water reservoirs in this research: small, medium, and large. The capacity and limitation of irrigation distance for each reservoir size are shown in Table 1

The algorithms used in previous research for solving location and sizing problems were genetic algorithm (GA), particle swarm optimization (PSO), flower pollination algorithm, simulated annealing (SA), and improved harmony search algorithm (Abdelaziz et al. 2016; Ali et al. 2016; García-Muñoz et al. 2021; Ghaffarinasab et al. 2018; Suman et al. 2021). The differential evolution algorithm (DE) was applied to solve the LASP in this research. DE is a type of population-based metaheuristic

Table 1 Size, capacity, and limitation of reservoir

Size of reservoir	Capacity (Million square metre)	Distance limitation (Kilometre)
Small	10	10
Medium	50	60
Large	100	100

algorithm and is currently one of the most interesting and impressive evolutionary algorithms. Normally, it has five general steps: (1) generate an initial solution; (2) perform a mutation process; (3) perform a recombination process; (4) perform a selection process; and then (5) repeat steps (2)–(4) until termination conditions, such as computational time or maximum number of iterations, are met.

DE has been successfully applied in several fields, such as production scheduling (Pitakaso 2015; Pitakaso and Sethanan 2015), manufacturing problems (López et al. 2003), vehicle scheduling problems (Liao et al. 2012), and vehicle routing problems (Hou et al. 2010). We developed an efficient DE for solving the LASP to minimize the cost of solving the aridity problem in the north-eastern region of Thailand, particularly in Ubon Ratchathani province. This paper is organized as follows. In Sect. 2, the mathematical model representing the location-allocation-sizing problem (LASP) is presented. In Sect. 3, the proposed methodologies are presented, and the computational framework and results are presented in Sect. 4. The conclusion is summarized in Sect. 5.

2 Mathematical Formulation

In this section, the mathematical model of LASP for agricultural water resources is introduced.

Sets

- I Set of agricultural water resource nodes i
- J Set of demand nodes j
- K Set of water resource sizes k

Parameters

- f_k Cost of constructing agricultural water resources with size k (THB).
- U_k Capacity of agricultural water resources with size $k (m^3)$
- v Cost of construct irrigation system per distance from agricultural water resources i to demand node j (THB)
- w_j Crop water requirement at node j (m^3)
- b_{ij} Hindrance value of water shed
- d_{ij} Distance from agricultural water resource i to demand node j (m)
- q_{ij} Water quantity from water resource i to demand node j (m^3)
- m_k Maximum distance of water flow from water resource with size k (m)
- s Subsidiary cost per aridity risk unit (THB)
- r_i Aridity risk in area of node i
- h_i Altitude of node $i (m)$
- h_j Altitude of node $j (m)$

Decision Variables

x_{ik} $\begin{cases} 1, \text{if node } i \text{ was selected to be agricultural water resources with size } k \\ 0, \text{otherwise} \end{cases}$

y_{ij} $\begin{cases} 1, \text{if water from node } i \text{ was assigned to demand node } j \\ 0, \text{otherwise} \end{cases}$

Objective Function

$$MinZ = \sum_{i \in I} \sum_{k \in K} f_k x_{ik} + v \sum_{i \in I} \sum_{j \in J} d_{ij} y_{ij} - s \sum_{i \in I} r_i x_{ik} + \sum_{i \in I} \sum_{j \in J} y_{ij} c_{ij} \quad (1)$$

Subject to

$$q_{ij} = y_{ij} w_j, i \in I, j \in J \quad (2)$$

$$\sum_{i \in I} \sum_{k \in K} x_{ik} \leq 1 \quad (3)$$

$$d_{ij} y_{ij} \leq \sum_{i \in I} \sum_{k \in K} m_k x_{ik}, \forall i \forall j \quad (4)$$

$$\sum_{i \in I} \sum_{j \in J} y_{ij} \geq 1 \quad (5)$$

$$\sum_{i \in I} \sum_{j \in J} q_{ij} \leq \sum_{i \in I} \sum_{k \in K} U_k x_{ik} \quad (6)$$

$$y_{ij} h_j \leq y_{ij} h_i, i \in I, j \in J \quad (7)$$

$$y_{ij} \leq b_{ij}, i \in I, j \in J \quad (8)$$

Objective function (1) is to minimize the cost of constructing the agricultural water resources. The cost terms in objective function consisted of fixed cost of installation of reservoir, cost of irrigation, subsidiaries cost for aridity risk, and receiver cost respectively. Constraint (2) is used to ensure that the volume of water supplied from node i to node j equals crop water requirements at node j. Constraint (3) is used to limit each water resource i to only one size k. Constraint (4) is used to ensure the desired distance of water supply from node i to node j does not exceed the maximum distance of water flow from a water resource with size k. Constraint (5) is used to ensure that each demand node j receives water from at least one supply node i. Constraint (6) is used to ensure that the volume of water supply from node i to node j does not exceed the capacity of the water resource with size k. Constraint (7) is used to ensure that the water flows from a higher altitude to a lower altitude. Constraint (8) is used to limit the flow if the watershed blocks the waterway from node i to node j.

3 Methodology

In this study, the differential evolution algorithm was modified to solve the LASP problem. The differential evolution algorithm (DE) is composed of five general steps, which are: (1) generate the initial vectors, (2) perform a mutation process, (3) perform a recombination process, (4) perform a selection process, and (5) repeat steps (2)–(4) until the termination condition is met. The DE used to solve the LASP can be explained by the steps described below.

3.1 Generate a Set of Initial Vectors

The vector for the representation of the LASP was designed as a 1 × WP vector, where WP is the number of work packages. A set of initial sample vectors was encoded, as shown in Table 2, with 10 nodes of candidate locations and 5 WPs.

A decoding method was developed to obtain the solution of the proposed problem, as explained below.

The decoding method

The decoding method is composed of five steps: (1) sort the probability of the WP in ascending order; (2) select the value node with the lowest probability as the water reservoir; (3) establish the probability criteria for assigning the size of the water reservoir; (4) assign the size of the reservoir according to its probability by using criteria established in step (3); and (5) assign demand nodes to the selected water reservoir. The conditions that need to be considered include (1) the distance limitation for irrigation, (2) the crop water requirements of assigned demand nodes, which must not exceed the capacity of water reservoirs in supply nodes, and (3) the height above sea level of supply nodes, which must be higher than that of the demand nodes.

Details of sample nodes, both supply and demand nodes, are shown in Table 3, including crop water requirements (CRWs), drought risk, and the height above sea level. CRWs of each node were calculated from the average CRWs of rice, which

Table 2 Example of vector used in the proposed method

Vector	Node									
	1	2	3	4	5	6	7	8	9	10
1	0.10	1.00	0.43	0.23	0.49	0.72	0.50	0.92	0.30	0.23
2	0.41	0.07	0.48	0.50	0.57	0.86	0.28	0.21	0.71	0.68
3	0.88	0.91	0.48	0.66	0.93	0.13	0.21	0.21	0.43	0.02
4	0.84	0.60	0.56	0.42	0.87	0.13	0.56	0.77	0.13	0.34
5	0.36	0.34	0.65	0.30	0.77	0.88	0.56	0.85	0.54	0.68

Table 3 Detail of the candidate nodes

Node no.	Crop water requirements (for demand node)	Drought risk	Height from sea level
1	25.77	0.85	144
2	32.67	0.85	184
3	52.81	0.85	149
4	58.24	0.85	190
5	34.90	0.85	183
6	31.65	0.65	164
7	47.02	0.65	164
8	24.17	0.65	148
9	19.89	0.65	164
10	20.63	0.65	135

Table 4 Detail of the water reservoir

Size of water reservoir	Criteria probability for selection	Capacity (Million square metre)	Distance limitation (Kilometre)
Small	0–0.33	10	10
Medium	0.34–0.66	50	60
Large	0.67–1.00	100	100

was the main crop in the area, multiplied by crop area. The drought risk of each node was also obtained from the average aridity statistics data in the area.

Table 4 shows the details of the water reservoir size, including the probability criteria for sizing selection, reservoir capacity, and distance limitation for irrigation. All information was inferred from the irrigation system manual of the Royal Irrigation Department, Ministry of Agriculture and Cooperatives.

From Table 5, nodes 2, 4, 7, and 8 were selected to be the water reservoirs. Node 2, which has a probability value of more than 0.67, was assigned to be the large reservoir and supplies water to node 2 (itself), node 5, and node 6. The construction of the large water reservoir is 1580 million Baht. The irrigation cost is 7.91 million Baht per kilometer. In this case, node 2 distributes its water to nodes 5 and 6 with a total distance of 20.47 km; therefore, the irrigation cost is 161.92 million Baht. Subsidiary cost is the money that the government pays to farmers affected by a drought disaster in their area. The recent average drought subsidiary rate is 22.26 million Baht per node. However, the amount of the subsidiary cost depends on the node's drought risk, which is calculated from the probability of drought in the area. In node 2, the drought risk is 0.85, so the subsidiary cost is equal to 18.92 million Baht. Receiver cost is the cost that nodes not selected to be water reservoirs have to pay for the construction of the receiving pond and necessary equipment. For geological engineering reasons, receiver cost is not the same for each node. In node 2, the receiver cost is 98.15. The total cost of node 2 selected to be the large water reservoir and supply water to nodes

Table 5 Result of the assignment

Water reservoir	Size	Supply to node	Construction cost	Irrigation cost	Subsidiaries cost	Receiver cost	Total cost
2	Large	2, 5, 6	1580.00	161.92	18.92	98.15	1821.15
4	Large	4, 9, 10	1580.00	417.57	18.92	108.40	2087.05
7	Large	3, 7	1580.00	200.91	14.47	45.96	1812.40
8	Medium	1, 8	790.00	260.32	14.47	20.59	1056.44
Grand total cost			5530.00	1040.72	66.78	273.10	6777.04

5 and 6 is 1,821.15 million Baht, which is calculated by the sum of the construction cost, irrigation cost, and receiver cost. Then, the subsidiary cost is subtracted from the total. Nodes 4, 7, and 8 follow the same procedure explained above, and the sum of the total cost for each node is the grand total cost of this sample solution. The procedure for the decoding method used in this article is shown in Algorithm 1 (Fig. 2).

```
Algorithm 1: DeCoding WP to Location Allocation Problem
input : Population (WP), Problem Size (D),Location Allocation Size (SL),
        Laying Pipes Cost (VC), Drought Risk Cost(RC), Digging Cost(DC)
output: Location_Allocation _Solution, Total_Cost
begin
   wp_sort = sorted(WP, key=" zk")
   select_route[1:D] = False
   for i=1: D      //Loop for the location supply selection
      supply_ route_i = []
      If select_route_i = False Then
         Uk_i, fk_i, mk_i = Select_Size(wp_sort_i, SL)
         supply_ route_i. add(wp_sort_i)
         select_route_i = True
         Uk_i = Uk_i - wp_sort_i.wj
         For j = i+1:D             //Loop for the location Demand selection
            If Uk_i - wp_sortj. wj > 0 Then
               If EuclideanDistance (wp_sort_i - wp_sort_j) > mk_i Then
                  If wp_sort_i.h ≥ wp_sort_j.h Then
                     supply_ route_i. add(wp_sort_j)
                     Uk_i = Uk_i - wp_sort_j.wj
                     select_route_j = True
         End For Loop
         cost_dis = sumRouteDistance(supply_ route_i) * VC
         cost_risk = wp_sort_i.ri * RC
         cost_ digging = sumRouteDiggingCost(supply_ route_i)
         Total_Cost = Total_Cost + (cost_dis + cost_risk + cost_ digging+ fk_i)
         Location_Allocation _Solution. add(supply_ route_i)
   End For Loop
   Return Location_Allocation _Solution, Total_Cost
end
```

Fig. 2 Pseudo code of the decoding method

3.2 Perform Mutation Process

The transformation of the target vector into the mutant vector shown in Table 2 is called the mutation process. The mutation process is implemented following Eq. (9):

$$V_{i,j,G} = X_{r_1,j,G} + F(X_{r_2,j,G} + X_{r_3,j,G}) \tag{9}$$

where r_1, r_2, and r_3 are the indices of randomly selected vectors; F is a scaling factor, which is set to 0.8 (Qin et al. 2009); i represents the vector number; $i = 1, 2, \ldots, NP$; and j *is* the position of a vector when $j = 1, 2, \ldots, D$.

3.3 Perform the Recombination Process

The transformation of the mutant vector into the trial vector is performed by a recombination process. In this process, Eq. (10) is applied, where $V_{i,j,G}$ is the mutant vector, $X_{i,j,G}$ is the target vector, and $U_{i,j,G}$ is the trial vector. In this formula, which was presented by Pitakaso and Sethanan (2015), rand b_{ij1} is random number 1 of vector i, position j, and $randb_{ij1}$ is random number 2 of vector i, position j.

$$U_{i,j,G} = \begin{cases} V_{i,j,G} \text{ when } j \le randb_{i,j,1} \text{ and } j \ge randb_{i,j,2} \\ X_{i,j,G} \text{ when } \quad randb_{i,j,1} < j < randb_{i,j,2} \end{cases} \tag{10}$$

3.4 Perform the Selection Process

Finally, before the vector can proceed to the next iteration, the selection process has to be carried out. The purpose of this process is to select the new target vector. The candidate for the next target vector is the current target ($X_{i,j,G}$) and the current trial vector ($U_{i,j,G}$). The selection is executed using Eq. (11), where $f(U_{i,j,G})$ and $f(X_{i,j,G})$ are the objective functions of the trial vector and target vector, respectively.

$$X_{i,j,G+1}^{pre} = \begin{cases} U_{i,j,G} \text{ if } f(U_{i,j,G}) \le f(X_{i,j,G}) \\ X_{i,j,G} \qquad \text{otherwise} \end{cases} \tag{11}$$

3.5 *Repeat Steps (Sects. 3.2–3.4) Until Termination Condition is Met*

In this research, the termination condition was set as the computational time (5–20 min, depending on the size of the test problem). The proposed differential evolution algorithm procedure is shown in algorithm 2 (Fig. 3).

To compare the efficiency of the proposed DE algorithm, the genetic algorithm (GA) was applied to solve the same LASP problem for the same real-world scenario. The GA is composed of five general steps, which are: (1) generate an initial solution, (2) perform a crossover process, (3) perform a mutation process, (4) perform an evaluation process, and (5) repeat steps (2)–(4) until the termination condition is met. The proposed GA procedure is shown in algorithm 3 (Fig. 4).

```
Algorithm 2: Differential evolution algorithm (DE)
input : Population size (NP), Problem Size (D), Mutation Rate (F),
Recombination rate (R)
output: Best_Solution, Best_Cost
begin
   WP = Initialize Population(NP, D)
   while the stopping criterion is not met do
      for i=1: NP
         V_rand1, V_rand2, V_rand3 = Select_Random_Vector (WP_i)
         For j = 1:D // Loop for the mutation operator
            V_y [j]= V_rand1 [j]+ F(V_rand2 [j]+ V_rand3 [j])
         End For Loop//end mutation operator
         For j = 1:D //Loop for recombination operation
            If(rand_j [0,1) <R ) Then
                  u [j]= V_i [j]
            Else
                  u [j]= V_y [j]
         End For Loop//end recombination operation
         IF(CostFunction(u) ≤ CostFunction(V_i)) Then
            V_i = u
      End For Loop
   End
   Best_Solution, Best_Cost =DeCodeLocationAllocation(WP)
   Return Best_Solution, Best_Cost
end
```

Fig. 3 Pseudo code of differential evolution algorithm

```
Algorithm 3: Genetic Algorithm (GA)
input : Population Size (NP), Problem Size (D), Mutation Rate (M),
Crossover Rate (CR)
output: Best_Solution, Best_Cost
begin
  WP = Initialize Population(NP, D)
  while the stopping criterion is not met do
    parents = WP
    for i=1: NP //Loop for crossover operation
      For j = 1:D
        If(rand_j [0,1) <CR ) Then
            offspring_i [j]= parents_i [j]
            offspring_i+1 [j]= parents_i+1 [j]
        Else
            offspring_i [j]= parents_i+1 [j]
            offspring_i+1 [j]= parents_i [j]
      End For Loop
    End For Loop//end crossover operation
    for i=1: NP //Loop for mutation operation
      For j = 1:D
        If(rand_j [0,1) <M ) Then
            Mutation(offspring_i [j])
      End For Loop
    End For Loop//end mutation operation
    // Add the child population to the parent population
    NWP = stack(parents, offspring)
    wp_size = length(NWP) // Set number of new population
    for i=1: wp_size //Loop for evaluate operation
      cost_ scores i+1 = CostFunction(NWP i+1)
    End For Loop//end evaluate operation
    //selection operation
    new_ wp = Sorted(new_ population, cost_ scores)
    WP = NWP [1:NP]
  End
  Best_Solution, Best_Cost =DeCodeLocationAllocation(WP)
  Return Best_Solution, Best_Cost
end
```

Fig. 4 Pseudo code of genetic algorithm

4 Results

In this research, differential evolution and genetic algorithms were coded with Python and tested using an Intel(R) Core (TM) i7-7500U CPU @ 2.70 GHz, 2904 MHz, two Core(s), and four logical processors. The algorithms were tested on a real-world case study of 219 nodes of candidate locations for water reservoirs. The results of the study are shown in Table 6. The termination condition of DE and GA was set to be the computational time. The execution time was set to vary from 5 to 30 min,

Table 6 Computational result of the test instances

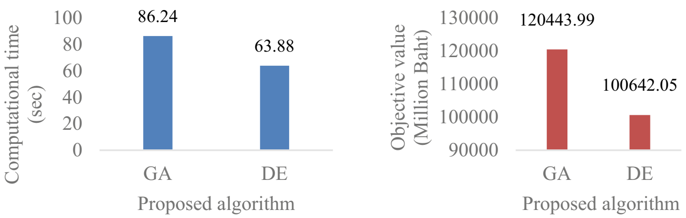
Number of candidate nodes	Result obtained from GA			Result obtained from DE		
	Number of water reservoirs (nodes)	Average computational time (sec)	Total cost (Million Baht)	Number of water reservoirs (nodes)	Average computational time (sec)	Total cost (Million Baht)
219	119 (S = 6, M = 79, L = 34)	86.2365	120443.99	94 (M = 67, L = 27)	2323.36	163818.41

depending on the size of the problem. The results of the experiment are shown in Table 6.

As indicated in Table 6, DE outperformed the GA in both the computational time and objective function value. DE consumed 25.93% less computational time than GA. The objective value of DE was also 16.44% better than that of GA. The total number of nodes selected to be water reservoirs differed between DE and GA. The DE resulted in a smaller number of water reservoirs than GA, which contributed to a major proportion of the total cost and the cost of construction. In addition, both algorithms tried to open more medium-sized water reservoirs than large ones because the latter doubled the cost of construction. The performance of DE and GA is plotted in Fig. 5.

The result from DE is plotted in the Google Earth map in Fig. 6, which shows 94 locations that were selected for opening agricultural water reservoirs with two different sizes.

In Fig. 6, the location pin symbols represent the candidate locations selected for the water reservoirs. Pins with ‘A’ represent a large reservoir, and ‘B’ represents a medium reservoir. Thumbtacks are used to represent demand nodes. The numbers on the pins and thumbtacks represent each node by subdistrict. The water reservoir locations are dispersed around the province, but there are some clusters of receivers in Muang Ubon Ratchathani and Warin Chamrab districts. This clustering phenomenon occurred because these two districts have a low risk of drought, and a large proportion of the area is not cropland; therefore, the cost of subsidiaries to subtract from the total is less attractive compared with other nodes.



(a) Computational time of DE and GA (b) Objective value of DE and GA

Fig. 5 Comparison of performance between DE and GA

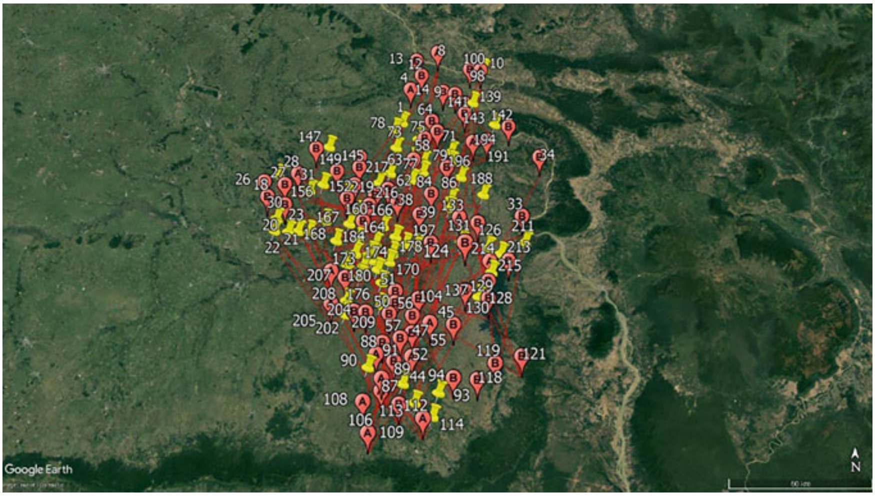


Fig. 6 Optimal result of the location-allocation-sizing problem

5 Conclusion

In this paper, a mathematical model of LASP for agricultural water reservoirs is introduced. The DE and GA were applied to solve a real-world scenario involving 219 subdistricts of Ubon Ratchathani, Thailand. The computational results show that both the objective value and computational time of the proposed DE are better than those of GA. Compared with GA, the DE consumed 25.93% less computational time, and its objective value was 16.44% better. The algorithm assigned 94 locations as water reservoirs to supply water to 219 districts. Two sizes of reservoirs, medium and large, were chosen and dispersed around the case study area. It can be concluded that the factors predominantly influencing the location of water reservoirs are the node's CWRs and drought risk. Therefore, urban areas with less cropland and low drought risk tend to be receiver nodes. Future extensions of this research can be carried out in many aspects. For instance, (1) the subsidiary cost in this research was combined into a single objective function, so in future research, the model could be transformed into a multi-objective model, and (2) the area of the study can be narrowed to the micro-level, from sub-districts to villages, which can be more practically implemented by the local government organization.

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References

Abdelaziz A, Ali E, Abd Elazim S (2016) Optimal sizing and locations of capacitors in radial distribution systems via flower pollination optimization algorithm and power loss index. Eng Sci Technol Int J 19(1):610–618. https://doi.org/10.1016/j.jestch.2015.09.002

Ali E, Abd Elazim S, Abdelaziz A (2016) Improved harmony algorithm and power loss index for optimal locations and sizing of capacitors in radial distribution systems. Int J Electr Power Energy Syst 80:252–263. https://doi.org/10.1016/j.ijepes.2015.11.085

Chandra S, Sarkhel M, Vatsa AK (2021) Capacitated facility location–allocation problem for wastewater treatment in an industrial cluster. Comput Oper Res 132:105338. https://doi.org/10.1016/j.cor.2021.105338

García-Muñoz F, Díaz-González F, Corchero C (2021) A novel algorithm based on the combination of AC-OPF and GA for the optimal sizing and location of DERs into distribution networks. Sustain Ener Grids Netw 27:100497. https://doi.org/10.1016/j.segan.2021.100497

Ghaffarinasab N, Motallebzadeh A, Jabarzadeh Y, Kara BY (2018) Efficient simulated annealing based solution approaches to the competitive single and multiple allocation hub location problems. Comput Oper Res 90:173–192. https://doi.org/10.1016/j.cor.2017.09.022

Haavisto R, Santos D, Perrels A (2019) Determining payments for watershed services by hydro-economic modeling for optimal water allocation between agricultural and municipal water use. Water Resour Econ 26:100127. https://doi.org/10.1016/j.wre.2018.08.003

Hou L, Zhou H, Zhao J (2010) A novel discrete differential evolution algorithm for stochastic VRPSPD. J Comput Inform Syst 6(8):2483–2491

Kalfakakou R, Tsouros CC (2001) Determining the size and location of suppliers for a minimum total distribution route problem. Int J Prod Econ 71(1–3):401–405. https://doi.org/10.1016/s0925-5273(00)00144-4

Kizito R, Liu Z, Li X, Sun K (2021) Stochastic optimization of distributed generator location and sizing in an islanded utility microgrid during a large-scale grid disturbance. Sustain Ener Grids Netw 27:100516. https://doi.org/10.1016/j.segan.2021.100516

Li M, Fu Q, Singh VP, Liu D, Gong X (2020) Risk-based agricultural water allocation under multiple uncertainties. Agric Water Manag 233:106105. https://doi.org/10.1016/j.agwat.2020.106105

Li Y, Lu H, Yang K, Wang W, Tang Q, Khem S, Yang F, Huang Y (2021) Meteorological and hydrological droughts in Mekong River Basin and surrounding areas under climate change. J Hydrol Reg Stud 36:100873. https://doi.org/10.1016/j.ejrh.2021.100873

Liao T, Egbelu P, Chang P (2012) Two hybrid differential evolution algorithms for optimal inbound and outbound truck sequencing in cross docking operations. Appl Soft Comput 12(11):3683–3697. https://doi.org/10.1016/j.asoc.2012.05.023

Liu K, Li Q, Zhang ZH (2019) Distributionally robust optimization of an emergency medical service station location and sizing problem with joint chance constraints. Transp Res Part B Method 119:79–101. https://doi.org/10.1016/j.trb.2018.11.012

López Cruz I, van Willigenburg L, van Straten G (2003) Optimal control of nitrate in lettuce by a hybrid approach: differential evolution and adjustable control weight gradient algorithms. Comput Electron Agric 40(1–3):179–197. https://doi.org/10.1016/s0168-1699(03)00019-x

Luís ADA, Cabral P (2021) Small dams/reservoirs site location analysis in a semi-arid region of Mozambique. Int Soil Water Conserv Res 9(3):381–393. https://doi.org/10.1016/j.iswcr.2021.02.002

Ministry of agricultural and cooperatives of Thailand (2020) Thailand's essential agricultural and cooperatives information 2020. Office of Planning, Ministry of agricultural and cooperatives of Thailand

Moellmann J, Thomas VM (2019) Social enterprise factory location and allocation model: small scale manufacturing for East Africa. Soc Econ Plann Sci 68:100694. https://doi.org/10.1016/j.seps.2019.02.009

Naghdi S, Bozorg-Haddad O, Khorsandi M, Chu X (2021) Multi-objective optimization for allocation of surface water and groundwater resources. Sci Total Environ 776:146026. https://doi.org/10.1016/j.scitotenv.2021.146026

National Statistics Organization of Thailand (2021) Ubon Ratchathani provincial statistical report. http://ubon.nso.go.th/index.php?option=com_content&view=article&id=382&Itemid=507

Pitakaso R (2015) Differential evolution algorithm for simple assembly line balancing type 1 (SALBP-1). J Ind Prod Eng 32(2):104–114. https://doi.org/10.1080/21681015.2015.1007094

Pitakaso R, Sethanan K (2015) Modified differential evolution algorithm for simple assembly line balancing with a limit on the number of machine types. Eng Optim 48(2):253–271. https://doi.org/10.1080/0305215x.2015.1005082

Suman GK, Guerrero JM, Roy OP (2021) Optimisation of solar/wind/bio-generator/diesel/battery based microgrids for rural areas: a PSO-GWO approach. Sustain Cities Soc 67:102723. https://doi.org/10.1016/j.scs.2021.102723

United Nations (n.d.) 2010–2020: UN decade for deserts and the fight against desertification. UN decade for deserts and the fight against desertification. Retrieved July 5, 2021, from https://www.un.org/en/events/desertification_decade/whynow.shtml

Water Crisis Prevention Centre of Thailand (2021) Flood and drought data of Thailand. http://mekhala.dwr.go.th/download-cate.php?txtdoccate=28

Weber A (1909) Über den Standort der Industrien, Tübingen. Theory of the location of industries, University of Chicago Press (English translation by Friedrich CJ (1929)).

Xie Y, Xia D, Ji L, Huang G (2018) An inexact stochastic-fuzzy optimization model for agricultural water allocation and land resources utilization management under considering effective rainfall. Ecol Ind 92:301–311. https://doi.org/10.1016/j.ecolind.2017.09.026

Yao J, Zhang X, Murray AT (2019) Location optimization of urban fire stations: access and service coverage. Comput Environ Urban Syst 73:184–190. https://doi.org/10.1016/j.compenvurbsys.2018.10.006

Zhang S, Chen N, She N, Li K (2021a) Location optimization of a competitive distribution center for urban cold chain logistics in terms of low-carbon emissions. Comput Ind Eng 154:107120. https://doi.org/10.1016/j.cie.2021.107120

Zhang Y, Hao Z, Feng S, Zhang X, Xu Y, Hao F (2021b) Agricultural drought prediction in China based on drought propagation and large-scale drivers. Agric Water Manag 255:107028. https://doi.org/10.1016/j.agwat.2021.107028

Simulation-Based Application for Improving Carton Production Process

Nara Samattapapong and Thiti Mhoraksa

1 Introduction

The industrial sector is continually undergoing changes at the moment. Regardless of how much technology rapidly advances, cartons continue to be used as packaging for electronics, automobile parts, and a variety of other industries. It continues to be widely used today because of the qualities that can protect the goods from scratches and damage, as well as its lightness. According to the case study factory's analysis, the company is a contract packaging company. The company receives raw materials from suppliers and applies made-to-order models to cut them into pieces based on the customer's requirements. Each client has specific product requirements, so each customer's product is manufactured using a specific production technique. It means that working systems are arranged in a variety of ways. As a result, the work system must be structured methodically and the number of machines and employees has to be suitably increased or decreased to keep production running and the project has to finish on time. According to the company's goal, "the company will produce the package in accordance with the specific needs and inventing the evolution of materials at a rapid rate in order to reduce the waiting time. The quality and punctuality must be consistent. The objective is to keep all of the partners' supply chains running smoothly. New innovations are continuously introduced as effective tools for

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developing and creating something better, more flexible, lighter, and more environmentally friendly. The research team collaborated together to design the work process and system placement, so that they could operate more efficiently. It would have the ability to increase production. The objective was to enhance efficiency and reduce waste in the carton manufacturing process by integrating simulation techniques into the process design.

2 Theoretical Framework

Definition of Simulation

There are researchers who have studied and discussed simulations in various contexts, as follows:

Kelton et al. (2007) suggested that simulation is a method and application that uses computer software to simulate the behavior of a real system. Pisuchpen (2008) said that simulation is defined as the process of building a model of a real system and then performing experiments to understand how the real system behaves. The experiment's results will next be evaluated before being used to solve problems in real-life situations. Surachetkiati (2001) said that the simulation is the process of designing a model of a real system and the experimental design in this model and then understand system behavior and estimating the variables important to the operation within the system.

3 Gen

It is a manufacturing philosophy in practice. This is a concept and practice that has been established as a model for the manufacturing sector. Based on the principle of "don't trust anyone," this approach can generate consistency between real circumstances and scenarios in production. It consists of (1) GENBA is the actual place, (2) GENBUTSU is the actual production piece, and (3) GENJITSU is the fact (Chalermjirarat 2006).

7 Waste

Taiichi Ohno, the founder of the Toyota production system, divides waste into seven categories: overproduction, waiting, transportation, inventory, movement, unnecessary processes, and waste (Praison 2011).

3 Related Studies

From the relevant research studies, it was found that computer-based simulations have been applied to the allocation of the number of employees to reduce labor costs and to improve employee efficiency. Kengpol and Youngswaing (2015) have adopted the principles of concurrent engineering and simulations used to allocate employees and adjust the production process of the oil pipe production process. It was found that the new production process can reduce the number of employees from 4 to 2 people. Moreover, it also reduces the machines used in the production process from 2 machines to 1 machine. Therefore, the remaining machines and staff can be allocated to support the new production line. As a result, there are benefits such as increasing production capacity by 50%, lowering the investment cost of purchasing pipe bending machines, and lowering the annual cost of recruiting employees. Samattapapong (2018) has employed simulation modeling to investigate the problem and to develop a better cassava starch packing process. The outcomes were compared to those of the common practice. The best alternative was shown to be capable of reducing testing time by 19.02%, sealing time by 17.99%, transit time by 47.18%, and moving time by 34.10%. Furthermore, it was able to cut the workforce by three individuals.

The efficiency and management system have been improved by using a situational model. Mhoraksa et al. (2020) have used the model to examine the production system and enhance the drinking water manufacturing process. As a consequence, the information and Flexsim® were utilized to construct a model. It was discovered that a bottleneck existed in the filling process. As a result, three solutions were devised to address the issue. After putting each alternative to the test, the findings revealed a 36.61% reduction in manufacturing time. Ghiyasinasab et al. (2018) have also employed lean approaches and simulations to improve their work. Kusoncum et al. (2018) have use the model to improve mill yard management that aims to reduce the time in the system for sugarcane transport vehicles. As a result, two solutions were devised to address the issue. After putting each alternative to the test, the findings revealed a 11.39% reduction in the system time. Klinlek et al. (2020) have use the model to increase the quantity of products and the quality of the working process. Jarernram and Samattapapong (2018) have used the model to production scheduling and to search makespan optimization of parallel machine production scheduling, the production process of this plant is parallel machine. Phanindra et al. (2019) have used the model to improve its productivity, optimizing it, and increase the overall efficiency of a Plant. The paper illustrates that the system can be optimized by high work station utilization through managing bottlenecks with the addition of buffers. Chanthakhot and Ransikarbum (2021) have used the simulation model that integrates fire dynamics simulation coupled with agent-based evacuation simulation to evaluate the impact of smoke and visibility from fire on evacuee behavior. Ransikarbum (2020) have used the agent-based simulation software to evaluate traffic problems at the intersection. Huihui et al. (2016) have used the Flexsim simulation to realize the storage for a simulation of the operation process and find out the bottleneck existing in the system according to the simulation results, finally, the bottleneck problem to optimize the model, and put forward improvement opinions and suggestions. Darayi et al. (2013) have used the simulation model to study the capacity enhancement scenarios in a tire manufacturing company located in Iran. Samattapapong (2017) have used the model to increase efficiency in the warehouse operation. The result for simulation analysis found that the conveyor belt was a bottleneck in the warehouse operation. Therefore, many scenarios to improve that problem were generated and testing through simulation analysis process. The result showed that an average queuing time was reduced from 89.8% to 48.7% and the ability in transporting the product increased from 10.2% to 50.9%. Thus, it can be stated that this is the test method for increasing efficiency in the warehouse operation. Nie and Wang (2019) have used the Flexsim simulation to improve the operation efficiency of rail mounted gantry crane and reduce the waiting time of container trains and trucks. Ishak et al. (2020) have used the simulation model to find out whether the vise production process time with the number of production targets can be met and is effective. In addition, He and Hua (2018) have established a model of the enterprise operating system to measure the service capabilities of the enterprise through the simulation of the model.

Computer-based simulation has been used increasingly in collaboration with lean manufacturing techniques to manage the number of employees in the production line and to optimize production processes. For example, Chandrakumar et al. (2016) used Flexsim® simulation software and a lean manufacturing system to improve the transfer process's performance. The issues have been identified, particularly wait time, line length, and employee idle time. Kumar et al. (2015) have used the Flexsim for measuring and analysis of performance measures of Flexible manufacturing system is applied. And it has been found that the simulation techniques are easy to analyze the complex flexible manufacturing system. Jarernram (2017) used Flexsim® simulation software to optimize production scheduling and discover the best appropriate overall production time for this issue. Furthermore, the issue was NP-Hard, which meant that finding a solution required a lengthy time. As the complexity of the issue became larger, it required exponentially longer to come up with a solution. The findings demonstrated that simulation techniques may be used to solve difficult and time- consuming issues. Luscinski and Ivanov (2020) have used the simulation model to developed flexible manufacturing system, then the example data were used to demonstrate the developed model applicability. "The Ontology on Flexibility" was applied for evaluation of achieved flexibility of manufacturing system.

Furthermore, Pawlak (2008) have proposes a new modelling framework for simulating flows of people between suburban areas and the metropolis. The model is based on a logit relationship used in researches of transport mode choice problems. Rodalwski (2006) presented the issue of building a model that reflects the real business process, as well as simulating the behavior of that model in order to draw conclusions about effectiveness and efficiency of a real business process. Cárdenas et al. (2018) have used the model to management of a high circulation road connecting two mainstream cities in Chile. Dobrzyński and Waszczur (2018) have used the model to show the opportunities of the analysis of the process according to the scenarios and variants developed in connection with the qualitative assessment process. Kluska (2021) presented mechanism is the basis for the methodology of automatic simulation modeling of warehouses. It allows significant reduction in simulation models building duration, and thus a significant reduction in the time of projects consisting in verifying the concept of spatial arrangement in various projects related to the storage area. The proposed tool is innovative and useful for practitioners specializing in simulation modeling and specialists in warehouse design. Due to the organization and simplification of data structures, it can be implemented in various simulation modeling environments. Also after implementation, it can be used by people who do not have advanced simulation skills.

4 Methodology

This research is a study of the carton manufacturing process A-01 of a case study: an establishment in the packaging carton manufacturing industry. The methods for conducting research were as follows:

(1) Studying the current situation to collect information by studying the procedures, working methods, factory planning, machine position, production aids, and the number of staff. The rule of 3 GEN was applied to explore the real workplace, actual production, and real situation.
(2) Analyzing the information gathered in the first phase and then developing a model for the current situation.
(3) Creating three alternatives and the model of each alternative.
(4) Proposing the most suitable approach to improvement.

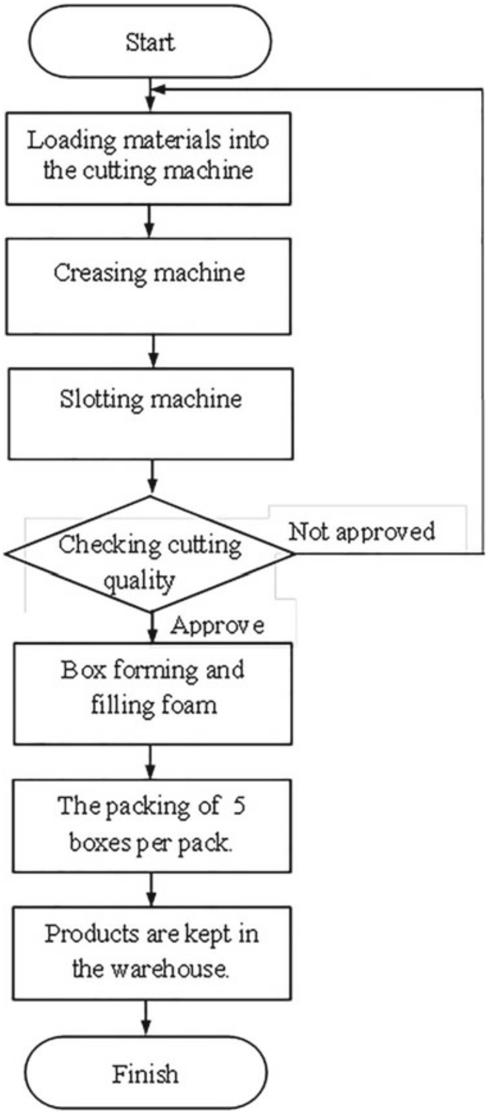
4.1 Information About the Current System

The production of paper boxes A-01, the steps are shown in Fig. 1. The first step is putting the raw materials into the paper cutter machine to get the required size. After that, take the cutting pieces to the machine and run them to create an outline that will be simple to fold into a box. The pieces will be checked again for evaluating their completeness and they will be separated into three groups. The first group is unfixable pieces; these products will be discarded. The second group is incomplete workpieces: they will be repaired. And the last group is complete workpieces: they can be formed and packaged into boxes then put into bags, 5 boxes per bag, which can then be kept in a warehouse. The total number of employees is 6, divided into six section (1 employee per section) that include working on a forklift to transport and store raw materials or products that must be sent to customers, paper cutting machine, creasing machine, slotting machine, box forming and packing, and storing.

Analysis of current operational data
From the analysis of the current operation, a large number of pieces in the waiting line had occurred because there was only one staff in the process of forming the boxes and adding foam into the box before delivering to the packing process which was a time consumer. As a consequence, production process was delayed, and employees who were in charge of keeping products faced waiting times. Furthermore, it was discovered that the inspection station for cutting was located at the back of the factory, causing unnecessary transportation, resulting in time wasted on transportation.

Hypothesis
Option 1: Increase the number of employees from one to two for folding and packing the boxes. To reduce the waiting time for the piece, each piece of work that comes out would be completed by the work of one person.

Fig. 1 A-01 carton manufacturing process



Option 2: Increase the number of employees from one to two. The first employee is responsible for folding, while the second employee is responsible for packing. The employees were assigned to do different tasks to be more proficient at that task. Therefore, the employee could work faster and the work would be completed more quickly.

Option 3: Modify the factory layout by relocating the checkpoints that would be kept closer to the paper cutter machine. Then, the storage station would be closer to the

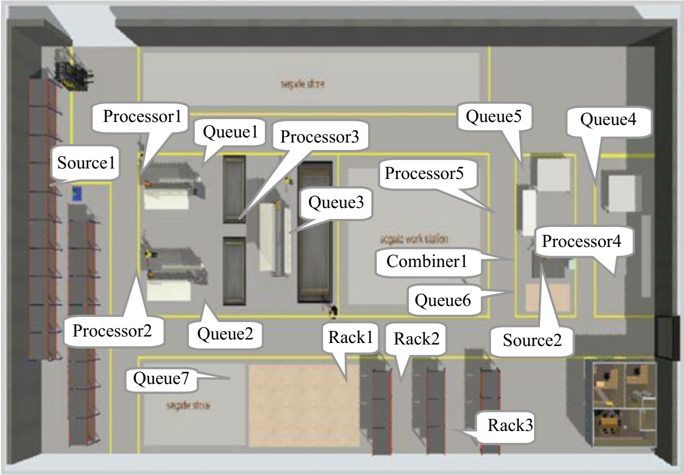


Fig. 2 System representative of the system in the simulation (Top View)

packing station. Thus, it would reduce transportation time and increase the number of products.

Modeling

The modeling processes are the steps to perform various tasks. It can modify the situation to try out new operating systems and it does not cause any impact on the actual operation. It uses computer systems to model and generate alternatives in order to test the most efficient process. Researchers utilized the Flexsim® software, which uses real-life data, to build a current functioning model and alternatives. The following information was utilized in the model's design which was represented in Fig. 2:

1. Source1 represents the arrival of raw materials into the production process.
2. Processor1 represents the paper cutter that cut the raw material to the specified size.
3. Queue1 represents the waiting of pieces before moving to the creasing machine.
4. Processor2 represents the creasing machine. It is used to make a mark which can be easy to form into a box.
5. Queue2 represents the waiting of pieces before moving to the slotting machine.
6. Processor3 represents the paper slotting machine. This will cut the paper into grooves at the specified points.
7. Queue3, Queue4 represent the waiting of pieces before moving to the check-point.
8. Processor4 represents the checking area for evaluating cutting quality.
9. Queue5 represents the paper-forming line.
10. Processor5 represents the area of forming the paper into a box and filling the foam into the box.

11. Combiner1 represents the packing of 5 boxes per pack.
12. Source2 represents the materials that will be used for packing 5 boxes.
13. Queue6 represents the area of the waiting of items before packing.
14. Queue7 represents the area of the warehouse before delivering to customers (Fig. 2).

Verification and validation

Verification is concerned with building the model correctly, according to the conceptual model and its assumptions.

Chi-Square Test for the relationship between the two variables from the number of boxes produced each day from 30 days of data collection of the current system and the generated model to verify that the generated model can be representative of the system.

Figures 4 and 5 show that the generated model can be used to represent the system.

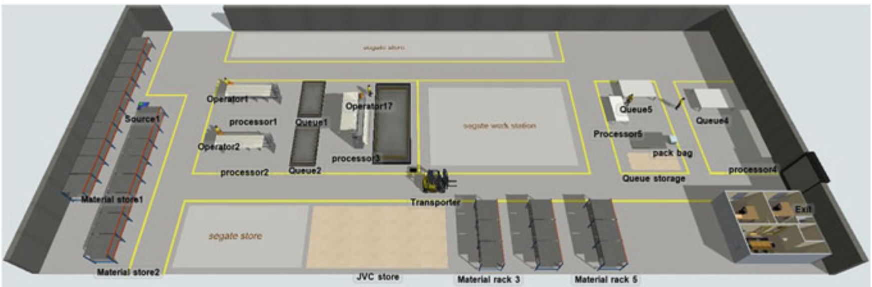


Fig. 3 System representative of the system in the simulation (Perspective View)

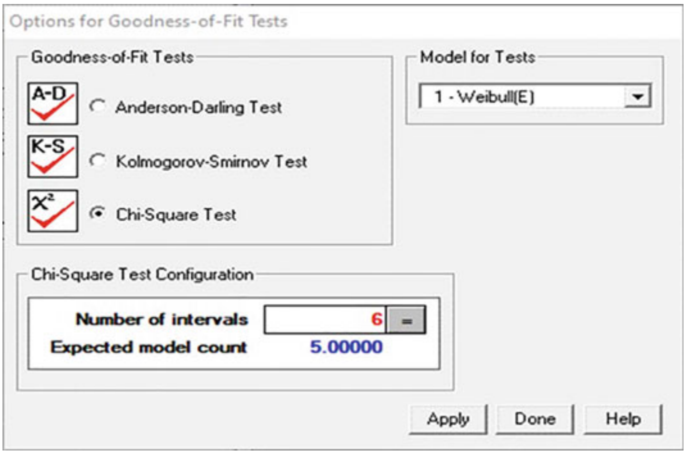
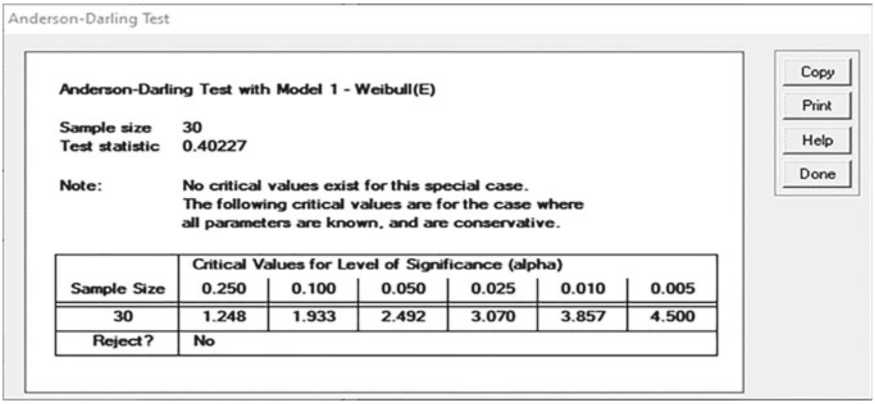


Fig. 4 Using Experfit in FlexSim for Chi-Square Test


Anderson-Darling Test

Anderson-Darling Test with Model 1 - Weibull(E)

Sample size 30
Test statistic 0.40227

Note: No critical values exist for this special case.
The following critical values are for the case where
all parameters are known, and are conservative.

Sample Size	Critical Values for Level of Significance (alpha)					
	0.250	0.100	0.050	0.025	0.010	0.005
30	1.248	1.933	2.492	3.070	3.857	4.500
Reject?	No					

Copy
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Fig. 5 Take the data obtained from the model when running 30 times and validate all 30 results, and the result is not reject

Generate Alternative Model

According to the results of the research of the working process using the Flexsim® software to build a model, the issue arose during the forming and packaging process because there were numerous waiting lines. There were three different alternatives to enhance it:

Option 1: Increase production capacity by adding one person to the box folding and packing station, which would reduce the waiting time of the prior stage (shown in Figs. 6 and 7).

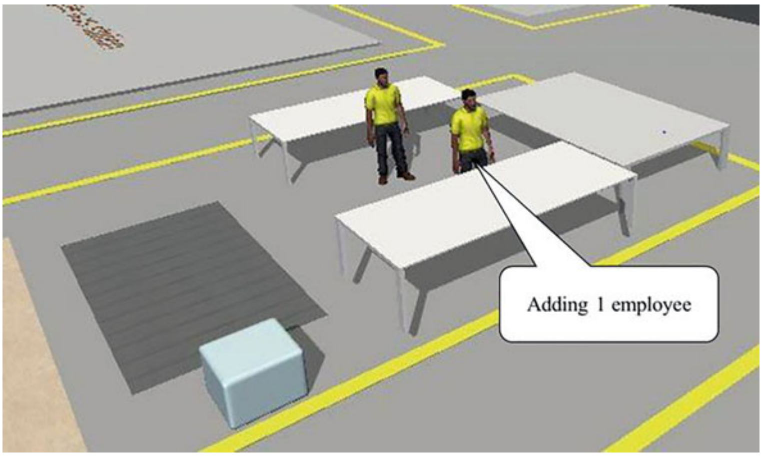

Fig. 6 Adding one employee for option 1

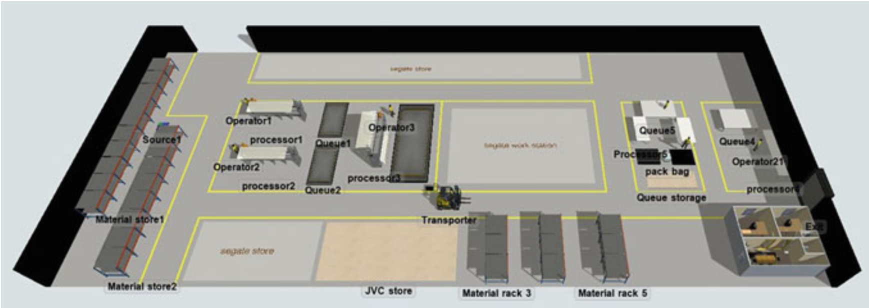

Fig. 7 System representative of the system in option 1

Fig. 8 Adding one employee in packing process for option 2

Option 2: Increase the number of employees in the packing area by enabling current employees to fold the boxes. It allowed workers to work more quickly. (As shown in Figs. 8 and 9).
Option 3: Change the layout of the factory by relocating the intersection check point to the storage site, the workpiece's transit distance was reduced (Shown as Figs. 10 and 11).

5 Results and Discussion

From the experiment using the Flexsim®, the test was run for 28,800 seconds that is 8 hours with the following results: in the traditional system, an average of 701 jobs was submitted, but only 530 were completed, meaning that 74.96% of the total number of jobs was completed and 177 jobs were still being processed (Table 1).

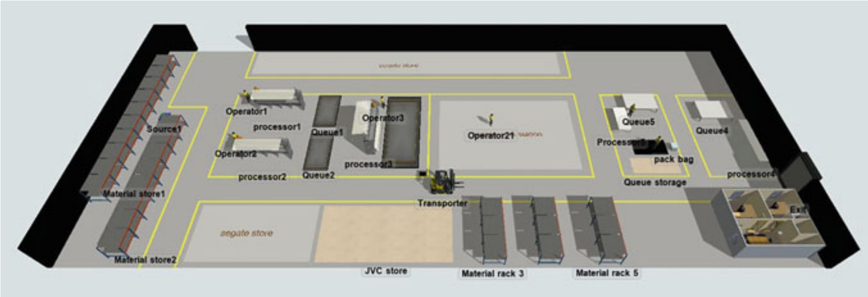

Fig. 9 System representative of the system in option 2

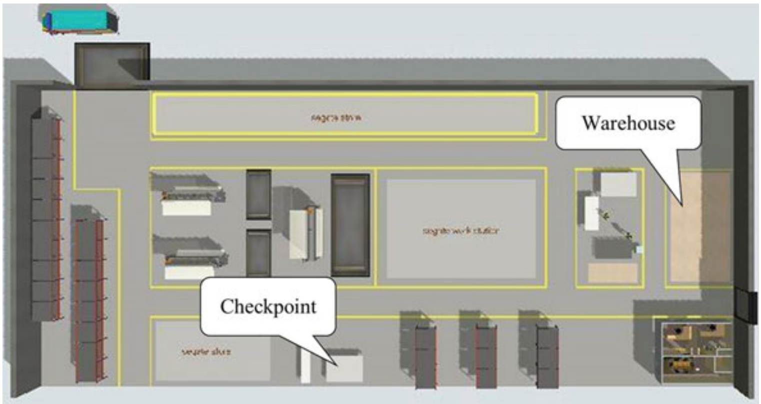

Fig. 10 Factory layout adjustment for option 3

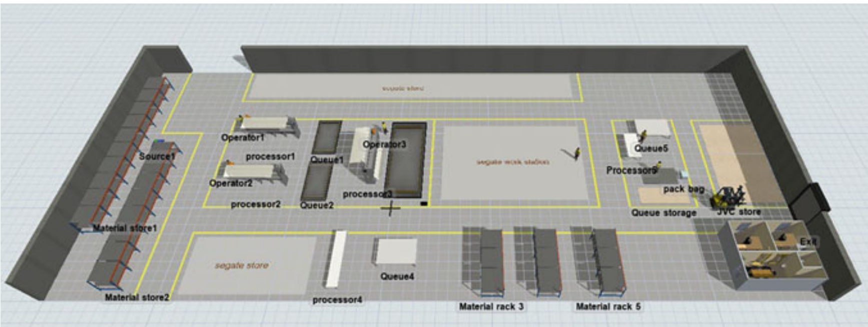

Fig. 11 System representative of the system in option 3

Table 1 Results from the experiment with various scenarios using Flexsim® (tested for 28,800 seconds)

Option	Status			
	Pieces from Source1	Pieces move to Queue7	Work capacity	Work in process
Current system	707	530	74.96%	177
Option 1	701	605	86.31%	96
Option 2	681	585	85.90%	96
Option 3	719	555	77.19%	164

Source Own work

Option 1 (adding 1 person to the forming and packaging unit) resulted in an increase of 11.35% in the number of jobs from the current system to 86.31%. Furthermore, there were 96 items of work in process, down from 45.76% at the present time (shown in Table 1). For the option 2 (one employee in packing process and one employee in forming process), this resulted in the number of jobs accounting for 85.90%, an increase of 10.94% from the current system, and 96 pieces of work in progress, or a 45.76% decrease from the current status (as shown in Table 1). The last option is to change the factory layout, which resulted in the current scenario in which the number of jobs accounted for 77.19% and there were 2.23% more jobs than before, with 164 in-process work items, which was 7.34% fewer than the normal system (shown in Table 1).

6 Conclusions

The findings of this study on simulation and comparing work productivity and waiting time for all three alternatives indicated that option 1 is the most suitable option by adding 1 staff in the forming and packing section. This resulted in the number of jobs representing 86.31% or an increase of 11.35% from the current situation and the work in progress decreased by 45.76%, which is quite similar to the second option. In terms of option 2, the development was planned by adding 1 employee for the packing section. And the remaining staff could work in the folding and forming process. As a consequence, the number of jobs increased by 10.94% from the regular operation, while the work in progress dropped by 45.76% from the regular operation. It was concluded that adding more staff to work in high-waiting areas would help to increase the quality of production and to reduce the wasted time. Therefore, the simulation is used to significantly improve the carton manufacturing process. It can also provide better alternatives, resulting in more effective decision-making, the capability of the process, and competitiveness of enterprises.

The results of this study can be applied to further studies in various aspects, such as modifying the structure of the factory, technology modification, and the appropriate amount of staff and machines for each process. However, choosing the alternative for the improvement also depends on other factors regarding the company's situation. To illustrate, the cost of improvements needs to be suitable with the budget of the company and the number of employees need to be sufficient for the improvement plan. Moreover, the improvement method should not affect the other products of the company. Therefore, it can be concluded that using simulation modeling with Flexsim® provides a clear visualization of the changes without having any impact on the real operation.

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References

Cárdenas O, Valencia A, Montt C (2018) Congestion minimization through sustainable traffic management. A micro-simulation approach. LogForum 14(1):21–31. https://doi.org/10.17270/J.LOG.2018.260

Chalermjirarat W (2006) The QC problem solving approach solving workplace problems the Japanese way. Technology Promotion Association (Thailand-Japan), Bangkok

Chandrakumar C, Gowrynathan J, Kulatunga AK, Sanjeevan N (2016) Incorporate lean and green concepts to enhance the productivity of transshipment terminal operations. Proc CIRP 40:301–306. https://doi.org/10.1016/j.procir.2016.01.042

Chanthakhot W, Ransikarbum K (2021) Integrated IEW-TOPSIS and fire dynamics simulation for agent-based evacuation modeling in industrial safety. Safety 7(2):47, 1–21. https://doi.org/10.3390/safety7020047

Darayi M, Eskandari H, Geiger CD (2013) Using simulation-based optimization to improve performance at a tire manufacturing company. Qsci Connect 13:1–12. https://doi.org/10.5339/connect.2013.13

Dobrzyński M, Waszczur P (2018) Simulation analysis of a production process with selected six sigma ratios. LogForum 8(1):47–54. Retrieved Jan 03, 2021, from https://www.logforum.net/pdf/8_1_6_12.pdf

Ghiyasinasab M, Lehoux N, Ménard S, Cloutier C (2018) Using lean techniques and simulation to improve the efficiency of engineered wood production: a case study in a small factory. Ind Eng Manag 7(4):1–11. https://doi.org/10.4172/2169-0316.1000269

He H, Hua Z (2018) Analysis of fast food service capability based on Flexsim modeling and simulation. IOP Conf Ser Mater Sci Eng 394:1–6. https://doi.org/10.1088/1757-899X/394/5/052005

Huihui S, Xiaoxia M, Xiangguo M (2016) Simulation and optimization of warehouse operation based on flexsim. J Appl Sci Eng Innov 3(4):125–128. https://doi.org/10.35940/ijrte.B1137.0782S419

Ishak A, Zubair AF, Cendani AS (2020) Production line simulation in vise using the Flexsim application. IOP Conf Ser Mater Sci Eng 1003:1–6. https://doi.org/10.1088/1757-899X/1003/1/012103

Jarernram J (2017) Makespan optimization of parallel machine production scheduling through simulation technique, Master's thesis, School of Industrial Engineering, Suranaree University of Technology. Retrieved Feb 10, 2021, from http://sutir.sut.ac.th:8080/jspui/handle/123456789/7652

Jarernram J, Samattapapong N (2018) Parallel machine scheduling using simulation software. In: 4th international conference on mechanical engineering and industrial automation held on, pp 150–155

Kelton WD, Sadowski RP, Sturrock DT (2007) Simulation with arena. McGraw-Hill Education, New York

Kengpol A, Youngswaing W (2015) Application of concurrent engineering and simulations in productivity improvement of the pipe bending: a case study in an oil pipe manufacturer. J KMUTNB 25(2):233–242. https://doi.org/10.14416/j.kmutnb.2015.01.005

Klinlek P, Samattapapong N, De Cadenet V (2021) Modeling, increasing efficiency and production capacity in melamine dish production line. EasyChair preprint no. 4652, pp 1–6. Retrieved Apr 10, 2021, from https://easychair.org/publications/preprint/7rMW

Kluska K (2021) Automatic simulation modelling of warehouses. LogForum 17(1):59–69. https://doi.org/10.17270/J.LOG.2021.547

Kumar BS, Mahesh DV, Kumar BS (2015) Modeling and analysis of flexible manufacturing system with FlexSim. Int J Comput Eng Res 5(10):1–6. Retrieved Jan 03, 2021, from https://www.ijceronline.com/papers/Vol5_issue10/A05100106.pdf

Kusoncum C, Sethanan K, Putri EP, Neungmacha W (2018) Simulation-based approaches for processes improvement of a sugar mill yard management system: a case study of the sugar industry in the central region of Thailand. Eng Appl Sci Res 45(4):320–331. https://doi.org/10.14456/easr.2018.44

Luscinski S, Ivanov V (2020) A simulation study of industry 4.0 factories based on the ontology on flexibility with using flexsim® software. Manag Prod Eng Rev 11(3):74–83. https://doi.org/10.24425/mper.2020.134934

Mhoraksa T, Samattapapong N, Yunyao S, Wongsakul P (2020) Simulation-based application for improving drinking water production process: a case study of the drinking water factory in Chanthaburi. RMUTL Eng J 5(2):36–42. https://doi.org/10.14456/rmutlengj.2020.11

Nie X, Wang L (2019) Simulation process design for scheduling mode of railway container terminals based on Flexsim. IOP Conf Ser Mater Sci Eng 1176:1–5. https://doi.org/10.1088/1742-6596/1176/5/052012

Pawlak Z (2008) An alternative application of logit modelling in management of metropolitan areas: the case study of Poznań urban area. LogForum 4(4):1–14. Retrieved Jan 03, 2021, from https://www.logforum.net/pdf/4_4_2_2008.pdf

Phanindra KD, Ratna PP, Kalamulla MD, Sai KP, Sai PBLN (2019) Analyze the production system of an body-in-white system through modelling and perform bottleneck, optimization using simulation software. Int J Rec Technol Eng 8(2S4):685–690. https://doi.org/10.35940/ijrte.B1137.0782S419

Pisuchpen R (2008) Modeling with arena. SE-Education, Bangkok

Praison J (2011) Operation management. SE-Education, Bangkok

Ransikarbum K (2020) Analysis of traffic flow at a red light intersection using computer simulation technique. Thai J Oper Res 8(2):1–14. Retrieved Mar 05, 2021, from https://ph02.tci-thaijo.org/index.php/TJOR/article/view/225684/164532

Rodalwski B (2006) Simulation of logistics process (SIMPROCESS). LogForum 2(1):1–15. Retrieved Mar 03, 2021, from https://www.logforum.net/pdf/2_1_4_06.pdf

Samattapapong N (2017) An efficiency improvement in warehouse operation using simulation analysis. IOP Conf Ser Mater Sci Eng 273:1–7. https://doi.org/10.1088/1757-899X/273/1/012013

Samattapapong N (2018) Productivity improvement of tapioca packing process through simulation modeling analysis. In: Proceedings of 2018 5th international conference on industrial engineering and applications (ICIEA), pp 453–457. https://doi.org/10.1109/IEA.2018.8387143
Suracherdkiati W (2001) Computer simulation. Skybook, Pathum Thani

Solving Multi-Echelon Location Allocation Problem Using Modified Differential Evolution Algorithm: Case Study of Agricultural Products Warehouse in Greater Mekong Subregion

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1 Introduction

This research aimed to design a transportation network for agricultural products' international trade among Thailand, Laos, and Cambodia. To that end, firstly, agricultural products must be delivered from the agricultural cooperatives (AC) that

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https://doi.org/10.1007/978-3-031-15412-6_9

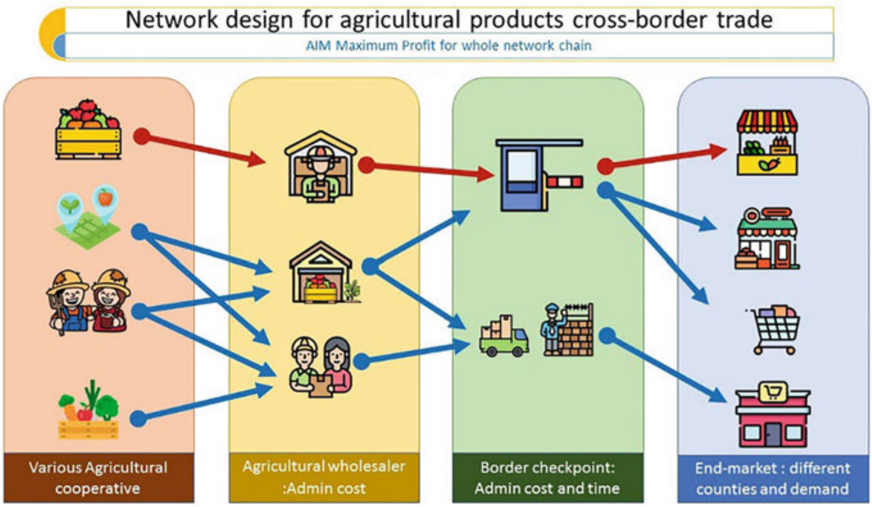

Fig. 1 Framework of the proposed problem

collected the products from the farmers. The AC will transport the products to the wholesaler agricultural market (WSAM), which will transport the products to the border checkpoint (BC). After the BC, the trucks delivering the products from the WSAM will pass through the border and deliver the products to the end-market in the specified countries and regions. The framework of this process is shown in Fig. 1.

As shown in Fig. 1, the model of transportation can be formulated as a multi-echelon transportation problem or multi-level network flow problem. The transportation problem for agricultural products has been widely studied by many researchers such as Hsu et al. (2007), who presented the food distribution planning model when taking into account the stochastic and time-dependent travel times and time-varying temperature. Osvald and Stirn (2008) addressed the distribution of fresh vegetables while considering time-dependent travel times. In that research, the quality degradation-based cost as an objective function was presented. Tarantilis and Kiranoudis (2001, 2002) studied milk transportation with a fixed fleet. Sethanan and Pitakaso (2016) presented an algorithm to resolve raw milk transportation while considering the special case of a truck with multiple compartments used to transport milk.

The agricultural product is one type of perishable product. Perishable products need intensive care during transportation to the final destination. Doerner et al. (2008) studied the Pickup and Delivery Problem (PDP) of blood products with strict time windows. Hsu et al. (2007) modelled a food distribution planning problem with stochastic and time-dependent travel times and time-varying temperatures. Osvald and Stirn (2008) not only addressed the distribution of fresh vegetables with time-dependent travel times but also add a quality degradation-based cost function to the objective function. Tarantilis and Kiranoudis (2001, 2002) studied the distribution of fresh milk with a heterogeneous fixed fleet, and the distribution of fresh meat in a multi-depot network, respectively. They considered strict time windows for delivery of the products. Derigs et al. (2011), Mendoza et al. (2011), and Reis and Leal (2015) proposed different shipping strategies, numbers of actors in the transportation chain, and limitations of the transportation modes. In our study, the transportation time is discussed as the time taken from the origin to the final destination needs to be within a certain time. As our products need to be transported via border checkpoints, this can delay the transportation time with a hold-up while the inter-trade document is checked. We select borders as candidates for the shipping route based on which borders are convenient for international trade shipping.

Transported agricultural products pass through different actors in the supply chain, and thus it forms a transportation or service network. A service network is a structure that brings together several entities to deliver a particular service. In our research, the service network is formed to deliver the agricultural product from the origin to the end-market. The network design problem has become more popular for researchers in the last decade. The service network design (SND) problem has been modelled and presented by Pedersen et al. (2009) and Andersen et al. (2009a, b, 2011). Moccia et al. (2011) presented a rail and road transportation system with both consolidated and dedicated services. Later, Thiongane et al. (2015) and Li et al. (2016) presented a capacitated multi-commodity with heterogeneous assets and non-bifurcated hop-constrained multi-commodity capacitated fixed-charge network design.

In this study, the network design for the transportation of the agricultural products from the origin to the end-market involves passing through the borders of several countries. The borders of different countries may have different regulations, which can give the transportation a higher or lower cost and lead to a shorter or longer transportation time, which can affect decisions on the transportation mode and methods. We will present the mathematical model for the proposed problem and solve it heuristically to obtain a promising solution that provides the highest profit throughout the supply chain while keeping a low computational time.

The method that we will use to solve the proposed problem is a differential evolution algorithm. A differential evolution algorithm is a metaheuristics method that iteratively improves the solution quality by changing the neighborhood structure using the differential of two or more sets of numbers. This was firstly proposed by Storn and Price (1997) and has been used to successfully solve many different types of problems. The problems it has solved include the unmanned aerial vehicle multi-tasking problem (Su and Wang 2021), reservoir production optimization problem (Jianwei et al. 2021); parameter calibration problem (Luo et al. 2021; Srichok et al. 2020, 2021), scheduling problem (Pitakaso and Sethanan 2019), vehicle routing problem (Dechampai et al. 2015), and employee transportation problem (Pitakaso et al. 2019).

In this research, we modify the differential evolution algorithm so that DE has better search behavior. We add one step into the original DE called the vector hybrid reincarnation process (HRP). This step is added before the recombination process. The defeated vector from the selection process will be randomly selected as the trunked (TV) set of vectors. This set of vectors will be hybrid exchanged with the best set of vectors (BV) to obtain the reincarnation vector (RV). The RV will be used as one choice to form the trial vector.

This paper will be organized as follows. In Sect. 2, the mathematical model that represents the network design will be presented. Sections 3 and 4 will show the proposed methods and computational results, and the last section, Sect. 5, will present the conclusions and outlook of this research.

2 Mathematical Model Formulation

Indices

i Wholesaler market i ($i = 1, 2, 3, \ldots, I$).
j Cooperative j ($j = 1, 2, 3, \ldots, J$)
k Border k ($k = 1, 2, 3, \ldots, K$).
l End-market l ($1 = 1, 2, 3, \ldots, L$)

Parameters

I	Number of wholesaler markets
J	Number of agricultural cooperatives
K	Number of border checkpoint
L	Number of end-market s.
D_{ij}	Distance from wholesaler market i to cooperative j (km).
TS	Transportation fuel cost ($/Km)
AC_i	Operating costs of wholesaler market i ($).
DM_l	The demand of end-market l (ton)
CP_i	Capacity of wholesaler market i (ton)
VL_i	Volume of central market I (ton).
EP_{ik}	Distance from wholesaler market i to border k (km)
SP_i	Sale price of end-market l ($)
VC_{kl}	Volume of goods delivered from border k to end-market l (ton).
NF_j	Product quantity of cooperative j (ton)
AMC_k	Operating costs of border k ($)
TTV_k	Cargo quantity of border k (ton)
DCE_{kl}	Distance from border k to end-market l (Km)
VCC_{ik}	Volume of goods delivered from wholesaler market i to border k

Decision variable

$$X_{ij} \quad \begin{cases} 1 \text{ if wholesaler market } i \text{ serves cooperative} j \\ 0 \text{ otherwise} \end{cases}$$

Z_{ik} $\begin{cases} 1 \text{ if wholesaler market } i \text{ serves border} k \\ 0 \text{ otherwise} \end{cases}$

V_{kl} $\begin{cases} 1 \text{ if border } k \text{ serves the end} - \text{market} l \\ 0 \text{ otherwise} \end{cases}$

Y_i $\begin{cases} 1 \text{ if wholesaler market } i \text{ is a collection point for agricultural products} \\ 0 \text{ otherwise} \end{cases}$

Objective function

$$Max = \sum_{k=1}^{K}\sum_{l=1}^{L} SP_l VC_{kl} - \sum_{k=1}^{K} AMC_k TTV_k - \sum_{i=1}^{I} AC_i VL_i - \sum_{i=1}^{I}\sum_{j=1}^{J} X_{ij} D_{ij} + \sum_{i=1}^{I}\sum_{k=1}^{K} TS.Z_{ik} EP_{ik} + \sum_{k=1}^{K}\sum_{l=1}^{L} TS.V_{kl} DCE_{kl} \quad (1)$$

Subject to

$$\sum_{j=1}^{J} NF_j X_{ij} \le Y_i CP_i \quad \forall_i (i = 1, 2, 3, ..., I) \quad (2)$$

$$\sum_{i=1}^{I} X_{ij} = 1 \quad \forall_j (j = 1, 2, 3, ..., J) \quad (3)$$

$$VL_i = \sum_{i=1}^{I} X_{ij} NF_j \quad \forall_i (i = 1, 2, 3, ..., I) \quad (4)$$

$$VCC_{ik} \le Z_{ik} VL_i \quad \forall_i (i = 1, 2, 3, ..., I) \forall_k (k = 1, 2, 3, ..., K) \quad (5)$$

$$Z_{ik} \le Y_i \quad \forall_i (i = 1, 2, 3, ..., I) \forall_k (k = 1, 2, 3, ..., K) \quad (6)$$

$$\sum_{k=1}^{K} VCC_{ik} = VL_i \quad \forall_i (i = 1, 2, 3, ..., I) \quad (7)$$

$$TTV_k = \sum_{i=1}^{I} VCC_{ik} \quad \forall_k (k = 1, 2, 3, ..., K) \quad (8)$$

$$VC_{kl} \le V_{kl} TTV_k \quad \forall_k (k = 1, 2, 3, ..., K) \forall_i (i = 1, 2, 3, ..., I) \quad (9)$$

$$\sum_{l=1}^{L} VC_{kl} = TTV_k \quad \forall_k (k = 1, 2, 3, ..., K) \quad (10)$$

$$\sum_{k=1}^{K} VC_{kl} \leq DM_l \quad \forall_l (l = 1, 2, 3, ..., L) \tag{11}$$

Equation 1 defines the objective function, attempting to maximize the total profit of the network chain. The profit comprises the selling price of the agricultural product at the end-market after subtracting all travel and administration costs of the actors in the chain. Equation 2 controls the total number of products delivered from all cooperatives to a wholesaler market so that these do not exceed its capacity. Equation 3 shows that a single cooperative must not deliver to more than one wholesaler market. Equations 4, 5, 6, and 7 define that the quantity of agricultural products traveling from wholesaler i to border k must not exceed the products' availability, while Eqs. 8, 9, and 10 control the numbers of products delivered from border k to end-market l as these must not exceed the products that are available at the border checkpoint. Equation 11 shows that the products delivered from all borders must not exceed the capacity of the end-market.

3 The Proposed Method

To solve the proposed problem in this research, the differential evolution algorithm (DE) will be used. In general, DE consists of five steps: (1) generate initial solution, (2) perform mutation process, (3) perform mutation process, (4) perform selection process, and (5) redo steps (2)–(4) until termination condition is met. In this research, the modified differential evolution algorithm (MDE) will be developed to improve the efficiency of the original DE. The hybrid reincarnation process will be added after step (3) before the recombination process is performed. Although the MDE proposed in this research consists of six steps, steps (1) to (3) are similar to those of the traditional DE. Step (4) of the MDE is to perform the hybrid reincarnation process, step (5) is to perform the recombination process, step (6) is to perform the selection process, and step (7) is to redo steps (2)–(6) until the termination condition is met. The modified DE can be explained stepwise as follows.

3.1 Generate the Initial Solution

Target vectors are generated in this step to obtain the vector that represents the proposed problem. In this research, the indirect coding technique is used to represent the problem, and the decoding process is applied to the coded vector to obtain the solution to the proposed problem.

Table 1 Five target vectors example

Vector	Cooperative					
	1	2	3	4	5	6
1	642	973	610	116	498	629
2	866	158	974	152	465	121
3	157	694	816	466	626	346
4	921	569	265	959	152	520
5	127	612	780	645	552	472

3.1.1 Encode the Target Vector

Integer number coding is used to represent the problem. Table 1 represents the five target vectors of the 1☐D vector when D is the number of agricultural cooperatives.

3.1.2 Decode the Target Vector

Figure 2 displays the decoding method and presents the problem for cooperative number 1 of vector 1. The coding number or value in position is 642. This number can be interpreted to mean that cooperative 1 will deliver its product to wholesaler market number 6, and then wholesaler number 6 will deliver the product to border number 4, passing through to end-market number 2. If some actors in the chain have more than 1 digit (e.g., there are 20 wholesaler markets), then the first two digits in the position will represent the wholesaler number and the total digits in the position will number four. In the same manner, the digits will run from 0 to 9 in every position if there are less than 10 actors at the horizontal level of the actors. For example, our system has three borders, but as can be seen in Fig. 1, it has the number in position 2 that runs from 0 to 9. This problem can be solved by dividing 10 digits into three groups: 1–3 (border 1), 4–6 (border 2), and 7–10 (border 3). When the second digit falls in one of these groups of numbers, it can be interpreted as corresponding to that border.

If the problem has six cooperatives, four wholesalers, three borders, and four end-markets, the digit presenting each actor is shown in Fig. 3.

Details of all actors are shown in Table 2.

The solution obtained from vector 1 is shown in Tables 3 and 4.

6	**4**	**2**
Label of the wholesaler market	Label of the border checkpoint	Label of the end-market

Fig. 2 Example of the result represent the problem's solution

Digit represent each wholesaler	Digit represent each borders	Digit represent each end-market
Digit position 1	Digit position 2	Digit position 3
0-2 wholesaler 1	0-2 border 1	0-2 end-market 1
3-4 wholesaler 2	3-6 border 2	3-4 end-market 2
5-6 wholesaler 3	7-9 border 3	5-6 end-market 3
7-9 wholesaler 4		7-9 end-market 4

Fig. 3 The interpretation of digit to problem's solution

Table 2 Details (supply, capacity) of all actors in network chains

Cooperative		Wholesaler		Border		End-market	
No.	Supply (ton)	No.	Capacity (ton)	No.	Capacity (ton)	No.	Capacity (ton)
1	1200	1	4000	1	6000	1	4500
2	1000	2	3000	2	6000	2	4000
3	900	3	4000	3	5000	3	3000
4	1400	4	4500			4	4000
5	2000						
6	1300						

Table 3 Result of the assignment result of the decoding method

	Wholesaler	Border	End-market
1	3	2	1
2	4	3	2
3	3	1	1
4	1	1	3
5	2	3	4
6	3	1	4

If the average prices per ton of the agricultural product at end-markets 1 to 4 are \$14, \$12, \$11, and \$15, respectively, then the total revenue generated is \$143,200. The administration costs of wholesalers 1 to 4 are \$2, \$1, \$2, and \$1.50, respectively and the administration costs at borders 1 to 1 are \$2.30, \$2.40, and \$2.10, respectively. The total administration cost is thus \$20,960. The travel cost is calculated by multiplying the total traveling distance by the traveling cost per kilometer, which is \$0.10 per kilometer. If this plan has a total distance of 8300 km, then it has a traveling cost of \$830. Therefore, the total profit generated from this plan is \$104,410.

After the decoding method is performed, the next steps of the MDE are to perform the mutation, recombination, hybrid reincarnation, and selection processes.

Table 4 Result of the volume transported within the chain

	Wholesaler			
	1	2	3	4
Cap	4000	3000	4000	5000
Total agricultural product	1400	2000	3400	1000
	Border			
	1	2	3	
Cap	6000	6000	5000	
Total agricultural product	3600	1200	3000	
	End-market			
	1	2	3	4
Cap	4500	4000	3000	4000
Total agricultural product	4100	1000	1400	3300

3.2 Perform the Mutation Process

The mutation process is used to transform the target vector to the mutant vector. The process uses the difference of two selected vectors as the indicator of the transformation. Equation (12) represents the mutation operators.

$$V_{i,j,G} = X_{r_1,j,G} + F(X_{r_2,j,G} + X_{r_3,j,G}) \tag{12}$$

where r1, r2, and r3 are the indices of the randomly selected vectors; F is the scaling factor, which is set to 0.8 (Qin et al. 2009); i represents the vector number; $i = 1$, 2,…, NP; j is the position of a vector when $j = 1, 2,\ldots, D$.

3.3 Perform the Hybrid Reincarnation Process (HR)

This process is a new process that we present in this paper. The reincarnated vector ($H_{i,j,G}$) is formed in this process. To form the reincarnated vector, we use two sets of vectors. The first set of vectors is known as trunked vectors (TV: $M_{i,j,G}$); this comprises NP vectors that are randomly selected from the vectors that are trunked in selection process of the last iterations. These vectors will be updated iteratively; the system that is used to update the trunked vectors is one in which the vector that stays on the list the longest is replaced first by a newly selected TV. The second set of vectors used in this process is that of the best vectors (BV). NP best vectors obtained for entire iterations will be collected in the best vector (BV: $B_{i,j,G}$). The procedure to generate the $H_{i,j,G}$ has three steps: (1) randomly select a vector from the trunked vectors ($H_{i,j,G}$), (2) randomly select a vector from the best vectors.

($B_{i,j,G}$), and (3) use Eq. (12) to construct a reincarnated vector ($RV : H_{i,j,G}$). An example of a reincarnated vector generator is shown in Fig. 4. CR is a predefined parameter that is set to 0.65 in this research.

$$H_{i,j,G} = \begin{cases} M_{i,j,G} \ when \ rand_{i,j,G} \leq CR \\ B_{i,j,G} \ \ otherwise \end{cases} \tag{13}$$

3.4 Perform the Recombination Process

Obtaining the trial vector is the aim of performing the recombination process. Equation (14) is used to transform the mutant vector into the trial vector.

$$U_{i,j,G} = \begin{cases} H_{i,j,G} \ if \ rand_{i,j,G} < CR1 \\ V_{i,j,G} \ if \ CR1 \leq rand_{i,j,G} < CR2 \\ X_{i,j,G} \ otherwise \end{cases} \tag{14}$$

where $U_{i,j,G}$ is the trial vector, $V_{i,j,G}$ is the mutant vector, $rand_{i,j,G}$ is a random number [0,1], $X_{i,j,G}$ is the target vector of vector i position j iterations G, and CR1 and CR2 are predefined numbers set to 0.35 and 0.65, respectively.

3.5 Perform the Selection Process

The selection process is executed to generate a new target vector. Equation (15) is used to select the new target vector to use in the next iteration. When $X_{i,j,G+1}$ is the target vector for the next iteration, $f(U_{i,j,G})$ is the objective function of the trial vector and $f(X_{i,j,G})$ is the objective function of the current target vector.

$$X_{i,j,G+1} = \begin{cases} U_{i,j,G} \ when \ if \ f\left(U_{i,j,G}\right) \geq f\left(X_{i,j,G}\right) \\ X_{i,j,G} \ otherwise \end{cases} \tag{15}$$

3.6 Redo Step (3.2–3.4) Until Termination Condition is Met

The stoppage criterion for this research is the computational time of the proposed method in order for a fair comparison with the other compared heuristics. The pseudo code of the proposed methods is shown in Fig. 5.

Trunked Vector ($M_{i,j,G}$)						
cooperative Vector	1	2	3	4	5	6
1	904	394	995	852	280	649
2	501	193	956	447	806	366
3	898	342	814	878	968	261
4	156	389	189	611	690	303
5	313	221	799	882	480	378

Best Vector ($B_{i,j,G}$)						
cooperative Vector	1	2	3	4	5	6
1	138	894	765	388	643	450
2	850	541	313	485	225	378
3	767	716	775	128	430	597
4	681	576	436	645	560	131
5	104	940	792	607	270	951

cooperative Vector	1	2	3	4	5	6
$M_{i,j,G}$ (2)	501	193	956	447	806	366
$B_{i,j,G}$ (4)	681	576	436	645	560	131
$rand_{i,j,G}$	0.41	0.76	0.18	0.41	0.89	0.34
CR	0.65	0.65	0.65	0.65	0.65	0.65
$H_{i,j,G}$	501	576	956	447	560	366

Fig. 4 Example of reincarnated vector generator

```
Algorithm 2: Differential evolution algorithm (DE)
input : Population size (NP), Problem Size (D), Mutation Rate (F),
Recombination rate (R)
output: Best_Solution, Best_Cost
begin
  WP = Initialize Population(NP, D)
  while the stopping criterion is not met do
    for i=1: NP
        V_rand1, V_rand2, V_rand3 = Select_Random_Vector (WP_i)
        For j = 1:D // Loop for the mutation operator
            V_y [j]= V_rand1 [j]+ F(V_rand2 [j]+ V_rand3 [j])
        End For Loop//end mutation operator
        For j = 1:D //Loop for recombination operation
            If(rand_j [0,1) <R ) Then
                u [j]= V_i [j]
            Else
                u [j]= V_y [j]
        End For Loop//end recombination operation
        IF(CostFunction(u) ≤ CostFunction(V_i)) Then
            V_i = u
    End For Loop
  End
  Best_Solution, Best_Cost =DeCodeLocationAllocation(WP)
  Return Best_Solution, Best_Cost
end
```

Fig. 5 Pseudo code of the proposed method

3.7 Compared Heuristics

In the experiment, we compare two other methods with the proposed method: (1) the original differential evolution algorithm and (2) the original genetic algorithm. The original DE is similar to the proposed method, but the original does not have the HS process, while the GA is a method taken from Mitchell (1996) to use in our problem. The pseudo code of GA used in our research is shown in Fig. 6.

4 Computational Results and Framework

We code the mathematical model in Lingo V.11 and code the modified DE, DE, and GA with C++, executing them using a PC Intel® Core ™ i5-2467 M CPU 1.6 GHz. Fifteen randomly generated datasets are tested to compare the performance of the proposed methods. Each has a different number of cooperations, central markets, border checkpoints, and end-markets. Table 5 details all test problems included in the case study.

The stoppage criterion of Lingo is the computational time when it can find the optimal solution within 24 h. If it cannot find the optimal solution within 48 h, the best

```
Algorithm 3: Genetic Algorithm (GA)
input: Population Size (NP), Problem Size (D), Mutation Rate (M), Crossover
Rate (CR)
output: Best_Vector_Solution
begin
    Population = Initialize Population (NP, D)
    encode Population to WP
    while the stopping criterion is not met do
       parents = WP
       for i=1: NP //Loop for crossover operation
          For j = 1:D
          If(rand_j [0,1) <CR ) Then
                offspring_i [j]= parents_i [j]
                offspring_i+1 [j]= parents_i+1 [j]
          Else
                offspring_i [j]= parents_i+1 [j]
                offspring_i+1 [j]= parents_i [j]
          End For Loop
       End For Loop//end crossover operation
       for i=1: NP //Loop for mutation operation
          For j = 1:D
          If(rand_j [0,1) <M ) Then
                Mutation(offspring_i [j])
          End For Loop
       End For Loop//end mutation operation
       // Add the child population to the parent population
       NWP = stack(parents, offspring)
       wp_size = length(NWP) // Set number of new population
       for i=1: wp_size //Loop for evaluate operation
          cost_ scores i+1 = CostFunction(NWP i+1)
       End For Loop//end evaluate operation
       //selection operation
       new_ wp = Sorted(new_ population, cost_ scores)
       WP = NWP [1:NP]
       decode WP to get the solution for the problem
       Return Best Vector Solution
end
```

Fig. 6 Pseudo code of GA used in this research

solution is instead recorded. The stoppage criterion of the heuristics is the computational time, which is set to five minutes for test instances 1–5, 10 min for instances 6¬–10, and 30 min for instances 11–15 (include case study). The computational results are shown in Table 6 and the statistical results of the Wilcoxon signed-rank test are shown in Table 7.

Tables 6 and 7 show that the MDE significantly improves the solution quality versus other methods, including the best objective obtained from Lingo v.11, which

Table 5 Detail of the test instances

Test instance no	Number of cooperative	Number of center-market	Number of border checkpoint	Number of end-market
1	15	6	4	11
2	20	6	4	11
3	25	6	4	11
4	30	6	4	11
5	35	6	4	11
6	40	6	4	11
7	45	6	4	11
8	50	6	4	11
9	55	6	4	11
10	60	6	4	11
11	65	6	4	11
12	70	6	4	11
13	75	6	4	11
14	80	6	4	11
Case study	86	6	4	11

Table 6 Computational result of all 14 test instances

Test instance no	Lingo v.11		GA		DE		MDE	
	profit ($)	ComT (min)	Profit ($)	ComT (min)	Profit ($)	ComT (min)	Profit ($)	ComT (min)
1	199202.6	53.49	193052.0	5	199202.6	5	199202.6	5
2	251162.6	94.89	241034.7	5	251162.6	5	251162.6	5
3	318072.4	120.82	318072.4	5	314500.6	5	318072.4	5
4	356517.6	1440	356517.6	5	356517.6	5	356517.6	5
5	414876.4	1440	423794.8	5	430783.2	5	443033.8	5
6	508729.8	1440	514712.5	10	523468.0	10	533945.9	10
7	598124.5	1440	605844.8	10	614590.1	10	636206.7	10
8	610287.7	1440	640889.0	10	649937.2	10	661569.9	10
9	639812.4	1440	691052.0	10	705855.1	10	717526.8	10
10	710183.2	1440	733103.0	10	733725.4	10	756481.2	10
11	832718.3	1440	889632.4	30	899002.1	30	920912.0	30
12	901273.8	1440	941495.5	30	946175.4	30	971764.7	30
13	922371.7	1440	966128.3	30	969167.9	30	997934.3	30
14	987273.2	1440	1056063.3	30	1065787.4	30	1088201.6	30
Case study	992741.7	2880	1145842.2	30	1155271.6	30	1167625.7	30

Table 7 Statistical test of the computational obtained in Table 13 (p-value)

	GA	DE	MDE
Lingo v.11	0.001	0,001	0.001
GA		0.000	0.000
DE			0.000

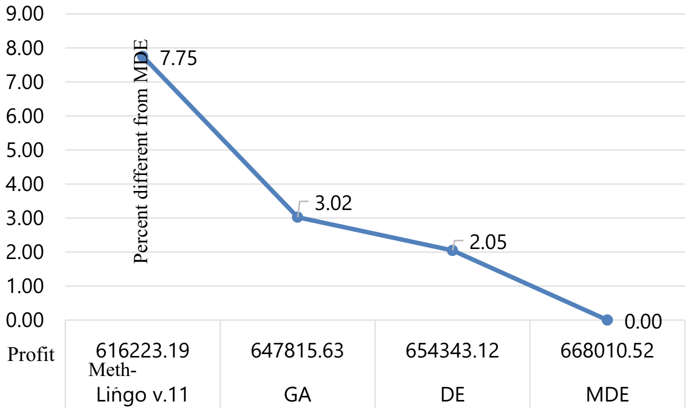

Fig. 7 Percent different of the solution quality of various method compared with MDE

uses a computational time of less than 2880 h. Figure 7 shows that the MDE can improve the solution of the original DE by 2.02%, which means that using the hybrid reincarnation process is useful to improve the solution quality versus the original DE.

Moreover, the MDE produces 7.75% and 3.02% better solutions than those of the best objective (obtained from Lingo v.11 using 2880 h computational time) and the GA, respectively.

Figure 8 shows the numbers and percentages of methods that can find the maximum profit of the proposed problem. We can see than the MDE can find 100% of the maximum profit Figs. (15 cases), while Lingo V.11, GA, and the original DE can find 26.67% (4 cases), 13.33% (2 cases), and 20% (3 cases), respectively.

Figure 9 shows that the MDE outperforms the original DE by finding a 100% better solution than that of the DE, which mean that using the hybrid reincarnation process contributes to improving the solution quality of the DE.

5 Conclusion and Future Outlook

This research aimed to design a transportation model for agricultural products' international trade among Thailand, Laos, and Cambodia. The agricultural products are transported from a farmers' cooperative to a foreign end-market. During transportation, they pass through wholesaler markets and border checkpoints. The mathematical

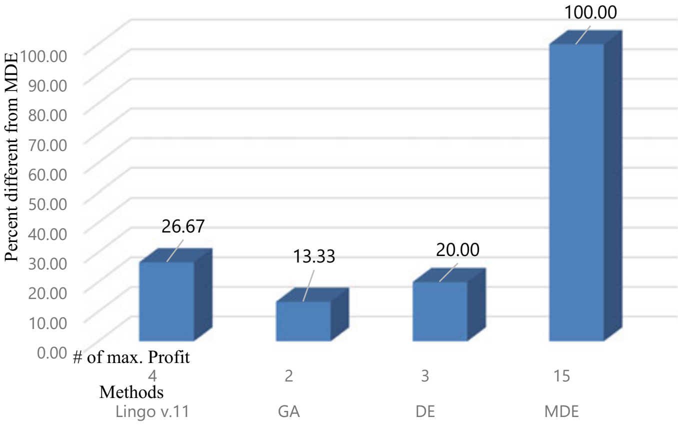

Fig. 8 Number of Maximum Profit Generated from Various Methods

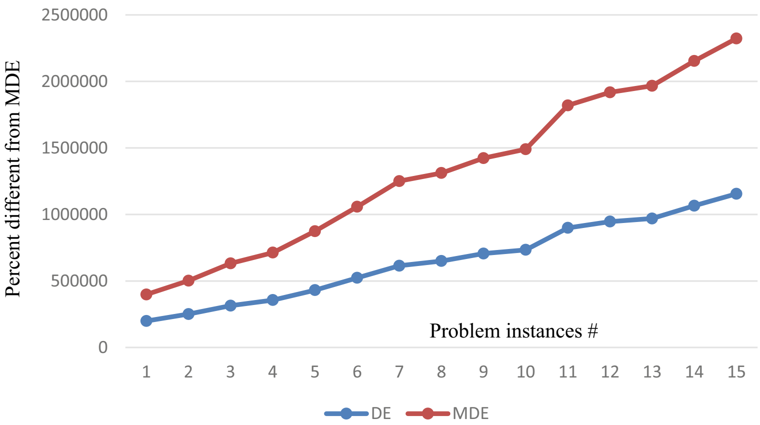

Fig. 9 Profit generated from DE and MDE

models GA, DE, and MDE have been developed to determine the optimal mode of transportation. The hybrid reincarnation process has been added to the original DE to improve its search capability.

The computational results show that the MDE gives better solutions than Lingo V.11, GA, and the DE by 7.75%, 3.02%, and 2.05%, respectively. The MDE, which is the DE with an added hybrid reincarnation process, can find 100% of the maximum profit, while the DE can find 20% of the maximum profit, which means the MDE can improve the solution quality of the original DE by 80%.

In future research, multiple fleets should be added into the model so the system can select the right fleet type for the right amount of agricultural product to be shipped. Moreover, planning over multiple periods and for multiple products could increase the performance of the model. These suggestions, when investigated in future research, should increase the performance of the MDE model.

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References

Andersen J, Crainic T, Christiansen M (2009a) Service network design with asset management: formulations and comparative analyses. Transp Res Part C 17(2):197–207

Andersen J, Crainic T, Christiansen M (2009b) Service network design with management and coordination of multiple fleets. Eur J Oper Res 193(2):377–389

Andersen J, Christiansen M, Crainic T, Grønhaug R (2011) Branch and price for service network design with asset management constraints. Transp Sci 45(1):33–49

Dechampai D, Tanwanichkul L, Sethanan K, Pitakaso P (2015) A differential evolution algorithm for the capacitated VRP with flexibility of mixing pickup and delivery services and the maximum duration of a route in poultry industry. J Intell Manuf 28(6). https://doi.org/10.1007/s10845-015-1055-3

Derigs U, Gottlieb J, Kalkoff J, Piesche M, Rothlauf F, Vogel U (2011) Vehicle routing with compartments: applications, modelling and heuristics. Or Spectr 33(4):885–914

Gu J, Liu W, Zhang K, Zhai L, Zhang Y, Chen F (2021) Reservoir production optimization based on surrograte model and differential evolution algorithm. J Pet Sci Eng 205:108879. ISSN 0920-4105.https://doi.org/10.1016/j.petrol.2021.108879

Hsu C, Hung S, Li H (2007) Vehicle routing problem with time-windows for perishable food delivery. J Food Eng 80(2):465–475

Li X, Wei K, Aneja Y, Tian P (2016) Design-balanced capacitated multicommodity network design with heterogeneous assets. Omega. Article in press

Luo G, Zou L, Wang Z, Lv C, Ou J, Huang Y (2021) A novel kinematic parameters calibration method for industrial robot based on Levenberg-Marquardt and Differential Evolution hybrid algorithm. Robot Comput Integr Manuf 71:102165. ISSN 0736-5845.https://doi.org/10.1016/j.rcim.2021.102165

Mendoza J, Castanier B, Guéret C, Madaglia A, Velasco N (2011) Constructive heuristics for the multicompartment vehicle routing problem with stochas- tic demands. Transp Sci 45(3):346–363

Mitchell M (1996) An introduction to genetic algorithms. Cambridge

Moccia L, Cordeau J, Laporte G, Ropke S, Valentini M (2011) Modeling and solving a multimodal transportation problem with flexible time and scheduled services. Networks 57(1):53–68

Pedersen M, Crainic T, Madsen O (2009) Models and tabu search metaheuristics for service network design with asset-balance requirements. Transp Sci 43(2):158–177

Pitakaso R, Sethanan K, Srijaroon N (2019) Modified differential evolution algorithms for multi-vehicle allocation and route optimization for employee transportation. Eng Optim 1–19. https://doi.org/10.1080/0305215x.2019.1640691

Pitakaso R, Sethanan S (2019) Adaptive large neighborhood search for scheduling sugarcane inbound logistics equipment and machinery under a sharing infield resource system. Comput Electron Agric 158:313–325. https://doi.org/10.1016/j.compag.2019.02.001

Qin K, Huang V, Suganthan P (2009) Differential evolution algorithm with strategy adaptation for global numerical optimization. Evolutionary computation. IEEE Trans 13:398–417. https://doi.org/10.1109/TEVC.2008.927706

Reis S, Leal J (2015) A deterministic mathematical model to support temporal and spatial decisions of the soybean supply chain. J Transp Geogr 43:48–58

Sethanan K, Pitakaso R (2016) Differential evolution algorithms for scheduling raw milk transportation. Comput Electron Agric 121:245–259. https://doi.org/10.1016/j.compag.2015.12.021

Srichok T, Pitakaso R, Sethanan K, Sirirak W, Kwangmuang P (2020) Combined response surface method and modified differential evolution for parameter optimization of friction stir welding. Processes 8:1080

Srichok T, Pitakaso R, Sethanan K, Kumphon O, Pattanapairoj S, Worasan K (2021) Novel approach to find the optimal parameters of a tractor disc plough used for land preparation. Eng Optim. https://doi.org/10.1080/0305215X.2021.1901284

Storn R, Price K (1997) Differential evolution—a simple and efficient heuristic for global optimization over continuous spaces. J Global Optim 11(4):341–359. https://doi.org/10.1023/A:1008202821328.S2CID5297867

Su J, Wang H (2021) An improved adaptive differential evolution algorithm for single unmanned aerial vehicle multitasking. Defence Technol. ISSN 2214-9147. https://doi.org/10.1016/j.dt.2021.07.008

Tarantilis C, Kiranoudis C (2001) A meta-heuristic algorithm for the efficient distribution of perishable food. J Food Eng 50(1):1–9

Tarantilis C, Kiranoudis C (2002) Distribution of fresh meat. J Food Eng 51(1):85–91

Thiongane B, Cordeau J, Gendron B (2015) Formulations for the nonbifurcated hop-constrained multicommodity capacitated fixed-charge network design problem. Comput Oper Res 53:1–8

Mathematical Modelling for Optimizing Tourist Trip Design with Considering Scoring on Arc Visits

Ryo Geoffrey Widjaja, A. A. N. Pewira Redi, Parida Jewpanya, Muhammad Asrol, and Nur Layli Rachmawati

1 Introduction

A number of application problems of logistics, tourism, and related fields have arisen in the last decade (Vansteenwegen et al. 2011). These problems are modelled as "Orienteering Problem", which was first introduced by Golden et al. (Golden et al. 1987). The generalized orienteering problem (GOP) is one extension of the orienteering problem (Urrutia-Zambrana et al. 2021). The objective of the GOP is to find the tour that maximizes the total score collected by visiting vertices without exceeding a distance or time constraint. A set of weights of each vertex associated with the vertices scores to calculate the objective functions.

The previous research has widely solved the GOP using a different algorithm for many applications, especially for tourist trip design. (Geem et al. 2005) introduced Harmony Search (HS), focusing on three significant behaviours (memory consideration, pitch arrangement, and irregular choice) of music players that translated into the context of the GOP. In the Harmony Matrix, the selection of any node invokes memory consideration. Pitch arrangement is related to selecting the closest node from the next node and irregular choice to choose one node from entire feasible nodes. HS applied to search for the best tour and compared it with ANN from Wang

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et al. (Wang et al. 1995), which concluded that HS had performed better than Artificial Neural Network (ANN). Another further research from Wang et al. (Wang et al. 2008) proposes a Genetic Algorithm (GA) to solve a similar problem and outperform the HS.

The GOP is not restricted only to the previous applications. The significant uses of GOP are modelling the tour for tourist to plan their trip to visit different attractions. The tourist has limited time and requires having an effective trip during that time. It means that the tourist does not necessarily visit all the attractions (Urrutia-Zambrana et al. 2021). This would prepare the most pleasant trip according to the tourist preferences.

One way to accommodate the tourist to their destination is using electric vehicles. Before the COVID-19 occurred, the appearance of shared mobility options such as bikes, electric scooters, or cars was increased (Mouratidis et al. 2021). This new market trend then emerges in Indonesia, showing the high usage of electric vehicles such as electric bikes or electric scooters for tourist accommodations. For that purpose, the critical consideration is the score related to the attraction and the score from the path they took since electric vehicles are necessary to have a compatible road. Therefore, the generalized orienteering problem will be combined with the arc orienteering problem.

Arc orienteering problem is also another extension orienteering problem. Only a few research studies consider this new variant OP where the price is associated with each arc instead of vertex (Aráoz et al. 2009a, b). The approach to consolidate arc score as the routing decision is proposed by Gavalas et al. (2015). The problem objective of AOP is to maximize the difference between profit and the total travel distance. Several AOP applications are collecting recycling bins where every arc in the area must be passed through, but only a few selected to have the highest profits by Aráoz et al. (2009a, b), which also introduced the team arc orienteering problem. Archetti et al. (2014) proposed the same problem using a different application where a limited fleet of vehicles needs to serve potential customers. Meanwhile, the extension orienteering problem is associated with node and arc score as the route decision has not been investigated before.

The combination of GOP and AOP is later denoted as generalized arc orienteering problem (GAOP) where the objective functions are calculated with the sum of vertices and arc scores. The novelty of the research lies in the introduction of the GAOP that indicates many potential applications in tourist trip design planning.

The major contributions of this paper are described as follows. (1) introduce the mathematical model for the combination of GAOP. (2) a metaheuristic algorithm will be used to solve the proposed problem categorized as an NP-hard problem. (3) the algorithm will be implemented using several attractions in Kota Tua, Jakarta, with the score attraction and arc based on user ratings and roads compatibility. Kota Tua was chosen due to one of the heritage attractions and its renowned name having a high historical value in Jakarta. Kota Tua is located in Indonesia's capital city, which gives an advantage in the strategic location compared to the other attraction (Damanik et al. 2019).

The rest of this paper is organized as follows: the problem and mathematical model are described in Sect. 2. Metaheuristic algorithms to solve the proposed problem and the result are presented in Sect. 3. The discussion towards the result is shown in Sect. 4. Lastly, the conclusion remarks and future research recommendations are drawn in Sect. 5.

2 Problem Description and Mathematical Model

OP classified as NP-hard by Golden et al. (1987), means that no polynomial-time algorithm is expected to get optimal solution by solving this problem. The exact solution method is very time consuming, due to the increase of the problem dimensions associated with computation complexity. Therefore, metaheuristics application will be necessary to discover a close optimal solution in a restrained schedule.

As explained before from Sect. 1, the main idea of the GAOP came up from the tourist trip design and the emerging new market trend of electric bikes/scooters in Indonesia. The GAOP consist of each vertex with a score vector and each arc with a score arc representing different attributes, and the overall objective function is nonlinear. The objective is to find the maximum tourist experience without exceeding the distance/time constraint. The score vector is measured by the user ratings of unique customer preferences from the google applications. The arc score is calculated by the distance and road compatibility for the electric bikes/scooters.

The mathematical model resulted from the assessment of previous GOP (Urrutia-Zambrana et al. 2021) and AOP (Yu et al. 2015) research with some combination or additional constraints and variables. A Mathematical Programming Language (AMPL) software was used to verify the combined mathematical model with Gurobi 9.0 solver. The problem illustration can be observed in Fig. 1. The proposed mathematical optimization model is designed as follows.

Let $G = (V, A)$, where $V = \{1, \ldots, N\}$ is the set of attractions, $A = \{(i, j)/i, j \epsilon V\}$ is a set of arcs between vertices. Vertex number 1 is the initial vertex (depot), N is the path's ending vertex. t_{ij} is the distance associated with arc $(i, j) \epsilon A$. T_{max} is the total maximum allowed defined time constraint, $S_f(i)$ is the vertex score associated with each vertex $S(i) = \left(S_i(i), ..., S_f(i)\right) \epsilon V$, and A_{ij} is the arc score associated with each arc. $W = \left(w_i, ..., w_f\right)$, w_f is the weight based on the traveller according to the f. The non-negative exponent for calculating the module of the vector is k.

Sets:

- V Set of vertices
- A Set of arcs between vertices
- N Set of all nodes
- P Set of all path
- F Set of traveler

Fig. 1 Illustration of GAOP depicted in Kota Tua

Parameters:

$S_f(i)$	Score of vertex i
A_{ij}	Arc score of vertex i and j
O_i	Opening time window of vertex i
C_i	Closing time window of vertex i
t_{ij}	Traveling time from vertex i to j
v_i	Visiting time at vertex i
T_{max}	Given time horizon
Ct_{ij}	Traveling cost from vertex i to j
M	A large constant
Cv_i	Visiting price at vertex i
B	Given budget for each path
w_f	Weight traveler
k	Non negative vector

Decision variables:

x_{ijp} If vertex *i* is followed by a visit to vertex *j* by path *p*, this binary variable equals one; Otherwise, it equals zero

y_{ip} If vertex i is visited by path p, this binary variable equals one; Otherwise, it equals zero

s_{ip} A variable of starting service time at vertex i in path p

Objective

$$\max Z = \sum_{f=1}^{F} w_f \left(\sum_{p=1}^{P} \sum_{i=2}^{N} \left[S_f(i) \right]^k y_{ip} \right)^{1/k} + \sum_{p=1}^{P} \sum_{i=1}^{N} \sum_{j=1}^{N} A_{ij} * x_{ijp} \tag{1}$$

Subject to

$$\sum_{p=1}^{P} \sum_{j=2}^{N} x_{1jp} \leq 1 \tag{2}$$

$$\sum_{p=1}^{P} \sum_{i=1}^{N-1} x_{iNp} \leq 1 \tag{3}$$

$$\sum_{p=1}^{P} \sum_{j=2}^{N} x_{Njp} = \sum_{p=1}^{P} \sum_{i=1}^{N-1} x_{i1p} = 0 \tag{4}$$

$$\sum_{p=1}^{P} x_{ikp} = \sum_{j=2}^{N} x_{kjp} = y_{kp} \quad \begin{matrix} \forall\, p = 1, \ldots, P \\ \forall\, k = 2, \ldots, N-1 \end{matrix} \tag{5}$$

$$s_{ip} + t_{ij} + v_i - s_{jp} \leq M\left(1 - x_{ijp}\right) \quad \begin{matrix} \forall\, i, j = 1, \ldots, N \\ \forall\, p = 1, \ldots, P \end{matrix} \tag{6}$$

$$\sum_{p-1}^{P} y_{kp} \leq 1 \quad \forall k = 2, \ldots, N-1 \tag{7}$$

$$\sum_{i=1}^{N-1} \left(v_i * y_{ip} + \sum_{j=2}^{N} t_{ij} * x_{ijp} \right) \leq T_{max} \quad \forall p = 1, \ldots, P \tag{8}$$

$$\sum_{(i=1)}^{(N-1)} \sum_{(j=2)}^{N} Ct_{ij} * x_{ijp} + \sum_{(i=2)}^{N} y_{ip} * Cv_i \leq B \quad \forall p = 1, \ldots, P \tag{9}$$

$$O_i \leq s_{ip} \quad \begin{matrix} \forall i = 1, \ldots, N \\ \forall p = 1, \ldots, P \end{matrix} \tag{10}$$

$$s_{ip} \leq C_i \quad \begin{matrix} \forall i = 1, \ldots, N \\ \forall p = 1, \ldots, P \end{matrix} \tag{11}$$

$$x_{ijp}, y_{ip} \in \{0, 1\} \qquad \begin{array}{c} \forall i, j = 1, \ldots, N \\ \forall p = 1, \ldots, P \end{array} \tag{12}$$

The objective function (1) is to maximize the total user experience from the sum of each traveler's weight with the sum of each vertex score and arc score. Constraints (2), (3), and (4) guarantee that each path start at vertex 1 (depot) and finish at vertex N (depot). Constraints (5) ensure the connectivity of each path. Constraints (6) ensure the feasibility of the schedule. Constraints (7) ensure that all vertex is visited at most once. Constraints (8) and (9) ensure limited time horizon and travelling budget in each path. Constraints (10) and (11) restrict the start of the service to the time window.

3 Computational Study

The AMPL was used to carry out the proposed algorithm. The program was executed on a laptop with specification: Intel® Core Processor™ i7-7700HQ 1.8 GHz, 64-bit operating system with 8 Gb of RAM. The appropriate vertex score determination could adopt from the tourist attraction evaluation proposed by Wang et al. (2020). Unfortunately, the scope of this study only covers attraction determination by user review based on google. The visiting cost is found from the entry price or the price range of Kota Tua attractions/restaurants. The vertex score and visiting cost are described in Table 1.

Distances covered by electric vehicles, especially e-scooters, are between 20 to 25 km, depending on battery capacity, driver weight, riding style, and the road's steepness (Martínez-Navarro et al. 2020). Although the power advantages, the applications highly correlate with user satisfaction. Therefore, the arc score was defined through the range of shorter distances. The arc score is described in Table 2.

The limitation on budget and time may vary depending on the user needs. The application budget and time limit have been defined as eighty thousand rupiah and two hours. The route result is shown in Fig. 2.

The result: initial place from the depot was visited through nodes (2) (*Museum Mandiri*), nodes (3) (*Museum Bank Indonesia*), nodes (4) (*Djakarta Kedai Seni*) and nodes (10) (*Museum Fatahillah*) at last before going back to the depot. The objective function reached 68.9 by visiting four attractions within two hours.

4 Discussion

AMPL application was used to obtain the optimal result by the exact method to validate the mathematical model of GAOP. The parameter input for the model has been given by observing the Kota Tua user review of the amount of attraction to

Table 1 Kota Tua attraction parameter

Nodes	Attractions	Values	
		Vertex score	Visiting cost (in thou. Rupiah)
2	*Museum Mandiri*	4.6	5
3	*Museum Bank Indonesia*	4.7	5
4	*Djakarta Kedai Seni*	4.5	50
5	*Toko Merah*	4.5	10
6	*Kantin Mega Rasa*	4.3	75
7	*Museum Wayang*	4.5	5
8	*Kafe Batavia*	4.4	100
9	*Museum Keramik*	4.4	5
10	*Museum Fatahillah*	4.5	5

Table 2 Arc score interpretation

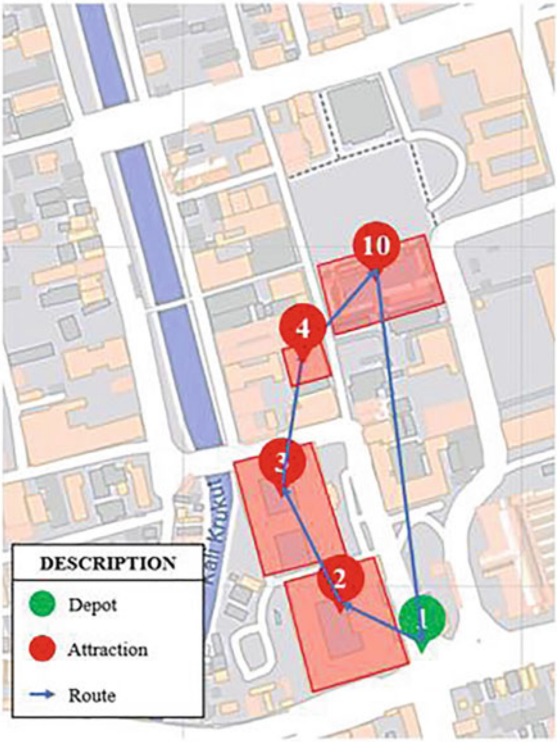
Distance	Arc score
1–10 m	5
10–50 m	4
50–100 m	3
100–200 m	2
>200 m	1

generate the score of each node. The distance of the road determines the score of the arc, while the electric bike/scooter is based on user satisfaction. The number of attractions and the distance between attractions was also achieved from google maps for Kota Tua in Jakarta. The data was executed, and the result showed that the optimal solution within the constraint/limitation was only to visit four from ten attractions.

5 Conclusion

This research proposes a combination of generalized and arc orienteering problems. The problem is modelled corresponding as GOP with additional arc score and constraints. The AMPL software performed the proposed model to get the optimal solution by using the exact method. The result has shown a higher user experience

Fig. 2 Tour result



represented as Z that is not necessary to visit all nodes. Meanwhile, the lower user experience indicates having visited attractions with lower vertex and arc scores. Thus, it is necessary to visit the best attractions based on the limited time and budget.

For further research, the arc score can be defined through the smoothness of the road or conducting a survey to use AHP and illustrate more into the actual conditions. The vertex score determination can also be specified using the proposed literature from Section III and associated with AHP or survey to compose a solid argument. The experiment can also be carried out by other heuristics or meta-heuristics approaches that enable obtaining closer to optimal results.

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References

Aráoz J, Fernández E, Franquesa C (2009a) The clustered prize-collecting arc routing problem. Transp Sci 43(3):287–300. https://doi.org/10.1287/trsc.1090.0270

Aráoz J, Fernández E, Meza O (2009b) Solving the prize-collecting rural postman problem. Eur J Oper Res 196(3):886–896. https://doi.org/10.1016/j.ejor.2008.04.037

Archetti C, Speranza MG, Corberán Á, Sanchis JM, Plana I (2014) The team orienteering arc routing problem. Transp Sci 48(3):442–457. https://doi.org/10.1287/trsc.2013.0484

Damanik D, Wachyuni SS, Wiweka K, Setiawan A (2019) The influence of social media on the domestic tourist's travel motivation case study: Kota Tua Jakarta, Indonesia. Curr J Appl Sci Technol 1–14. https://doi.org/10.9734/cjast/2019/v36i630263

Gavalas D, Konstantopoulos C, Mastakas K, Pantziou G, Vathis N (2015) Approximation algorithms for the arc orienteering problem. Inf Process Lett 115(2):313–315. https://doi.org/10.1016/j.ipl.2014.10.003

Geem ZW, Tseng CL, Park Y (2005) Harmony search for generalized orienteering problem: best touring in China. Lect Notes Comput Sci 3612(PART III):741–750. https://doi.org/10.1007/11539902_91

Golden BL, Levy L, Vohra R (1987) The orienteering problem. Naval Res Logistics (NRL) 34(3):307–318. https://doi.org/10.1002/1520-6750(198706)34:3<307::AID-NAV3220340302>3.0.CO;2-D

Martínez-Navarro A, Cloquell-Ballester VA, Segui-Chilet S (2020) Photovoltaic electric scooter charger dock for the development of sustainable mobility in urban environments. IEEE Access 8:169486–169495. https://doi.org/10.1109/ACCESS.2020.3023881

Mouratidis K, Peters S, van Wee B (2021) Transportation technologies, sharing economy, and teleactivities: implications for built environment and travel. Transp Res Part D Transp Environ 92(February):102716. https://doi.org/10.1016/j.trd.2021.102716

Urrutia-Zambrana A, Tirado G, Mateos A (2021) Variable neighborhood search to solve the generalized orienteering problem. Int Trans Oper Res 28(1):142–167. https://doi.org/10.1111/itor.12800

Vansteenwegen P, Souffriau W, Oudheusden DV (2011) The orienteering problem: a survey. Eur J Oper Res 209(1):1–10. https://doi.org/10.1016/j.ejor.2010.03.045

Wang Q, Sun X, Golden BL, Jia J (1995) Using artificial neural networks to solve the orienteering problem. Ann Oper Res 61(1):111–120. https://doi.org/10.1007/BF02098284

Wang X, Golden B, Wasil E (2008) Using a genetic algorithm to solve the generalized orienteering problem. Oper Res/comput Sci Interfaces Ser 43. https://doi.org/10.1007/978-0-387-77778-8

Wang Y, Shen S, Sotiriadis M, Zhang L (2020) Suggesting a framework for performance evaluation of tourist attractions: a balance score approach. Sustainability (switzerland) 12(15):1–22. https://doi.org/10.3390/su12156220

Yu VF, Perwira Redi AAN, Jewpanya P (2015) The orienteering problem with time windows and arc scores, pp 1–6

Two-Echelon Vehicle Routing Problem for Agricultural Area Mapping Operation with Drone

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1 Introduction

A study conducted by the Indonesian National Land Agency also known as *Badan Pertanahan Nasional* mention that the conversion rate of agricultural land to non-agricultural lands in Indonesia has reached around 50,000 hectares or 500,000,000 m^2 in 2011, which is categorized as high (Darmanto 2017). Given that it is now 2021, the development of the rate of land-use change is substantial and very fast. Indonesia as an agrarian country needs to ensure the provision of agricultural land in a sustainable manner by prioritizing the principles of efficiency, sustainability, independence and environmental insight. On the other hand, the increasing population growth with a fairly high growth rate of around 1.4–1.5% per year as well as economic and industrial developments have resulted in degradation and conversion of agricultural land so that it affects the national carrying capacity in maintaining self-reliance and food security (Gunawan 2013). Based on this, the government formed a program that specifically works to protect sustainability of agricultural land, such as by conducting act of identifying and store information on sustainable agricultural land. The information regarding agricultural land can be carried out by using current technology such as remote sensing, photogrammetry, and GIS. Among many techniques for measuring and mapping, photogrammetric mapping techniques with drones are one

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of the favorable and cheapest techniques to carry out to map an agricultural land or area. It is because drones are normally equipped with an autopilot system, equipped with precision GPS, have high camera resolution, produce a high-scale map detail, are not constrained by clouds, and the data retrieval can be done at any time (Utomo 2018).

Mapping activities with drones can have several problems. One in particular including mapping operation that carried out in a wide area while the coverage of a drone to operate is limited to its battery. This can be seen and led to a routing problems where the access point from takeoff location or mapping area needs to be planned accurately, taking into account the cost or capacity of land vehicles and the type of drone used. This situation can be optimize by join operation between drones combined with ground vehicle. This can be seen as an optimization problem more specifically vehicle to solve routing problems (VRPD) which was developed by combining ground vehicles that can carry drones to extend their reach to customers with these drone vehicles (Wang and Sheu 2019). The application of cooperation between land vehicles and drones is often found in delivery services. The mechanism is modeled as a two-echelon vehicle routing problem with drones (2EVRPD) which is applied for last-mile delivery of packages or parcels.

The use of ground vehicles and drones can increase the efficiency in mapping operations. Moreover, it can increase the coverage area being mapped. Thus, this study take the consideration on combination of ground vehicles and drones to reach the entire mapping area of agricultural land. Despite that, the study on applying collaboration of ground vehicles combined with drones for agricultural land mapping operations is rare. One particular research use a combination of ground vehicles and drones with the Single Depot Vehicle Routing Problem (SDVRP) model for mapping forest area activities with land vehicles as filling drones (Maini and Sujit 2015). The closest research to this study perhaps is the application of 2EVRPD on the disaster mapping operation which is later denoted as the two echelon vehicle routing problem for mapping operation with drone (2EVRP-MOD) (Liperda et al. 2020). The 2EVRP-MOD model is categorized as a complex problem (NP-Hard), so it can be solved using a metaheuristic algorithm. One particular example of a metaheuristic algorithm that perform good to solve VRP problems and its variant is the simulated annealing algorithm (Liperda et al. 2020). Affi et al. (2013) reporting that SA finds all known optimal solutions (20 out of 30) instances in a very short computation time compared to other methods for solving a variant of VRP. Therefore, this study adopt the problem of two-echelon vehicle routes for agricultural mapping operations using drones (2EVRP-MOD) to be implemented for agricultural area mapping and develop a simulated annealing algorithm to solve the problem.

The remainder of this paper is organized as follows: In Sect. 2, we shows the methodology being used for this study including formulation of the two-echelon vehicle routing with drone model and the procedure of simulated annealing algorithm. We demonstrate the numerical experiments of this problem and discussion of the result in Sect. 4. Finally, the conclusion and future research direction are discussed in Sect. 5.

2 Problem Description and Mathematical Model

The 2EVRP model is widely used in delivering goods with a combination of ground vehicles (trucks) and drones. The objective of this model also varies from cost minimization or carry out relief mapping assessments on research. This study aims to minimize the total operating time for mapping agricultural land inventories in rice fields in Subang, West Java, Indonesia. The data needed for this research are including: the type of drone used, the location, and the area included in the image. One ground vehicle is assumed to carry one drone. The land inventory was obtained from the sentinel-2A satellite imagery and the NDVI vegetation index processing for the mapping area on May 18, 2021. The number of stopover point and mapping point for this study can be seen in Table 1. Furthermore, an illustration of one instance can be seen in Fig. 1. The following discussion describe the mathematical formulation and the procedure of the solution algorithm.

This model is adopted from the proposed model by Liperda et al. (2020). The mathematical formulation can be stated as follows. Let $G = (N, E)$ be a graph where $N = C \cup S$ is a set of nodes. S is a set of nodes in the first echelon in which $S = S0 \cup \{1\}$ consist of $S0 = \{2 \ldots |S|\}$ represents the set of stopover nodes and [7] represent the depot or the disaster relief centrecenter. While $C = \{|S| + 1 \ldots |S| + |C|\}$ represents the nodes in the second echelon which are the mapping points

Table 1 Number of stopover points and mapping points at each benchmark instance

Initial temp	Final temp	Alpha	MaxIteration
200	0.0001	0.5	6000

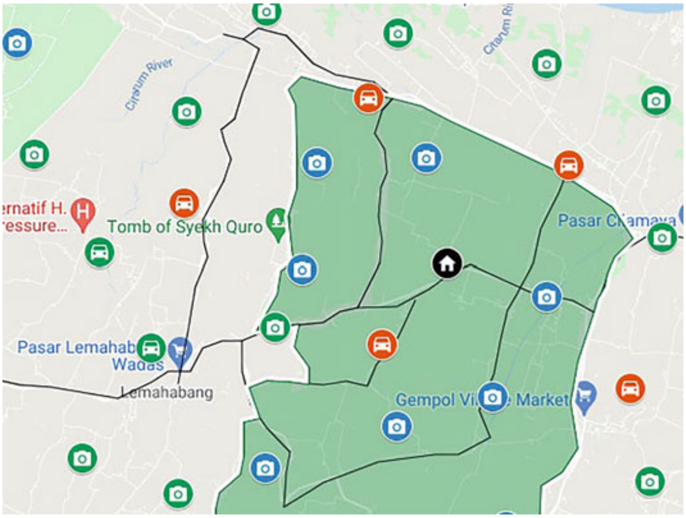

Fig. 1 Illustration of the distribution of point map points in the mapping area

or target points. Set $E = E1 \cup E2$ is the set of edges $(i,)$ such the edge set $E1 = \{(i, j): i, j \in S\}$ includes the set of edges connecting all nodes in the first echelon. Meanwhile, set $E2 = \{(i,): i \in S0, j \in C\}$ includes the set of edges connecting all the satellites in the second echelon to the mapping points. Each mapping point has a non-negative mapping time or surveillance time to gather information according to the coverage area denoted as Di where $i \in C$. Each pair of nodes in the first echelon $(i,)$ is associated with traveling time Cs_{ij} where edge$(i, j) \in E1$. While each pair of nodes in the second echelon $(i,)$ is associated with traveling time Cc_{ij} where edge$(i, j) \in E2$. In this model, each vehicle can carry one drone to serve each route v in a set of routes V. The mapping operations of each route are limited by the drone flying time limit, which is denoted as Qd_v where $v \in V$. The formulation is stated as follows.

Sets:

- S Set of all nodes the first echelon (including the depot)
- S_o Set of all nodes of *Stopover Point* (without depot).
- C Set of all nodes of *mapping point*
- V Set of all vehicles in the first echelon

Parameters:

- $C_{S_{ij}}$ travel time of vehicle from gathering point or stopover point i to stopover point j in the first echelon
- $C_{C_{ij}}$ travel time of drone stopover point I to mapping point j in the second echelon
- D_i required mapping time for capturing the area of a mapping point i
- Q_{d_v} maximum flight time of drone
- L Sufficiently large number

Decision variables:

- x_{ijv} a binary variable that equals to one of vehicle v is traveled from node i to j where edge $(i, j) \in E1$; otherwise it is zero
- z_i A binary variable equals one if the stopover point is visited where $i \in S$; Otherwise, it is zero
- y_{ij} A binary variable equals one if drone is traveled from node i to j where *edge* $(i, j) \in E2$; Jika tidak, nol
- Q_j The total amount of time needed for taking pictures in a stopover point j where $j \in S$
- T_j The total amount of time needed for traveling in the second echelon, where $j \in S$
- a_{iv} The total accumulated amount of information gathering time has been used up to stopover point i using vehicle v where $i \in S$ dan $v \in V$
- b_{iv} The total accumulated amount of mapping time has been used up in a stopover point i using vehicle v where $i \in C$ dan $v \in$ V

Objective

$$\text{Minimize} Z = \sum_{i \in S} \sum_{j \in S} \sum_{v \in V} C_{S_{IJ}} x_{ijv} + \sum_{i \in C} \sum_{j \in S_0} C_{C_{IJ}} y_{ij} + \sum_{i \in S_o} \sum_{j \in C} D_i y_{ij} \quad (1)$$

Subject to

$$\sum_{i \in S} \sum_{v \in V} x_{ijv} = z_j \qquad \forall j \in S_o \tag{2}$$

$$\sum_{j \in S} \sum_{v \in V} x_{ijv} = z_i \qquad \forall i \in S_o \tag{3}$$

$$\sum_{i \in S} x_{ilv} - \sum_{j \in S} x_{ljv} = 0 \qquad \begin{matrix} \forall l \in S_o \\ \forall v \in V \end{matrix} \tag{4}$$

$$\sum_{j \in S_o} x_{1jv} \le 1 \qquad \forall v \in V \tag{5}$$

$$\sum_{i \in S_o} x_{i1v} \le 1 \qquad \forall v \in V \tag{6}$$

$$\sum_{i \in C} D_i y_{ij} \le Q_j \qquad \forall j \in S_o \tag{7}$$

$$Q_j \le L * z_J \qquad \forall j \in S_o \tag{8}$$

$$\sum_{i \in S_0} y_{ij} = 1 \qquad \forall i \in C \tag{9}$$

$$a_{iv} + Q_j - L\left(1 - x_{ijv}\right) \le a_{jv} \qquad \begin{matrix} \forall i \in S \\ \forall j \in S_0 \end{matrix} \tag{10}$$

$$\sum_{i \in S} \sum_{j \in S} x_{ijv} Q_j + \sum_{i \in C} \sum_{j \in S_0} C_{C_{ij}} y_{ij} \le Qd_v \qquad \forall v \in V \tag{11}$$

The objective function (1) seeks to minimize the total mapping operation time that consists of the total time traveled by ground vehicles, the total time traveled by drone, and the total mapping or information gathering time at each target point. Constraints (2) and (3) restrict that the stopover points are visited only once in the routing decision of the first echelon. Constraint (4) ensures the consecutive movement of vehicles in the first echelon. Constraints (5) and (6) ensure that a ground vehicle starts and returns to the depot. Constraints (7) and (8) are utilized to denote the total mapping time at each stopover point. Constraints (9) restrict a target point to be accessed from only one stopover point. Constraints (10) ensure the flow continuity of the ground vehicle. L is a sufficiently large number that should be greater than or equal to the total mapping time for each target point. Lastly, constraints (11) ensure the flying capacity of the drone at each route does not exceed its limit.

The algorithm used in this study is Simulated Annealing (SA). SA algorithm is inspired by a slow cooling process on material, commonly called annealing. The purpose of this cooling process is to crystallize materials and reduce damage. A material's temperature needs to be reduced slowly in an annealing process to prevent damage due to its irregular structure (Sylvester 2018). SA generates a new solution that considers the previous solution within certain criteria. In each iteration, a new solution can be accepted if it meets the Metropolis criteria. If the solution generated by the iteration is better than the solution in the previous iteration, the new solution is accepted and used as the current best solution in future iterations. The steps of the SA algorithm can be seen in the pseudocode in Algorithm 1. SA algorithm also adopts the thermodynamics method, namely the Boltzmann function shown in formula (13).

$$P\,(m)\;\approx\;exp\left(-\frac{\mathrm{E\,(m)}}{\mathrm{kT}}\right) \tag{13}$$

Algorithm 1: Simulated Annealing Heuristics

Paramter initialization

S = generate the initial solution (); T_0= Initial temperature; N = umber of iteration at each temperature;

T = T_0
While $T < T_{final}$;
{
Until (N $\leq$ 1-Iter).
{
Generate Solution *S'* in the neighborhood *S*.
if $f(\mathrm{S}') < (f(S)$.
S $\leftarrow$ S$'$.
else
$\Delta = f\ (S') - f(S)$
r = *random*();
if (r < exp($-\frac{\Delta}{k} * T$)).
$S \leftarrow S'$.
}
$T = \alpha\ x\ T$;
}

3 Computational Study

Data processing is carried out using AMPL (mathematical programming tools) with Gurobi solver and Microsoft Visual Studio 2019 with device specification are 8 GB RAM, Intel® Core Processor™ i7-6500U, 64-bit operating system type and the programming language used was C#.. The number of drones used is one vehicle with maximum drone capacity flight time, which is 30 min. The time required to take a

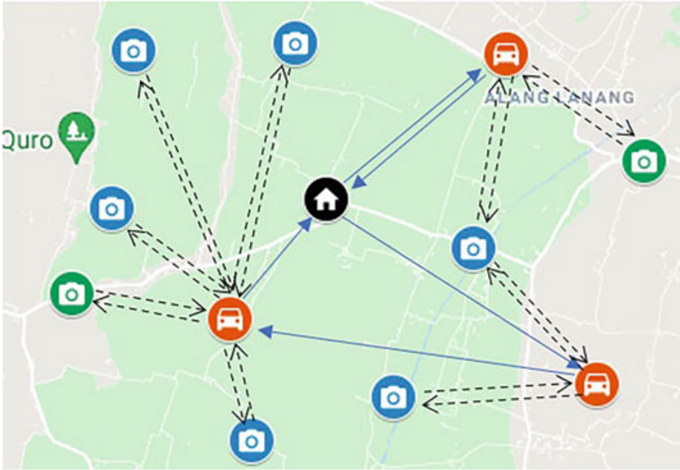

Fig. 2 Illustration of the vehicle route from the depot to the mapping point

picture depends on the area. This value is adopted from one of the studies conducted by Boccardo et al. (2015). Illustration of the maps can be seen in Fig. 2.Data preparation regarding to the initial map data and configuration of drone is predetermined. The satellite image being used is Sentinel-2A satellite imagery to see the distribution of rice fields. The type of drone used is the DJI Phantom 4 Pro V2.0 with the following specifications of flight time is 30 min and flying speedis 5.56 m/s. The classification of rice fields using the NDVI vegetation index. While the process of data processing is carried out after the post-stage. It is assumed that each vehicle can carry one drone.

The final parameter being used for this SA algorithm are shown in Table 2 are the values that generate the lowest average process time for the entire data. Each area instance was experimented ten times with three neighborhoods with the same probabilty: swap, insert, and reverse. Table 3 shown the results show that the average objective value of SA for all instances is 171.079. Meanwhile the optimal objective value reported by AMPL is 142.820. This result indicates that SA result is not yet able to perform well. However, there are still a lot of potential procedure can be implemented to be able to improve the SA result. Meanwhile in term of computational time, the SA algorithm can generate solution with average computational time of 0.35 s.

Table 2 Number of stopover points and mapping points at each benchmark instance

Instance	AMPL				Simulated annealing
	1st echelon	2nd echelon	Mapping time	Total	
Instance1.1	40.040	32.599	39.988	112.627	104.252
Instance1.2	34.328	47.221	37.593	119.142	122.907
Instance1.3	20.550	43.640	38.369	102.559	94.565
Instance1.4	6.386	40.725	24.331	71.442	72.057
Instance1.5	20.408	70.459	32.591	123.458	145.060
Instance1.6	44.559	27.130	19.337	91.026	220.155
Instance1.7	90.922	70.590	50.338	211.850	240.897
Instance2.1	45.312	37.659	38.274	121.245	107.773
Instance2.2	60.356	72.543	60.768	193.667	223.602
Instance2.3	26.126	59.647	43.656	129.429	125.737
Instance2.4	64.675	101.748	46.190	212.613	318.924
Instance2.5	83.899	79.508	61.375	224.782	277.016
Average				142.820	171.079

4 Discussion

The AMPL application is used to obtain optimal results with exact methods to validate the Linear mathematical model. The parameters entered for the model were given by observing the review of the characteristics and the drone flight of the number of attractions to generate a score for each node. The route distance of the car vehicle determines the arc score, while the distance from the flying drone is based on user satisfaction. The number of attractions and the distance between attractions are also obtained from google maps for the Mapping Area in Subang, West Java. The data is executed, and the results show that the optimal solution is within the constraints obtained by using the annealing simulation algorithm.

5 Conclusion

This study explore the application two echelon vehicle routing problem for drone mapping operation of agricultural area. The problem is known as an NP-hard problem. Therefore, a simulated annealing heuristics is proposed to find the solution for the problem. The proposed algorithm is compared to the result obtained by the exact solution solver that indicate the optimal solution. The result shows that in terms of the solution quality, the proposed algorithm are not yet able to provide optimal solution value same as provided by AMPL. In addition, the computational time of the proposed algorithm are considerably fast. For further study, the difference in results between AMPL and SA can be analyzed using statistical analysis. Other than that, many improvement need to be performed on SA for example by introducing a better initial solutions, better parameter tuning, and hybrid method so that it able to have a performance that very near to optimal solution.

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References

Afifi S, Dang D-C, Moukrim A (2013) A simulated annealing algorithm for the vehicle routing problem with time windows and synchronization constraints, pp 259–265. https://doi.org/10.1007/978-3-642-44973-4_27

Boccardo P, Chiabrando F, Dutto F, Tonolo F, Lingua A (2015) UAV deployment exercise for mapping purposes: evaluation of emergency response applications. Sensors 15(7):15717–15737. https://doi.org/10.3390/s150715717

Darmanto (2017) Limitasi Laju Alih Fungsi Lahan Pertanian Ke Non Pertanian Melalui Pembentukan Brigade LP2B Berintegritas Untuk Penguatan Dan Kedaulatan Pangan. Diklatpim Tingkat III Angkatan XXIX. http://bpsdmd.jatengprov.go.id/eproper/cetakinovasi/?nourut=52

Gunawan B (2013) Pemetaan dan inventarisasi data komoditas pertanian dan informasi kondisi lahan di kabupaten Kudus berbasis sistem informasi geografis

Liperda RI, Pewira Redi AAN, Sekaringtyas NN, Astiana HB, Sopha BM, Maria Sri Asih A (2020) Simulated annealing algorithm performance on two-echelon vehicle routing problem-mapping operation with drones. In: IEEE international conference on industrial engineering and engineering management. https://doi.org/10.1109/IEEM45057.2020.9309923

Maini P, Sujit PB (2015) On cooperation between a fuel constrained UAV and a refueling UGV for large scale mapping applications. In: 2015 international conference on unmanned aircraft systems (ICUAS), pp 1370–1377.https://doi.org/10.1109/ICUAS.2015.7152432

Sylvester G (2018) E-agriculture in action: drones for agriculture. Food and agriculture organization of the United Nations and International

Utomo B (2018) Drone Untuk Percepatan Pemetaan Bidang Tanah. Media Komunikasi Geografi 18(2):146. https://doi.org/10.23887/mkg.v18i2.12798

Wang Z, Sheu J-B (2019) Vehicle routing problem with drones. Transp Res Part B Method 122:350–364. https://doi.org/10.1016/j.trb.2019.03.005

Sustainable, Social and Legal Challenges in Supply Chain Management and Logistics

Environmental and Economic Value Prediction of Waste Electrical and Electronic Equipment Recycle Using Reverse Logistics: The Case of China's Waste Mobile Phones

Sung Woo Kang and Yu Quan

1 Introduction

As product lifecycles shorten due to continuous innovation, WEEE has gradually increased to 44.7 (Mt) in 2016 (Kumar et al. 2017). Only 20% (8.9 Mt) of these WEEEs are properly documented, collected, and recycled, and the remaining 80% (35.8 Mt) are discarded as residual waste or are untraced and unreported (Baldé et al. 2017). Asia generated the largest amount of WEEE (18.2 Mt) in 2016, followed by Europe (12.3 Mt), the Americas (11.3 Mt), Africa (2.2 Mt), and Oceania (0.7 Mt) (Baldé et al. 2017). According to the Environmental Protection Agency, only 25% of WEEE are recycled, of which computers account for 38%, televisions 17%, and mobile phones only 8% (EPA 2014). The total global value of WEEE is 55 billion euros. Most of the WEEEs that are unaccounted for become landfill, and the various hazardous materials contained in WEEE can cause serious environmental pollution (Baldé et al. 2017). Consequently, it is important to manage and reduce WEEE (Cui and Zhang 2008). However, despite the importance, the volume of WEEE and the amount that is disposed continue to grow globally (Niu and Li 2007). This is explained by the fact that there is no specific system or network to control WEEE properly. In addition to economic losses, disposal of WEEE, such as in landfills, can cause environmental problems and human diseases (Olympio et al. 2017; Ongondo et al. 2011; Widmer et al. 2005; Zhang and Xu 2016). Specifically, the landfill of

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WEEE causes about 572 million euros worth of environmental damage (Baldé et al. 2017; Rabl et al. 2008).

In recent years, many global companies have used various SCM- (Supply Chain Management) related strategies and techniques to solve these problems (Chen et al. 2012). For example, Apple Inc. recycles raw materials from old iPhones and re-uses them to manufacture new iPhones (Apple 2017). In addition, many researchers have also made efforts to increase the efficiency of various measures such as recycle and reuse (Buekens and Yang 2014; Cucchiella et al. 2015; Gu et al. 2016). In particular, reverse logistics (RL), a field of SCM, has attracted much attention as an eco-friendly problem-solving method (Tsai and Hung 2009). RL, which helps sustainable management strategy, is used in various fields such as aircraft, computer, and mobile phone equipment industries. Unlike forward logistics (FL), which represents the process from product manufacturing to consumer, RL is a concept that refers to the flow from disposal or return of consumer. However, research to solve this problem is mostly related to processing, construction, or theoretical model building (Ayvaz et al. 2015). To provide a more realistic and quantitative indication, this paper predicts the environmental and economic values of WEEE recycle using real industrial cost structure and RL.

2 Literature Review

SCM is the concept that encompasses the entire lifecycle of a product from production to consumer and FL and RL (Sari 2017). Figure 1 shows the overall supply chain flows.

2.1 Forward Logistics

FL refers to the flow from the supplier through the manufacture and transportation of products to delivery to consumer. Research related to FL has been primarily focused on methodologies such as production methods (Lean manufacturing, Just In Time, etc.), and transportation methods (milk-run logistics, cross docking systems, etc.) from a supplier to a customer through a manufacturer and a retailer (Cua et al. 2001; Kovács 2011; Shah and Ward 2003; Yu and Egbelu 2008). These studies were aimed at cost reduction and service improvement. This paper will deviate from these goals and discuss innovative value creation and environmental protection using RL, EOL analysis, and WEEE recycling.

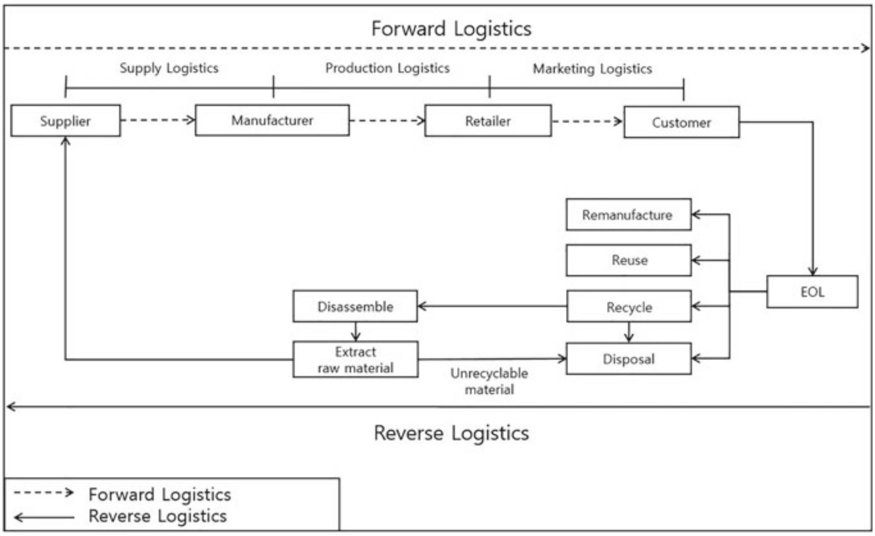

Fig. 1 Supply chain flow chart

2.2 Reverse Logistics

RL plays an important role in building sustainable systems such as recycling WEEE (Kilic et al. 2015). In general, RL is defined as a series of activities such as recycling products, collection, disassembly, cleaning, reassembly, distribution, and marketing of reverse supply chain processes for the purpose of recouping value or proper disposal (González-Torre et al. 2004; Rogers and Tibben-lembke 2001).

2.2.1 End-of-Life

There are two kinds of studies on RL, namely research on return logistics and research on EOL (Ravi et al. 2005). In particular, EOL is a stage in which products are generally reused, remanufactured, recycled, or disposed of through several stages of recovery as shown in Fig. 2. (Kang et al. 2013).

Reuse

Reuse means using a product for longer than the existing lifecycle in terms of the original function and purpose. For reuse, depending on the condition of the product, a simple repair can be carried out if necessary (Lu et al. 2017).

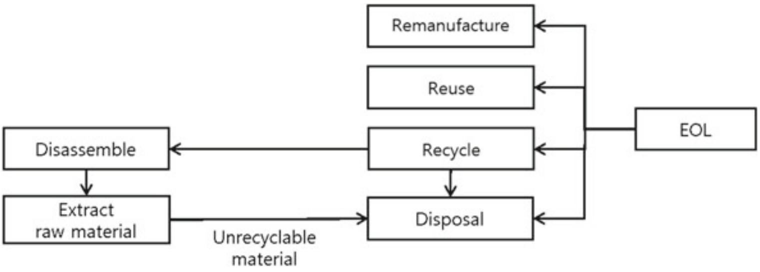

Fig. 2 General flow of EOL products

Remanufacture

Remanufacture is an important element in sustainable production and refers to making a broken product look like new by replacing or repairing component parts (Yang et al. 2016). WEEE remanufacturing, especially for EOL products, has difficulties in system integration, data exchange, and resource management. Various studies have been carried out to solve these difficulties such as introducing a new EOL option known as resynthesis or a utilization of the cloud manufacturing paradigm in the WEEE remanufacturing environment (Wang and Wang 2015; Kang et al. 2013).

Recycle

Recycle means that products that have reached the end of their life are decomposed to the raw material level and used again as a resource to make new products. If collection of WEEE increases, this can result in WEEE recycling (Geyer and Blass 2010).

Disposal

Disposal relates to the abandonment of the EOL product without using a relatively productive method, such as the aforementioned three methods. The main disposal methods of EOL products are landfill and incineration (Kulhawik 2016). Although WEEE contains a lot of valuable resources, most are still disposed in landfills (Geyer and Blass 2010).

3 Methodology

This section builds a basic model for forecasting the value of economic and environmental benefits of WEEE recycling. Figure 3 shows the WEEE recycling process.

First, to recycle WEEE, products and components should be classified as recyclable and non-recyclable. Then, non-recyclable products are disposed of and recyclable products are disassembled into smaller parts. Disassembled parts are also classified as recyclable and non-recyclable parts, and the non-recyclable parts are disposed of. Finally, raw materials are extracted from recyclable parts. Table 1 shows the process, factors and their definitions for model building (Guo and Yan 2017; Rabl et al. 2008).

Formula 1 is the basic model of value prediction using the factors above.

Formula 1. Value prediction model

$$\mathbf{Value} = \text{Raw material content} \cdot \text{WEEE} \cdot \text{Collection rate} \cdot \text{Recycling rate} - \text{Landfill cost} \cdot \text{WEEE} \cdot (1 - \text{Collection rate} \cdot \text{Recycling rate})$$

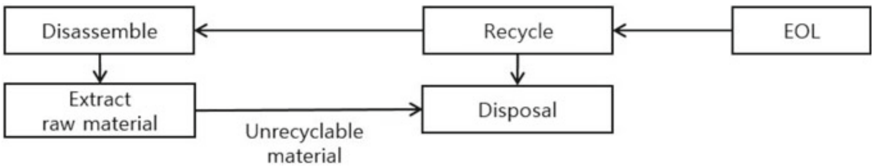

Fig. 3 WEEE recycling process

Table 1 Process, factors and their definitions of EOL

Process	Factor	Definition
Recycle	WEEE	Generation amount
Recycle	Collection rate	Current collection rate
Disassemble	Disassembly cost	Disassembly cost per Gg
Disposal	Landfill cost	Landfill cost per Gg
Disposal	Environmental cost	Environmental costs of WEEE Landfill
Disposal and raw materials	Recycling rate	Percentage of recyclable materials
Raw materials	Raw material content	Content of valuable raw materials per Gg
Raw materials	Raw material price	Price per Gg of raw materials

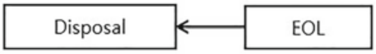

Fig. 4 Flow of EOL products in case (A)

$$- \text{Disassembly cost} \cdot \text{WEEE} \cdot \text{Collection rate}$$
$$- \text{Environmental cost} \cdot \text{WEEE} \cdot (1 - \text{Collection rate} \cdot \text{Recycling rate}) \quad (1)$$

3.1 *Case (A)*

Case (A) is the case in which collection of WEEE is not performed at all (Fig. 4).
Formula 2 predicts the value of WEEE recycling in this case.

Formula 2. Prediction formula for case (A)

$$\textbf{Value} = -\text{Landfill cost} \cdot \text{WEEE} - \text{Environmental cost} \cdot \text{WEEE} \quad (2)$$

3.2 *Case (B)*

Case (B) is the case in which some WEEE are collected (Fig. 5).
Formula 3 predicts the value of WEEE recycling in this case.

Formula 3. Prediction formula for case (B)

$$\begin{aligned}\textbf{Value} = {} & \text{Raw material content} \cdot \text{WEEE} \cdot \text{Collection rate} \cdot \text{Recycling rate} \\ & - \text{Landfill cost} \cdot \text{WEEE} \cdot (1 - \text{Collection rate} \cdot \text{Recycling rate}) \\ & - \text{Disassembly cost} \cdot \text{WEEE} \cdot \text{Collection rate} \\ & - \text{Environmental cost} \cdot \text{WEEE} \cdot (1 - \text{Collection rate} \cdot \text{Recycling rate})\end{aligned} \quad (3)$$

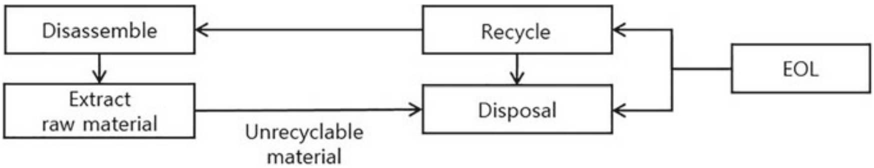

Fig. 5 Flow of EOL products in case (B)

3.3 Case (C)

Case (C) is the case in which all WEEE are collected (Fig. 6).

Formula 4 predicts the value of WEEE recycling in this case.

Formula 4. Prediction formula for case (C)

$$\begin{aligned}\textbf{Value} = {} & \text{Raw material content} \cdot \text{WEEE} \cdot \text{Collection rate} \cdot \text{Recycling rate} \\ & - \text{Landfill cost} \cdot \text{WEEE} \cdot (1 - \text{Recycling rate}) \\ & - \text{Disassembly cost} \cdot \text{WEEE} \cdot \text{Collection rate} \\ & - \text{Environmental cost} \cdot \text{WEEE} \cdot (1 - \text{Recycling rate}) \end{aligned} \tag{4}$$

4 Experiment

This section calculates economic and environmental values of recycling WMP, which is a type of WEEE. WEEE has similar procedural characteristics in various processes such as collection, decomposition, refurbishment, assembly, and so on (Kim et al. 2006). In this sense, WMP is the subject of this experiment. In addition, China was selected as the target country because it has the widest territory and the largest number of people in Asia that generated the largest amount of WEEE (Baldé et al. 2017). To establish various aspects, the experiment consisted of three detailed cases, and the estimated values were calculated at five-year intervals from 2000 to 2025. Table 2 shows the definition of the parameters and model parameters for predicting the WMP value.

Table 3 refers to the price of each parameter, and in this paper CASEA, CASEB and CASEC are calculated based on the price of Table 3.

In addition, Table 4 refers to the estimated amount of waste mobile phones every five years based on the duration of mobile phone use and the amount of mobile phone use of Chinese people, and the unit is ton.

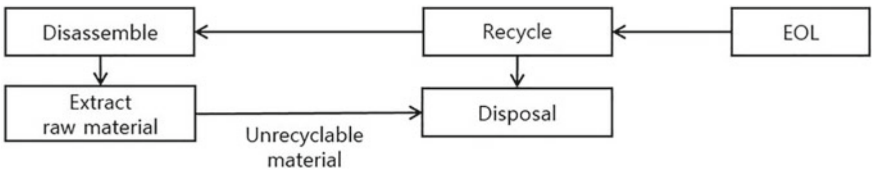

Fig. 6 Flow of EOL products in case (C)

Table 2 Parameters of formula for predicting each case

Process	Factor	Parameters	Definition of parameter
Recycle	WEEE	OP	The amount of WMP
Recycle	Collection rate	CR	Current collection rate of WEEE
Disassemble	Disassembly cost	DCCC	Collection cost
		DCLC	Labor costs
		DCPC	Plant operating cost
		DCUC	Unrecyclable parts disposal cost
Disposal	Landfill cost	LCLC	Labor costs
		LCFC	Fuel cost
		LCEF	Excavator fee
		LCBF	Bulldozer fee
		LCTF	Tamping machine fee
		LCLF	Loader fee
		LCCF	Cargo truck fee
		LCVF	Vehicle fee
		LCWF	Tire Washing Machine fee
		LCFF	Street flusher truck fee
		LCWB	Water bill
		LCEB	Electricity bill
		LCLB	Landfill bill
		LCSC	Sewage treatment cost
		LCOC	Other maintenance costs
		LCAE	Administrative expenses
Disposal	Environmental cost	EC	Environmental cost by WEEE Landfill
Disposal and raw material	Recyclable rate	RR	Percentage of recyclable materials of mobile phones
Raw material	Raw material content	RCG	Gold
		RCS	Silver
		RCCP	Copper
		RCP	Palladium
		RCCB	Cobalt
Raw material	Raw material price	RCGp	Price of gold
		RCSp	Price of silver
		RCCPp	Price of copper
		RCPp	Price of palladium

Table 3 Price for each parameter

Factor	Parameters	Cost
Landfill cost	LCLC	3.18
	LCFC	0.86
	LCEF	0.08
	LCBF	0.24
	LCTF	0.24
	LCLF	0.06
	LCCF	0.01
	LCVF	0.06
	LCWF	0.11
	LCFF	0.06
	LCWB	0.06
	LCEB	0.05
	LCLB	0.42
	LCSC	5.27
	LCOC	2.42
	LCAE	0.56
	LCEC	1.49
Environmental cost	EC	10.50
Recyclable rate	RR	0.36
Raw material content	RCG	280.00
	RCS	2000.00
	RCCP	190000.00
	RCP	100.00
	RCCB	168000.00
Raw material price	RCGp	42.34
	RCSp	0.52
	RCCPp	0.01
	RCPp	31.06
	RCCBp	0.08

Table 4 Amount of waste mobile phones for each year

Year	Reclamation amount (ton)
2000	1300
2005	10,200
2010	30,000
2015	111,600
2020	130,000
2025	140,000

4.1 Case (A)

Case (A) means that only landfill costs and environmental costs exist because WMP is not collected or recycled. Formula 5 is used to predict the value in Case (A).

Formula 5. Formula for prediction of case (A)

$$\textbf{Value Y}_{\textbf{(A)}} = -(LCLC + LCFC + LCEF + LCBF + LCTF + LCLF + LCCF + LCVF + LCWF + LCFF + LCWB + LCEB + LCLB + LCSC + LCOC + LCAE + LCEC) \cdot OP - EC \cdot OP \tag{5}$$

4.2 Case (B)

Case (B) means that WMP is collected at the current level (Bian et al. 2016). Therefore, there are landfill, environmental, and disassembly costs for recycling and benefits from raw materials from WMP. Formula 6 is used to predict the value in Case (B).

Formula 6. Formula for prediction of case (B)

$$\textbf{Value Y}_{\textbf{(B)}} = (RCG \cdot RCGp + RCS \cdot RCSp + RCCP \cdot RCCPp + RCP \cdot RCPp + RCCB \cdot RCCBp) \cdot OP \cdot CR \cdot RR - (LCLC + LCFC + LCEF + LCBF + LCTF + LCLF + LCCF + LCVF + LCWF + LCFF + LCWB + LCEB + LCLB + LCSC + LCOC + LCAE + LCEC) \cdot OP \cdot (1 - CR \cdot RR) - (DCCC + DCLC + DCPC + DCUC) \cdot OP \cdot CR - EC \cdot OP \cdot (1 - CR \cdot RR) \tag{6}$$

4.3 Case (C)

Case (C) means that all WMP are collected. Therefore, there are disassembly costs for recycling and a small amount of landfill and environmental costs for non-recyclable parts of WMPs. However, there is a large amount of benefit from raw materials from such phones. Formula 7 is used to predict the value in Case (C).

Formula 7. Formula for prediction of case (C)

$$\textbf{Value Y}_{\textbf{(C)}} = (RCG \cdot RCGp + RCS \cdot RCSp + RCCP \cdot RCCPp + RCP \cdot RCPp + RCCB \cdot RCCBp) \cdot OP \cdot RR$$

$$
\begin{aligned}
&- (LCLC + LCFC + LCEF + LCBF + LCTF + LCLF \\
&+ LCCF + LCVF + LCWF + LCFF + LCWB + LCEB \\
&+ LCLB + LCSC + LCOC + LCAE + LCEC) \cdot OP \\
&\cdot (1 - RR) - (DCCC + DCLC + DCPC + DCUC) \cdot OP \\
&\cdot CR - EC \cdot OP \cdot (1 - RR)
\end{aligned} \tag{7}
$$

5 Results

This section explores results of the experiment with each case. Calculation of Case (A), Case (B), Case (C) using the COST of Table 3 is as follows in Table 5.

5.1 Case (A)

Figure 7 shows the predicted value of economic and environmental benefits of WMP recycling in case (A). In 2000, the predicted value is around −\$33,000. Since then, it has dropped sharply, reaching around −\$3.6 million in 2025. In particular, this figure shows the rapid change from 2010 to 2015.

5.2 Case (B)

Figure 8 shows the predicted value of economic and environmental benefits of WMP recycling in case (B). In 2000, the predicted value was around \$960,000. Since then, it has increased sharply, reaching around \$104 million in 2025. In particular, this figure shows the rapid change from 2010 to 2015.

Table 5 COST of Case (A), Case (B), Case (C) for each year

Year	Case (A)	Case (B)	Case (B)
2000	−33,397	965,267	14,432,654
2005	−262,040	7,573,633	113,240,823
2010	−770,705	22,275,391	333,061,245
2015	−2,867,023	82,864,453	1,238,987,832
2020	−3,339,723	96,526,693	1,443,265,396
2025	−3,596,624	103,951,823	1,554,285,811

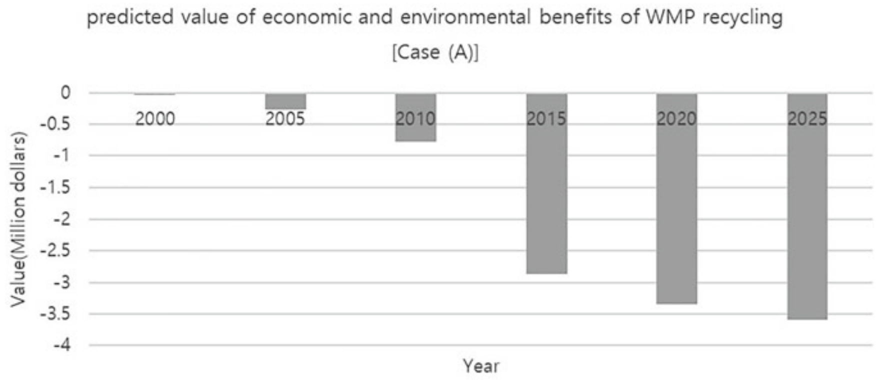

Fig. 7 Predicted benefits of WMP recycling in case (A)

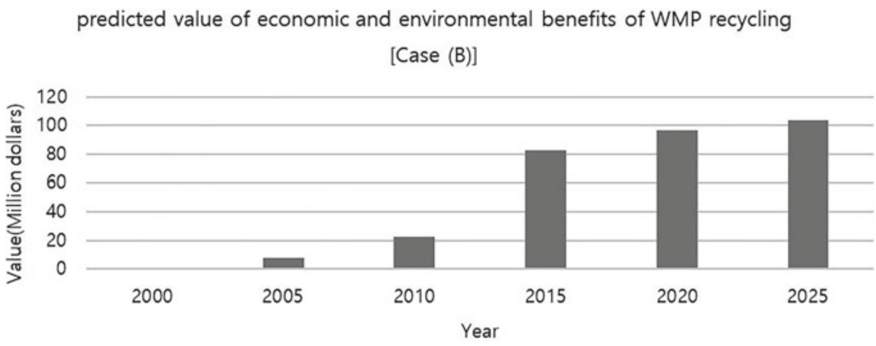

Fig. 8 Predicted benefits of WMP recycling in case (B)

5.3 Case (C)

As shown in Fig. 9, the predicted value was around \$14 million in 2000. Since then, it has increased sharply, reaching around \$1.5 billion in 2025. The amount of WMP increased sharply from 2010 to 2015 hereby incrementing benefits rapidly during the same period.

5.4 Comparison of Case (A), (B), and (C)

As shown in Fig. 10, the difference between Case (B) and Case (C) is much larger than that between Case (A) and Case (B). This means that the current WMP recovery and recycling rate is very low compared to the ideal situation. In addition, if the recovery and recycling rate of WMP increase, the model makes additional benefits as large as the gap between Case (B) and Case (C).

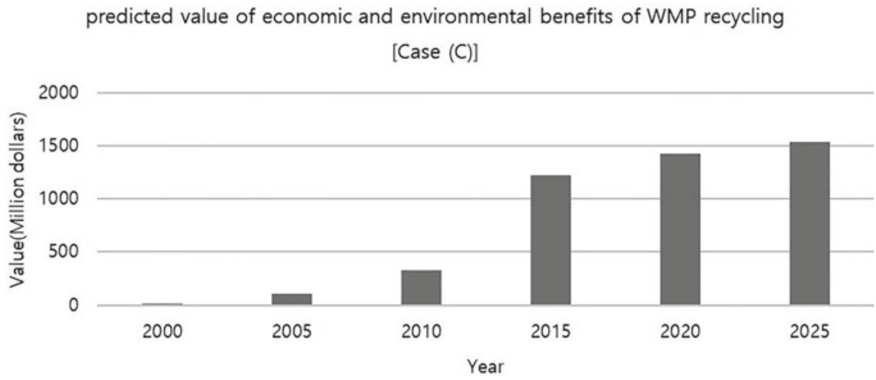

Fig. 9 Predicted benefits of WMP recycling in case (C)

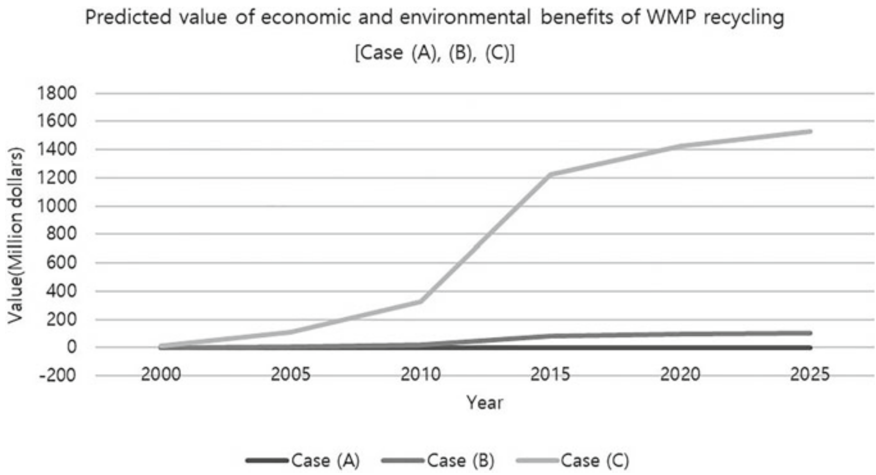

Fig. 10 Predicted benefits of WMP recycling in entire case

6 Conclusion and Future Work

This study analyzed the flow of RL and EOL products to create a value prediction model of WEEE recycling from an economic and environmental viewpoint. The literature review described forward logistics, RL, and four options regarding EOL products (reuse, remanufacture, recycle, and disposal). This research proposed the basic model for prediction through EOL analysis and created three models according to the basic model of WEEE collection rate. In order to verify the models presented in this research, the WMP recycling structure of the Chinese industry data set was used for the experiment. The results from the case study confirmed that the economic and environmental values significantly increase when the recovery rate of WEEE increases. Specifically, when all WMP are collected, companies can achieve profits around 14 times higher than the current situation. This study confirms the value of abstract WEEE recycling as a more quantitative figure. This figure can be an indication of more intuitive assessment of the effectiveness of WEEE recycling. However, this study focuses on recycling among various flows of EOL such as reuse and remanufacture and as a result, there may be a few errors. In addition, the factors and parameters of this study will need to be revised and supplemented in future research. To overcome these limitations, various follow-up studies will be required including a study that considers the total flow of EOL or the value of WEEE according to the recycling rate.

In addition, as a future study, economic and environmental value analysis will be conducted by considering various WEEE such as household appliances, office supplies, and recycling other raw materials such as plastic.

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References

Apple (2017) Environmental report 2017. Apple 50

Ayvaz B, Bolat B, Aydın N (2015) Stochastic reverse logistics network design for waste of electrical and electronic equipment. Resour Conserv Recycl 104:391–404. https://doi.org/10.1016/j.resconrec.2015.07.006

Baldé CP, Forti V, Gray V, Kuehr R, Stegmann P (2017) The global e-waste monitor

Bian J, Bai H, Li W, Yin J, Xu H (2016) Comparative environmental life cycle assessment of waste mobile phone recycling in China. J Clean Prod 131:209–218. https://doi.org/10.1016/j.jclepro.2016.05.047

Buekens A, Yang J (2014) Recycling of WEEE plastics: a review. J Mater Cycles Waste Manag 16:415–434. https://doi.org/10.1007/s10163-014-0241-2

Chen CC, Shih HS, Shyur HJ, Wu KS (2012) A business strategy selection of green supply chain management via an analytic network process. Comput Math Appl 64:2544–2557. https://doi.org/10.1016/j.camwa.2012.06.013

Cua KO, McKone KE, Schroeder RG (2001) Relationships between implementation of TQM, JIT, and TPM and manufacturing performance. J Oper Manag 19:675–694. https://doi.org/10.1016/S0272-6963(01)00066-3

Cucchiella F, D'Adamo I, Lenny Koh SC, Rosa P (2015) Recycling of WEEEs: an economic assessment of present and future e-waste streams. Renew Sustain Energy Rev 51:263–272. https://doi.org/10.1016/j.rser.2015.06.010

Cui J, Zhang L (2008) Metallurgical recovery of metals from electronic waste: areview. J Hazard Mater 158:228–256. https://doi.org/10.1016/j.jhazmat.2008.02.001

EPA (2014) Statistics on the management of used and end-of- life electronics

Geyer R, Blass VD (2010) The economics of cell phone reuse and recycling. Int J Adv Manuf Technol 47:515–525. https://doi.org/10.1007/s00170-009-2228-z

González-Torre PL, Adenso-Díaz B, Artiba H (2004) Environmental and reverse logistics policies in European bottling and packaging firms. Int J Prod Econ 88:95–104. https://doi.org/10.1016/S0925-5273(03)00181-6

Gu Y, Wu Y, Xu M, Wang H, Zuo T (2016) The stability and profitability of the informal WEEE collector in developing countries: a case study of China. Resour Conserv Recycl 107:18–26. https://doi.org/10.1016/j.resconrec.2015.12.004
Guo X, Yan K (2017) Estimation of obsolete cellular phones generation: a case study of China. Sci Total Environ 575:321–329. https://doi.org/10.1016/j.scitotenv.2016.10.054
Kilic HS, Cebeci U, Ayhan MB (2015) Reverse logistics system design for the waste of electrical and electronic equipment (WEEE) in Turkey. Resour Conserv Recycl 95:120–132. https://doi.org/10.1016/j.resconrec.2014.12.010
Kim K, Song I, Kim J, Jeong B (2006) Supply planning model for remanufacturing system in reverse logistics environment. Comput Ind Eng 51:279–287. https://doi.org/10.1016/j.cie.2006.02.008
Kovács A (2011) Optimizing the storage assignment in a warehouse served by Milkrun logistics. Int J Prod Econ 133:312–318. https://doi.org/10.1016/j.ijpe.2009.10.028
Kulhawik K (2016) Direct landfill disposal versus Mechanical Biological Treatment (MBT) Bezpośrednie deponowanie na składowisku a mechaniczno- biologiczne przetwarzanie odpadów (MBP) 27:19–23
Kumar A, Holuszko M, Espinosa DCR (2017) E-waste: an overview on generation, collection, legislation and recycling practices. Resour Conserv Recycl. https://doi.org/10.1016/j.resconrec.2017.01.018
Lu B, Yang J, Ijomah W, Wu W, Zlamparet G (2017) Perspectives on reuse of WEEE in China: lessons from the EU. Resour Conserv Recycl 0–1. https://doi.org/10.1016/j.resconrec.2017.07.012
Niu X, Li Y (2007) Treatment of waste printed wire boards in electronic waste for safe disposal. J Hazard Mater 145:410–416. https://doi.org/10.1016/j.jhazmat.2006.11.039
Olympio KPK, Gonçalves CG, Salles FJ, da Silva Ferreira APS, Soares AS, Buzalaf MAR, Cardoso MRA, Bechara EJH (2017) What are the blood lead levels of children living in Latin America and the Caribbean? Environ Int 101:46–58.https://doi.org/10.1016/j.envint.2016.12.022
Ongondo FO, Williams ID, Cherrett TJ (2011) How are WEEE doing? A global review of the management of electrical and electronic wastes. Waste Manag 31:714–730. https://doi.org/10.1016/j.wasman.2010.10.023
Rabl A, Spadaro JV, Zoughaib A (2008) Environmental impacts and costs of solid waste: a comparison of landfill and incineration. Waste Manag Res 26:147–162. https://doi.org/10.1177/0734242X07080755
Ravi V, Shankar R, Tiwari MK (2005) Analyzing alternatives in reverse logistics for end-of-life computers: ANP and balanced scorecard approach. Comput Ind Eng 48:327–356. https://doi.org/10.1016/j.cie.2005.01.017
Rogers DS, Tibben-lembke R (2001) An examination of reverse logistics practices 22:129–148
Sari K (2017) A novel multi-criteria decision framework for evaluating green supply chain management practices. Comput Ind Eng 105:338–347. https://doi.org/10.1016/j.cie.2017.01.016
Shah R, Ward PT (2003) Lean manufacturing: context, practice bundles, and performance. J Oper Manag 21:129–149. https://doi.org/10.1016/S0272-6963(02)00108-0
Tsai WH, Hung SJ (2009) Treatment and recycling system optimisation with activity-based costing in WEEE reverse logistics management: an environmental supply chain perspective. Int J Prod Res 47:5391–5420. https://doi.org/10.1080/00207540801927183
Wang XV, Wang L (2015) WR cloud: a novel WEEE remanufacturing cloud system. Proc CIRP 29:786–791. https://doi.org/10.1016/j.procir.2015.02.011
Widmer R, Oswald-Krapf H, Sinha-Khetriwal D, Schnellmann M, Böni H (2005) Global perspectives on e-waste. Environ Impact Assess Rev 25:436–458. https://doi.org/10.1016/j.eiar.2005.04.001
Sung Woo Kang S, Sane C, Vasudevan N, Tucker CS (2013). Product resynthesis: knowledge discovery of the value of end-of-life assemblies and subassemblies. J Mech Des 136:011004. https://doi.org/10.1115/1.4025526

Yang SS, Nasr N, Ong SK, Nee AYC (2016) A holistic decision support tool for remanufacturing: end-of-life (EOL) strategy planning. Adv Manuf 4:189–201. https://doi.org/10.1007/s40436-016-0149-2

Yu W, Egbelu PJ (2008) Scheduling of inbound and outbound trucks in cross docking systems with temporary storage. Eur J Oper Res 184:377–396. https://doi.org/10.1016/j.ejor.2006.10.047

Zhang L, Xu Z (2016) A review of current progress of recycling technologies for metals from waste electrical and electronic equipment. J Clean Prod 127:19–36. https://doi.org/10.1016/j.jclepro.2016.04.004

A Financial Feasibility Study of Zero Waste Manufacturing: Opportunity and Value Added of Agricultural Products on the R9 Route

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1 Introduction

The Food and Agriculture Organization (FAO) defines food waste as "wholesome edible material intended for human consumption, arising at any point in the food supply chain (FSC) that is instead discarded, lost or degraded Factors that influence food losses and waste; that occur along a food supply chain (Machines, Materials, Management, Methods, and People) come from the surroundings of a food supply chain. (Kowalska 2017) Factors influencing food losses and waste; that occur along a food supply chain (Machines, Materials, Management, Methods, and People) come from the surroundings of a food supply chain (Kowalska 2017). Food losses or waste are the quantities of edible material wasted or lost in the food supply chain at various stages, including harvesting, post-harvest storage and material handling, processing, distribution and consumption. A large amount of energy and other resources are consumed for food production and distribution (Gustavsson et al. 2011). Food supply will need to increase by around 70% from its current levels in order to meet the

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world population growth of 9.6 billion by 2050. Food waste is the biggest challenge in global food security, wherein approximately 20–30% of food waste occurs in the post-harvest stage of the food supply chain in developing countries. This food waste generates significant negative environmental effects in addition to the unnecessary usage (and wastage) of resources consumed in producing the wasted food (Krishnan et al. 2020).

Mango is a tropical fruit with a long history of production, cultivation and trade, mainly cultivated in tropical Asian countries. The data statistics of The Food and Agriculture Organization of the United Nations currently show that there are 103 countries in the world where mangoes are cultivated. The mango is considered a fruit that has various benefits and properties such as helping to build immunity for the body, good for liver and kidneys and it can also help reduce nausea or dizziness. But the fruit is a difficult commodity to keep. Modern technology has been introduced into the food processing industry which helps preserve the fruit. It also helps to elevate the value of the fruit as well. Food processing industry plays an important role in enhancing the economic growth of the country. It increases values for agricultural products in accordance with close linkage with the agricultural sector, which is in the majority in Thailand. The food processing industry creates more employment and boosts the country's exporting figures. In 2020, the value of Thailand's mango exports was at 4,602,668,283 THB (Commerce 2021). Due to the COVID-19 pandemic exporting the product becomes too difficult, resulting in domestic consumption only, this in turn causes an overflow in the domestic market. C19 has raised food insecurity and safety concerns, increased supply chain and logistics costs, and radically changed consumer behavior. On the positive side, the pandemic has improved awareness of food waste and the importance of self-grown foods (Rejeb et al. 2020). After consumption or industrial processing of the mango, considerable amounts of seeds are discarded as waste. We can analyze the amount of waste that may occur by predictive reference markets, which are base on crowdsourcing, use collective crowd intelligence, and support many business areas (Czwajda et al. 2019). The seed alone accounts for 20–25% of the whole fruit. The kernels inside the seed are approximately 45–75% of the seed and about 20% of the whole fruit. More than one million tons of mango seed are produced annually and often discarded as waste. Approaches to reduce waste and add value into new products for consumption (Babaria 2012). At the same time can cure a serious environmental problem.

The east–west economic corridor (EWEC) is one of the most strategic cooperation in the development of the Economic Corridor, with potential areas along the three main communication lines, namely the north–south line. North south economic corridor (NSEC), east–west economic corridor (EWEC) and southern economic corridor (SEC) of the Economic cooperation development project in the 6 countries of Greater Mekong Sub-region (Greater Mekong Subregion GMS) which was formed by cooperation of Thailand, Myanmar, Lao PDR, Cambodia, Vietnam and South China (Yunnan Province and Guangxi Province). The objective is to promote the expansion of trade, investment, industry, agriculture and services that create employment and improve the livelihood of people in the area promoting the development of cooperation in technology and education to use natural resources that promote each other effectively and promoting capacity-building and economic opportunities in the global trade arena. The initial development of the Economic Corridor is the development of transportation infrastructure. EWEC or Route 9 (R9) is the most developed route among the entire Economic Corridor, with a length of 1450 km in Thailand. The route starts from the coastal port city of Da Nang in Vietnam, passing through Hue City, Dong Ha City and the city of Laos (Lao Bao) which is a special economic zone of Vietnam, then takes Highway no. 9 through Savan-Seno Special Economic Zone of Lao PDR through Savannakhet and crossing over the Mekong at the 2nd Thai-Laos Friendship Bridge (Mukdahan—Savannakhet) into Thailand, at Mukdahan Province, Kalasin, Khon Kaen, Phitsanulok, Sukhothai through to the end of the Mae Sot border checkpoint, Tak Province, crossing into Myanmar by the Myawaddy passing through the bay of Matama in Mawlamyine. It is considered to connect the area on the east side of the South China Sea. (Fig. 1) International logistics corridors have many benefits. First, they significantly reduce transit time and costs, thus expanding access to markets and opening new opportunities for regional industries. Second, they eliminate infrastructural bottlenecks and increase the technical and organizational interoperability of national systems. However, it should note that the development of these corridors requires efficiently functioning intermodal logistics centers that act as load generators and play the crucial role of nodes in transport systems and supply chains. Therefore, to make them feasible should build new logistics centers, dry ports (Popp 2018), airports with ensured customs clearance and storage services, and economic zones with tax incentives along the corridor should be created (Joanicjusz Nazarko and Czerewacz-Filipowicz 2016).

The EWEC has a large and growing strategic advantage over other transportation networks in terms of time for delivery between large commercial hubs. Since the opening of the Second Friendship Bridge, time consuming from Bangkok to Da Nang has been reduced by around three to three-and-a-half days. (Fig. 2) At present, the export route to China is from the original route by ship and has to go through many steps, such as by vessel from Laem Chabang, via Vietnam and Hong Kong, before reaching Guangzhou or Shanghai of China, it takes almost 2 weeks (average 12–13 days). There is an additional option, which is road transportation. Thailand can deliver fruit to China by four routes one of them is the R9 route from Mukdahan via Da Nang, transit Hanoi. and then to Guangxi—Beijing. Cinfady market is the biggest distribution center of Thai fruit in Beijing. It takes only 36 h by truck from Thailand (Bangkokbanksme 2015). Nevertheless, as of late June 2020, despite the lack of scientific evidence, China is demanding that all foreign food shipments guarantee that the food and food containers have tested for the virus before shipping to China (Patton 2020).

The province located on the R9 of Thailand is an important mango growing area in Thailand. Therefore, there is interest in studying the possibility of setting up a mango processing plant and using this strategic point for transportation for export to China to increase economic value according with national economic development plan no.12 aimed at strengthening the economy by sector goal 1: sectoral economy grows strongly and serves as a base for building economic growth of the country. Including sustainable development goals (SDGs) goal 9 builds an infrastructure that is resilient

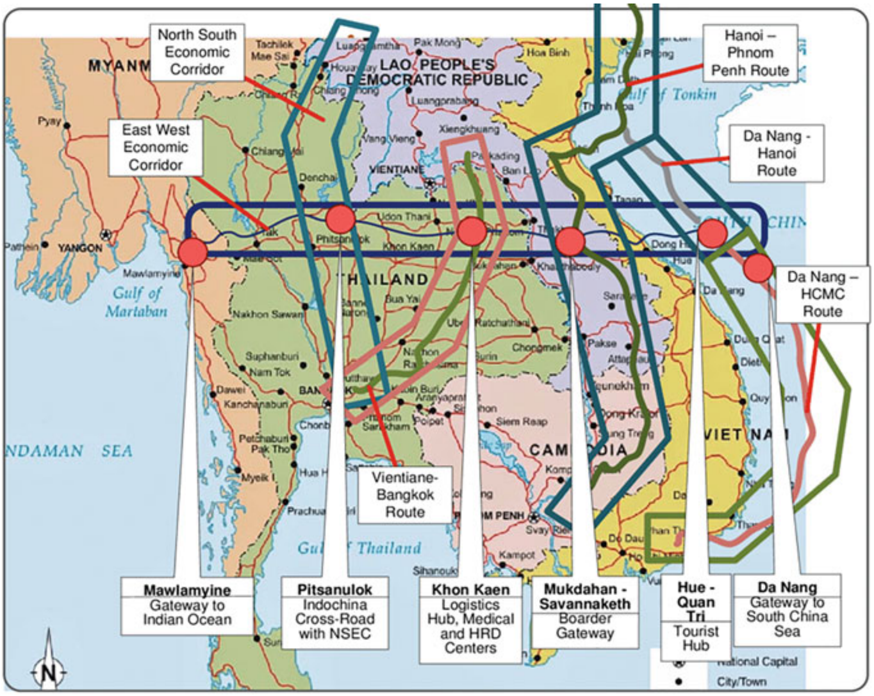

Fig. 1 EWEC complementary corridors and routes (Lord 2009)

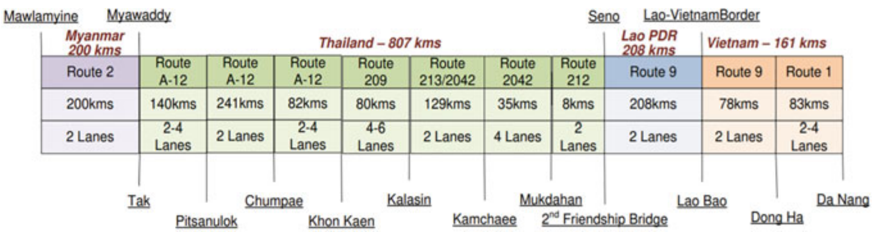

Fig. 2 EWEC road network (Lord 2009)

to change, promotes industrial development comprehensively and sustainably and innovation. Sub-goal 9.2 promotes inclusive and sustainable industrial development and by 2030 increase the industrial sector share in employment and gross domestic product in accordance with the national context and to double the share in the least developed countries (Council 2017).

Route number 9 was expected to be the location for setting up a mango oil production plant. This paper attempts to fill this research gap within the three suitable locations by using loading distances method, factors rating method. In the model is included criteria, weights and classification. AHP gives the opportunity for understanding indicators to help make decision. The export route to China is from the original route one steps for to reduce production costs in the transportation sector.

2 Methodology

2.1 Collect Mango Data

1.1 Import and export data of mango

1.2 Export value of dried mangos

1.3 Information on mango production in the provincial area on route R9

2.2 Analyze the Optimal Location of the Mango Processing Plant by Center of Gravity Method

$$\overline{X} = \frac{\sum X_i Q_i}{\sum Q_i} \qquad \overline{Y} = \frac{\sum Y_i Q_i}{\sum Q_i}$$

Q_i = Quantity of goods

X_i = X—coordinate of location i

Y_i = Y—coordinate of location i.

2.3 Verify the Results of the Data Analysis to the Analytic Hierarchical Process (AHP)

The use of the AHP is to help analyze problems in decision making in plant location selection or decision making in various fields is popular because AHP is an effective method. There is a simple and easy to understand operation procedure. Therefore, the analytical hierarchical process was applied in selecting the factory location. Therefore, it is something that should be considered highly.

The development process consists of three main steps for both AHP. Step one using analytical process to define criteria. In this study, the criteria have been identified based on the raw materials, labors, markets, land prices, transportation, infrastructure, environmental, society and community, laws and taxes, opportunities in future, industrial estates, community attitude, political freedom and free trade zones. Next, the 12 experts from a mango manufacturing company located area on route R9. Tak, Sukhothai, Phitsanulok, Khon kaen, Kalasin and Mukdahan provinces and and from inquiry 10 samples of experts from 5 groups, namely logistics entrepreneurs, industrial factory, agricultural product collector, related government agencies and academic groups. The comparative importance of attributes is provided by the decision maker using a rating a 1–9 scale. Finally, the AHP method obtains the priority weights of attributes of each category by computing the vector of matrix.

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1j} \\ a_{21} & a_{22} & \dots & a_{2j} \\ a_{31} & a_{32} & \dots & a_{3j} \\ \dots & \dots & & \dots \\ a_{i1} & a_{i2} & \dots & a_{ij} \end{bmatrix}$$

a_{ij} are the judgments or the relative importance of alternative i over alternative j and $a_{ij} = 1$ for $i - j$ and $a_{ij} = 1/\ a_{ij}$ for $i \neq j$.

2.4 Economic Analysis Data (The Processed Products are Mango Crisps and Mango Seed Oil)

2.4.1 The Break-Even Point (BEP)

$$BEP = \frac{Fixed\ cost}{Selling\ price - Variable\ cost}$$

2.4.2 Net Present Value (NPV)

It is the difference between the sum of present value of benefits and sum of present value of costs for a given discount rate. If a positive value of NPV is obtained when discounted at the opportunity cost of capital, then the investment is considered viable.

$$NPV \frac{R_t}{(1 + i)^t}$$

t = time of the cash flow

i = discount rate

R_t = net cash flow

2.4.3 Interest Rate of Return (IRR)

The IRR is the discount rate that makes the net present value of cash flow equal to zero. The investment is considered viable if the calculated IRR is greater than the opportunity cost of capital.

$$IRR = \sum_{t-1}^{t} \frac{C_t}{(1+r)^t} - C_0$$

C_t = Net Cash Inflow during the period t

r = Discount Rate

t = Number of time periods

C_0 = Total initial investment cost.

3 Results

3.1 Import and Export Data of Mango

From the Table 1 of quantity and value of mango imports and exports from 2017–2020, the export and import grew every year, except the year 2019 when the coronavirus outbreak occurred. Thailand imported mangoes as raw material for mango processingInventory practically accounts for over 70% of the food processing firm's overall capital assets in developed and developing economies. Its proper management is key to promoting the performance, growth, and competitiveness of food processing firms and their supply chains (Opoku et al. 2021).

Table 1 Volume and value of mango imports and exports during the year 2017–2020 (Commerce 2021)

Quantity (KG)				
Year	2017	2018	2019	2020
Export	59,138,566	94,102,385	85,182,868	117,656,521
Import	24,838,355	55,352,592	29,081,368	53,731,619
Value (Bath)				
Year	2017	2018	2019	2020
Export	3,326,799,100	4,383,712,861	4,067,105,304	4,602,668,283
Import	219,718,778	289,928,938	331,697,885	803,593,125

The significant increases of mango consumption in domestic activity lead to the accumulation of waste. Mango seed kernels are usually wasted when it is processed. After consumption or industrial processing of mangoes, approximately 40–60% waste is generated; 12–15% consists of peels and 15–20% of kernels. According to mango varieties, the seed represents from about 10 to 25% of the whole fruit weight. The kernel inside the seed represents from 45 to 75% of the seed and about 20% of the whole fruit. However, more than one million tons of mango seeds are being treated as waste. Mango kernel extracts are hidden treasures. Because the kernel, when cold pressed, renders mango kernel butter, not oil. This butter itself is highly prized and could pose as a good substitute for cocoa or shea butter. Being an excellent source of essential fatty acids, rich in minerals and vitamins, mango kernel butter exhibits beneficial moisturizing properties for skin lotions and lubricants. It is solid at room temperature, smells sweet and nutty in its pure form and has a smooth creamy color. It has a mild aroma, similar to olive oil.

Semi-solid mango kernel oil is obtained during the refining of mango kernel butter. This soft yellow coloured oil is said to have a stronger odor than the butter, and has a melting point of around 23–27 °C, meaning that it effectively melts when it comes in contact with skin. An average mango kernel contains about 8% to 15% extract potential (butter and oil). This seed, which is usually discarded, can be used in cosmetics and beauty products. It's shelf life is 3–4 years if stored under cool conditions. Most mango oils are refined and during that process the therapeutic quality is altered (Karunanithi et al. 2015).

From Table 2, Quantity and value of dried mango exports from 2017 to 2020, there is an upward trend. But the price per kilogram has a downward trend. The popularity of mango crisps (freeze dried mango) and mango seed oil processing is trending these days. Lean production is a well-established managerial concept that helps companies provide customer value and reduce cost (Golińska 2014).

Euromonitor forecasts that the fruit snack market is expected to grow in value at 15–20% annually, bringing the market size to 2740 million THB in 2023 compared to the current market size. The growth rate of the market size is increasing (Suwannachote 2018).

Laokasemsukwong (2013) A study on the potential of the dried fruit industry in Thailand shows that Thailand has an advantage to export dried fruit products to the world. The factors that contribute to competitive advantage are abundance in fruits, skilled workers, increasing demand for dried fruit from Thailand and support from the government. However, entrepreneurs have to face tough competition from China and Vietnam and deal with the volatility of agricultural prices.

Table 2 Export value of dried mangoes during the year 2017–2020 (Commerce 2021)

Year	2017	2018	2019	2020
Quantity (KG)	1,619,615	2,594,805	3,135,936	4,959,761
Value (Bath)	438,027,122	619,352,914	708,886,363	991,674,347
Price (Bath): 1 kg	270.4513863	238.6895794	226.0525607	199.9439786

Table 3 Information of mango production in the provincial located on route R9 during the year 2017–2020 (*Sources* Information Technology and Communication center: Department of Agricultural Extension (Center 2021))

	Mango harvested produce (KG)				
Year	2017	2018	2019	2020	Total
Tak	1,888,510	1,812,500	1,115,500	298,250	5,114,760
Sukhothai	27,723,012	43,021,490	28,559,076	50,825,583	150,129,161
Phitsanulok	23,700	16,506,130	11,906,300	41,897,450	70,333,580
Khon kaen	13,556,087	7,811,028	7,557,352	5,867,379	34,791,846
Kalasin	281,213	231,654	218,357	621,868	1,353,092
Mukdahan	209,960	57,093	133,593	351,000	751,646
Total	43,682,482	69,439,895	49,490,178	99,861,530	262,474,085

Remark Mangoes including Khiew Sawoey, Raet, Golden, okrong, Falan, Chotanan, Mahachanok and Kaew mangoes

From Table 3 of the provinces located on route R9, the volume of mango between the year 2017– 2020 in total was 262,474,085 kg. Sukhothai has the highest volume of mangoes at 50,825,583 kg. Followed by Pitsanulok at 41,897,450 kg, and Khon Kaen at 5,867,379 kg.

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3.2 Location Analysis Data

Location of an international logistics center in Poland as a part of the One Belt One Road initiative. The method used is the analysis of literature sources. As the choice and location of an international logistics center in Poland on the New Silk Road is the new one. (Kauf and Laskowska-Rutkowska 2019).

From a detailed study and information collected by a mode of road transport, which is, a 10-wheel truck carries 1.45 tons/trip of mango for mango processing. If we consider the inevitable imbalance in intercity freight demand, the efficient transport of empty trucks becomes necessary to a certain extent (Hirata and Fukaya 2020). The location was analyzed using the center of gravity technique (Center of Gravity Method). Azeem and Hussain (2012) applied the Gravity Model to analyzing the geographical pattern of international trade. It was found that the mango consolidation place should be set up at the geographic coordinates $X = 16.93751677$, $Y = 100.295235$, which is at Wat Bot district in Phitsanulok province as shown in Table 4.

Table 4 Location analysis data by center of gravity method

	Latitude (X)	Longitude (Y)	Mango volume in 2020 (Kg)	Wi X	Wi Y
Tak	16.679717	98.572691	298,250	4974725.595	29399305.09
Sukhothai	17.035915	99.891168	50,825,583	865860311.8	5077026850
Phitsanulok	16.910321	100.356777	41,897,450	708499328.6	4204693047
Khon kaen	16.349338	102.806863	5,867,379	95927762.45	603206829
Kalasin	16.578963	103.967506	621,868	10309926.56	64654065.02
Mukdahan	16.621893	104.431703	351,000	5834284.443	36655527.75
Total	99,861,530	1,691,406,339	10,015,635,624	16.93751677	100.295235

3.3 Verify the Analysis of the Optimum Location of the Mango Factory by Means of AHP

Thomas L. Saaty developed the Analytical Hierarchy Process (AHP) theory in 1970. The principle is to divide the problem structure into individual layers. The first layer is Goal, Criteria, Criteria. Sub-criteria and Alternatives, respectively (Saaty and Vargas 2001), analyze the best alternatives. Analyzing and comparing (Trade-off) the selection criteria for each pair individually (Pairwise) makes it easier to decide. They have graded the comparative significance of each criterion according to importance. After scoring to prioritize the criteria, consider analyzing the options one by one according to the specified criteria until they meet all the criteria. If the rating of importance or preference is reasonable, Consistency will be able to prioritize alternatives to find the best option. Supporting investment choices in oil tank farm (Meteethunyarat 2020), biomass plant using AHP (Phankong et al. 2020) and Multi-criteria comparative analysis method can create a hierarchy of optimal locations of logistics centers. In this method, the final set of criteria is not strictly defined and can be supplemented by criteria relevant to a particular investor and the investment. When deciding on financial investments, it is advisable to consider several criteria (including all kinds of indicators, simple and discounted stimulators, and development), chosen based on knowledge and literature and tested on the example of the Lubuskie Province. This approach allows the use of the proposed method regardless of legal conditions and geographical location (Witkowski et al. 2018).

The review of related research found that AHP location determination was used to determine local and national locations. Therefore, it is why the researcher has adopted the AHP method. So, come check out the location of the mango processing plant. The researcher has designed the decision-making with AHP as shown in Fig. 3.

The factors considered for applying in AHP are raw material sources, labor sources, markets, land prices, transportation, infrastructure, environmental, society and community, laws and taxes, opportunities in future, industrial estates, community attitude, political freedom and free trade zones and investment promotion zones which was used to select the location of the factory from 3 alternative locations,

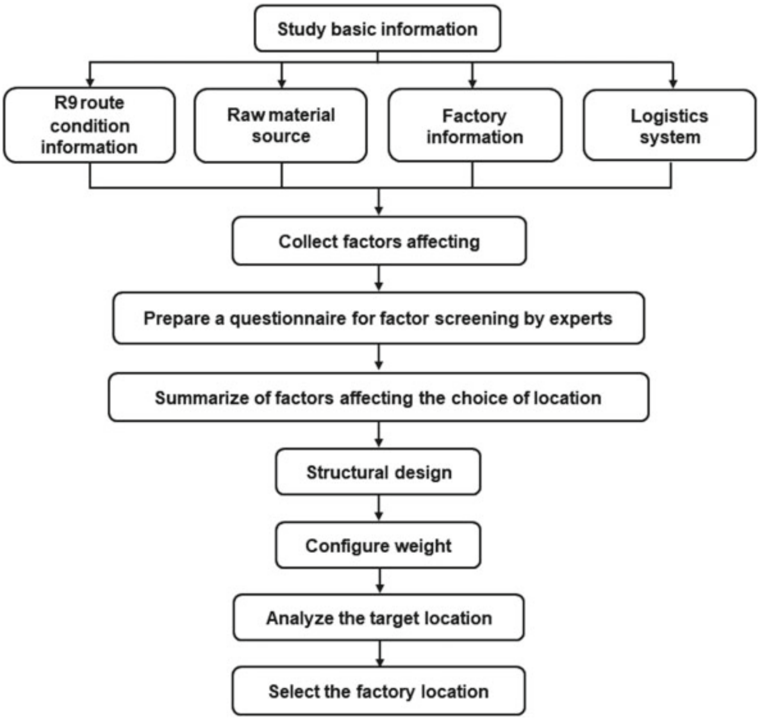

Fig. 3 The process of decision-making with AHP

namely Muang District, Sukhothai Province. Wat Bot District Phitsanulok Province and Puey Noi District Khon Kaen Province as shown in the following Fig. 4 and Table 5.

Then the experts in each field consider and scrutinize the factors. The results of the consideration revealed that the top 5 most important factors are raw material sources, transportation, labor sources, public infrastructure and investment promotion zones which can create a decision chart as shown in the following Fig. 5.

From a study of the importance of all 5 factors, it was found that the most important factor influencing the selection of the agricultural processing plant location was the raw material sources, transportation, labor sources, public infrastructure and investment promotion zones respectively as shown in the Table 6.

The CR calculating value 0.10, comparisons by pairs are consistent within acceptable criteria. The weight of each factor that influences the location selection. It is consistent and acceptable. Then, the total ranking of the alternatives was calculated by weighting the importance of the evaluation criteria for each factor. It was found that the most appropriate location for the processing mango plant is Wat Bot District, Phitsanulok Province as shown in the following Table 7.

This conforms to the industrial area development project to support investment of the Department of Industrial Works. Furthermore, stressing the importance of

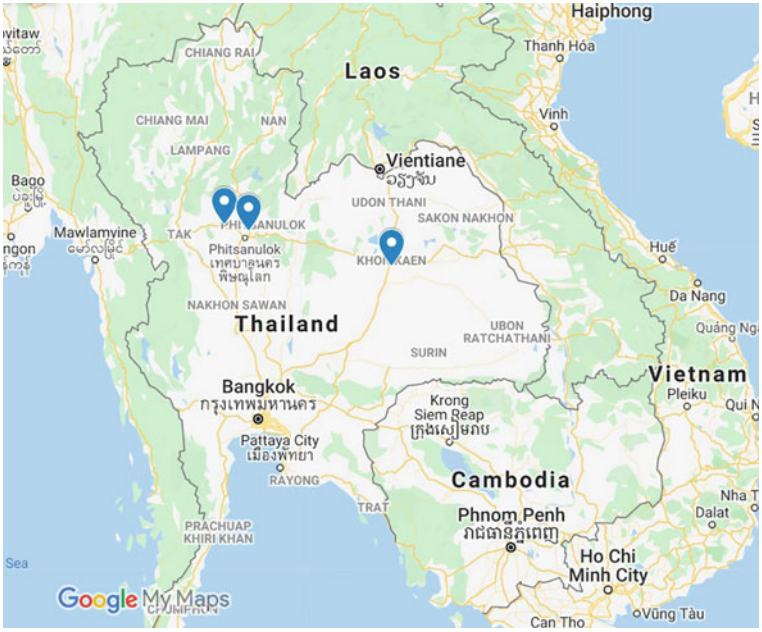

Fig. 4 Map of 3 alternative locations (google map)

Table 5 Latitude and longitude of 3 alternative locations

Location	Latitude (X)	Longitude (Y)
Muang district, Sukhothai Province	17.035915	99.891168
Wat Bot district, Phitsanulok Province	16.93751677	100.295235
Puey Noi district, Khon Kaen Province	16.349338	102.806863

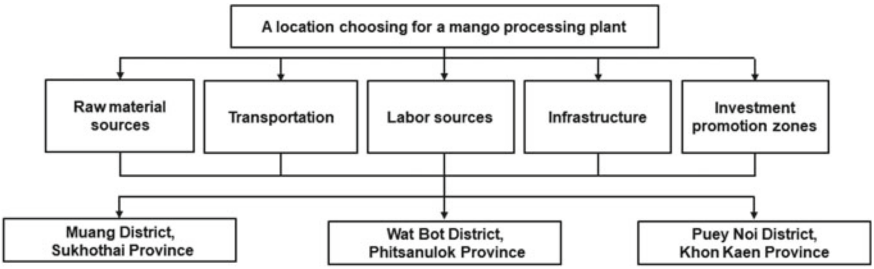

Fig. 5 A hierarchical chart or a model of decision making

Table 6 The evaluation criteria weight value for each factor

Criteria	Raw materials sources	Transportation	Labor sources	Infrastructure	Investment Promotion zones	Mean (X) 100% (%)
Raw materials sources	0.43	0.60	0.39	0.29	0.23	38.80
Transportation	0.14	0.20	0.39	0.29	0.23	25.00
Labor sources	0.14	0.07	0.04	0.03	0.08	7.20
Infrastructure	0.14	0.07	0.13	0.29	0.23	17.20
Investment Promotion Zones	0.14	0.07	0.04	0.10	0.23	11.58
Total	1.00	1.00	1.00	1.00	1.00	100

Table 7 The overall weight criteria of each option

Criteria	Raw materials sources	Transportation	Labor sources	Infrastructure	Investment promotion zones	Total Ranking
	0.39	0.25	0.17	0.12	0.07	
Muang District, Sukhothai Province	0.22	0.04	0.05	0.02	0.01	0.33
Wat Bot District Phitsanulok Province	0.05	0.14	0.10	0.07	0.04	0.40
Puey Noi District Khon Kaen Province	0.11	0.07	0.02	0.03	0.02	0.27

investment in the potential industries of Phitsanulok Province, ranking number one is the Agro-processing industry which has a strong point of being the transportation hub of the North. Phitsanulok is one of the provinces located along the EWEC and NSEC Economic Corridors and is also a center for agricultural products, vegetables, and fruits (Works 2016).

3.4 Economic Analysis Data

Farmers in Phitsanulok province must steam treat mangoes to avoid attracting golden flies before export to prevent outbreaks in the destination countries. The farmers have to carry mangoes to steam plants in Chiang Mai, Chon Buri, Nakhon Pathom, farmers must also bear costs of approximately 7 THB per kilogram. During the Covid-19 crisis, over 100 tons of mango products of the Phitsanulok farmers were damaged, due to the steam room at Chanthaburi province not being available. Another reason is that the mangoes are not delivered to the steam plant on time. If the government could offer support by building a steam plant located in Phitsanulok, the mango farmers would be relieved (News 2020).

A feasibility study of investing in the construction of a mango processing plant in Phitsanulok Province by using the investment structure as follows: 30% own capital and 70% from financial institutions based on the cost calculation from Lorenzo Stratta: Economic Analysis of a Freeze-Drying Cycle (Stratta et al. 2020). The economic feasibility study found that there was a high investment in the construction of a factory and buying machines. But mango crisps and mango seed oil value are also high and it tends to increase consumption in the future. Therefore, it is suitable for investment in a buildup of mangoes processed factories for processing crispy mangoes and mango seed oil. The researchers used economic tools to make it easier to analyze the results as follows:

1. Break-even point is 130,097,639 THB
2. Net present value NPV is 72,970,316 THB, which is greater than 0 means it is worth it to invest
3. The internal rate of return for the IRR project is 27%.

4 Conclusion and Directions for Future Investigations

Mangoes are grown in Thailand in large numbers most of which are for consumption followed by processing after being consumed and processed. It produces waste both in the household and the mango processing plant has to pay for the mango seed removal as well. Food waste management is a fundamental challenge in the global economy and contemporary business in the light of sustainable development requirements. Generally, a spectrum of international, national, and local initiatives, including legal acts and voluntary programs, has been developed to reduce food waste. Similarly, different supply chain practices have advanced so far to decrease food waste and enhance sustainability (Ocicka and Razniewska 2018). Therefore, this research has selected mangoes to find value-added opportunities by processing mangoes into crispy mangoes, which are becoming popular in the food snack market among health and mango seed oil extraction which has many benefits and can be extended to other industries as well. This paper has developed a financial feasibility study of zero waste manufacturing: Opportunity and value added of agricultural products on the R9 route in accordance with analyzing the optimal location of the mango processing plant by Center of Gravity Method and then verifying the results of the data analysis to the analytic hierarchical process (AHP) and analysis of economic data. The optimal location for the manufacturing plant is Phitsanulok Province and it is feasible from the values of BEP, NPV, and IRR. Definitely suitable for investing to build a mango processing plant. The new transport route promotes investments into production sites for export at locations in the Northern provinces. It opens new opportunities for exports of industrial goods and FMCG for the growing middle class in China (Wagener et al. 2020). Making the sectoral economy grow strongly and serves as a base for building economic growth of the country. In the National Economic Development Plan No. 12 (Council 2017). Including Sustainable Development Goal 9 build an infrastructure that is resilient to change, promote industrial development comprehensively and sustainably and promote innovation. Sub-goal 9.2 promotes inclusive and sustainable industrial development and by 2030 increase the industrial sector share in employment and gross domestic product in accordance with the national context and to double the shares in the least developed countries.

With further research, the feasibility study could consider other target markets apart from China and the cost of preferred stock to calculate the WACC and the other methods like financial value added (FVA) and economic value added (EVA).

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References

Azeem SW, Hussain H (2012) The determinants of foreign investment in Pakistan: a gravity model analysis. Logforum 8(2):81–97

Babaria PM, Vashney AK (2012) Extraction of oil from mango kernel by hydraulic pressing. LAP Lambert Academic Publishing

Bangkokbanksme (2015) 4 + 2 routes to send Thai fruits to China

Center ITC (2021) Information of mango production in the provincial located on route R9

Commerce MO (2021) tradereport. http://tradereport.moc.go.th/TradeThai.aspx

Council OOTNEASD (2017) 12th national development plan (2017–2021). Retrieved from https://www.nesdc.go.th/ewt_dl_link.php?nid=6422

Czwajda L, Kosacka-Olejnik M, Kudelska I, Kostrzewski M, Sethanan K, Pitakaso R (2019) Application of prediction markets phenomenon as decision support instrument in vehicle recycling sector. Logforum 15(2):265–278. https://doi.org/10.17270/J.Log.2019.329

Golińska P (2014). The lean approach for improvement of the sustainability of a remanufacturing process. Logforum, 10(3):235–293

Gustavsson J, Cederberg C, Sonesson U, Van Otterdijk R, Meybeck A (2011) Global food losses and food waste. In: FAO Rome

Hirata T, Fukaya T (2020) Potential of truck platooning for transporting empty trucks considering intercity freight demand imbalances. Logforum 16(3):373–383. https://doi.org/10.17270/J.Log.2020.450

Joanicjusz Nazarko KAK, Czerewacz-Filipowicz K (2016) The new silk road—analysis of the potential of new Eurasian transport corridors. In: Paper presented at the 9th international scientific conference, business and management

Karunanithi B, Bogeshwaran M, Tripuraneni S, Reddy (2015) Extraction of mango seed oil from mango kernel 32–41

Kauf S, Laskowska-Rutkowska A (2019) The location of an international logistics center in Poland as a part of the one belt one road initiative. Logforum 15(1):71–83. https://doi.org/10.17270/J.Log.2019.311
Kowalska A (2017) The issue of food losses and waste and its determinants. Logforum 13(1):7–18. https://doi.org/10.17270/J.Log.2017.1.1
Krishnan R, Agarwal R, Bajada C, Arshinder K (2020) Redesigning a food supply chain for environmental sustainability—an analysis of resource use and recovery. J Clean Prod 242:118374. https://doi.org/10.1016/j.jclepro.2019.118374
Laokasemsukwong K (2013) The potential of dried fruit industry in thailand. Thummasat
Lord DMJ (2009) East-West Economic Corridor (EWEC) strategy and action plan. In: Munich Personal RePEc Archive
Meteethunyarat T (2020) Oil tank farm site selection in Thailand by using the analytic hierarchy process. Ladkrabang Eng J 32(3):37–42
News MO (2020) Mango farmers submit to the Administrative Court again pointing out that the state-private groups Northern provinces to move budget to set up a steam plant affecting exports. In: Manager Online News
Ocicka B, Razniewska M (2018) Food waste reduction as a challenge in supply chains management. Logforum 14(4):549–561. https://doi.org/10.17270/J.Log.2018.303
Opoku RK, Abboah CKB, Owusu RT (2021) Inventory management strategies of food manufacturing industries in a developing economy. Logforum 17(1):37–48. https://doi.org/10.17270/J.Log.2021.557
Patton D (2020) Food exporters to China asked to declare produce is coronavirus-free. Reuters
Phankong W, Manesri T, Manesri C (2020) Applicate analytic hierarchy process for evaluation of biomass plant location. Ladkrabang Eng J 33(2):70–76
Popp J, Oláh J, Nestler S, Nobel T, Rakos M (2018). Development of dry ports in Europe. Int J Appl Manag Sci 10(4):269–289
Rejeb A, Rejeb K, Keogh JG (2020) Covid-19 and the food chain? Impacts and future research trends. Logforum 16(4):475–485. https://doi.org/10.17270/J.Log.2020.502
Saaty T, Vargas L (2001) Models, methods, concepts & applications of the analytic hierarchy process
Stratta L, Capozzi L, Franzino S, Pisano R (2020) Economic analysis of a freeze-drying cycle. Processes 8:1399. https://doi.org/10.3390/pr8111399
Suwannachote T (2018) Businees plan for dnacher freeze dried fruit, Master Degree. Thammasat university, Retrieved from http://ethesisarchive.library.tu.ac.th/thesis/2018/TU_2018_6002030614_9851_9903.pdf
Wagener N, Aritua B, Zhu T (2020) The new silk road: opportunities for global supply chains and challenges for further development. Logforum 16(2):193–207. https://doi.org/10.17270/J.Log.2020.403
Works DOI (2016) Project to develop industrial areas with potential to support investment. Retrieved from http://gisweb.diw.go.th/diwzonning/diwzoning62/images/content/5download/pdf2/8zoning59_Phitsanulok.pdf

The Impact of Tighter Regulations of Export Controls in Global Logistics

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1 Introduction

As the globalization of international logistics progresses, tariff barriers have lowered. The introduction of information technology has advanced and export and import procedures have simplified. Opportunities to export high-performance industrial products, materials, and parts to developing countries, emerging nations, and "rogue states" has increased, as these products, materials, and parts were not easily exported in the past.

At the same time, various risks associated with exports have attracted attention. The terror attacks against the United States and its allies, such as September 11, 2001, international disputes and civil wars have also occurred frequently, and Japan has been constantly exposed to the risk of missile strike from North Korea. In this international situation, the direct export of conventional weapons and weapons of mass destruction has been restricted. Moreover, a sense of crisis has arisen about the situation in which generally used in daily living are being converted into weapons in rogue states.

From Japan's viewpoint, this study attempts to confirm that the shipping processes of international logistics bears a heavy burden from the series of export processes under tightened export regulations.

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2 Tightening Regulations on Export Controls

The terrorist attacks on September 11, 2001, led to the introduction of export controls. Since the attacks, successive events have occurred in which the United States' science and technology is converted into military technology in Iraq, Iran, Libya, and North Korea. Therefore, the movement for ensuring strict measures for export controls has accelerated in the United States. In Japan, illegal exports have also occurred repeatedly. For example, a freeze dryer and a pulverizer that can have military applications were exported without permission in November 2006, as was an unmanned helicopter in 2007.

Moreover, from the end of 1980 until recently, textile manufacturer A and its subsidiary have exported carbon fiber made by textile manufacturer A to Taiwan for the purpose of "manufacturing sporting goods, such as tennis rackets." However, carbon fiber can have military uses such as in the manufacture of missiles. Therefore, Japan's Ministry of Economy, Trade and Industry (METI) issued a warning to textile manufacturer A and its subsidiary for "false applications."

The advancement of economic globalization and integration was followed by an increase in the export of advanced technology in developed countries to developing countries and emerging nations. Further, advanced technologies have frequently been put to military use in rogue states. Consequently, strict restrictions have been imposed on exports. To avoid the risk of nonmilitary products being put to military use, catch-all controls were introduced in developed countries.

The Foreign Exchange and Foreign Trade Act provides that a person seeking to export specific kinds of goods (hereinafter referred to as specific goods) that have been found to compromise world peace and international security must first get permission from METI to do so (hereinafter referred to as export permission) (Article 48). Before a resident or a non-resident conducts a transaction with the objective of providing technologies that have been found to compromise world peace and international security, they must get the permission from METI (Article 25).

3 Previous Studies

Research on export control has increased in recent years and is not limited to the ban on arms exports from the perspective of military or international politics such as the United States. General-purpose products produced on the basis of US technology are also regulated. Scholars examine Americans' concern over the risk of military diversion outside the United States. For example, Black and Holle describe and discuss the export control policy perspectives shared by most of the US satellite industry. Also, Nayan examines the salient features of the principal statutory authority. In addition, Rudney and Anthony help us to understand the strengths and weaknesses of the export control systems of the major supplier countries. A paper by Gill, Ebata, and Stephenson pioneered Japan's export control.

However, Seyoum points out that export restrictions could be a response to international threats, with supply chain security in mind. However, export restrictions have not kept pace with rapid changes in the global economy and technological innovation, and thus concerns arose that export restrictions may adversely affect the economic performance of global companies.

4 The List and Catch-All Controls

4.1 Outline

The list control regulates the export of weapons or technologically sophisticated general-purpose products that can have military uses by listing the product names. To export these goods, exporters must obtain permission from the Minister of Economy, Trade, and Industry regardless of the stated purpose or who the end users are. The catch-all controls regulate the export of all goods except foodstuffs and wood. Therefore, when exporting a product to a country not on the "whitelist" and that product corresponds to either "informed" or "objective" conditions then permission must first be obtained from METI.

4.2 Classification

The classifications assessment process begins with an examination slip to determine whether the engineer providing the technology has followed the list control. The assessment often adopts a double-check system in which the engineering section assesses technical aspects such as the specifications, while the export control section confirms the technical aspects from a legal perspective. Using this double-check system, the contents of invoices and parameter sheets are confirmed to ensure that they are correct.

The classification is performed not only for items subject to the list control (related to weapons of mass destruction and conventional weapons) but also for items that may have military uses and may be used to develop weapons of mass destruction and conventional weapons (items subject to catch-all controls). Items that fall under the objective and informed conditions cannot be exported without permission from METI. The objective conditions assess the end-use and end-user conditions based on the exporter's judgment. The informed conditions are applied when an exporter obtains permission from METI.

4.3 Transaction Screening Using the ST Control Form

The export control section assesses the end use and end user of a product using the ST control form before deciding whether to grant approval. The process is explained in greater detail below.

General transactions include the export of goods and technologies subject to the list control, which do not correspond to products related to weapons of mass destruction, restricted purchasers, and suspicious transactions.

Specially designated countries, such as Iran, Iraq, North Korea, Cuba, Syria, and Sudan, are subject to the transactions of products related to weapons of mass destruction. Inquiries from foreign militaries, national defense-related organizations, or persons who have received orders of products from the above-mentioned militaries or organizations or other items that have military uses are subject to the transactions of products for military or military-related end use.

For restricted purchasers (in Japan and other countries), a master file of restricted purchasers was created. Companies and persons who placed on the master file are subject to the conditions of restricted purchasers.

Suspicious transactions are defined as: (1) the objective condition, which consists of the objective condition for weapons of mass destruction (end-user and end-use conditions) and the objective condition for conventional weapons (end-use conditions), (2) the informed condition (a notice from METI), (3) the administrative guidance condition (including cases in which a product is proven to be used for the development of nuclear weapons), and (4) other suspicions can be cited.

Attachments for the ST control form include (1) transaction documents (inquiry documents, order sheets, specifications, contracts, and minutes), (2) customer information (company brochures, company yearbooks, and documents related to a company's homepage), (3) classification documents (classification sheets, the master files of products and parts, the master file of instruments, and judgment lists), (4) HRP check sheets, and (5) end-use confirmation letters are prepared.

4.4 Export Permission from METI

There are two export permission licenses, the individual validated license (IVL) and the general bulk license (GBL).

The IVL grants permission to export goods and technologies based on the Foreign Exchange and Foreign Trade Act. To export goods, export permits must be issued, and to provide technologies, service transaction permits must be issued.

Regarding GBL, the export of goods and the provision of technologies in the specified range to the specified regions are collectively permitted for up to three years. When permission is obtained, no individual application for a license is required for the export of goods and the provision of technologies within the permitted range.

4.5 Catch-All Check Sheets

Regarding catch-all controls, the following are confirmed by creating the catch-all check sheets: (1) whether the purchaser is restricted, (2) whether the products are related to weapons of mass destruction, (3) whether end-user conditions apply, (4) whether end-use conditions apply, (5) whether informed conditions apply, and (6) whether the transactions are suspicious.

Regarding the classification of specific goods and technologies, transaction screening is performed after confirming the transaction classification (general transactions, suspicious transactions, transactions for specially designated countries, transactions for military or military-related end use, and transactions for restricted purchasers).

The roles of transaction-related sections are explained below. The sales section confirms whether the transaction corresponds to the list of restricted purchasers, products for military or military-related end-use, or specially designated countries. If it does, an ST control form is issued. The sales section also confirms the classification of inquired products.

The technology section classifies goods and technologies and controls for providing technologies. For technologies subject to the list control, a management ledger for technology provision histories is issued.

The export control section performs transaction screening, approves EMC transactions, checks the ST control form, approves catch-all check sheets, checks export licenses (export permission from the Minister of Economy, Trade and Industry), and obtains export permission from the United States Secretary of Commerce.

5 Case: Exports of Personal Computers

Whether a product corresponds to specific goods that require export permission is confirmed in both the list control shown in rows 1 to 15 of the appended Table 1 of the Export Trade Control Order (hereinafter referred to as the Export Order) and the catch-all controls shown in row 16 of the same table.

5.1 Classification of Goods in the List Control

Personal computers belong to the category of "electronic computers, electronic assemblies or components therefor whose specifications comply with the Ordinance of the Ministry of Economy, Trade and Industry" in row 8 of appended Table 1 of the Export Order. The specifications are provided in Article 7 of the Ordinance of the Ministry Specifying Goods and Technologies Pursuant to Provisions of appended Table 1 of the Export Control Order and appended table of the Foreign Exchange

Table 1 Minimum total time/Maximum total time

	Assistant work	Minimum total time (h)	Maximum total time (h)
①	Liaison and related work with export control departments and the ministry of economy, trade and industry	48	48
②	Liaison with list control/catch-all control classification department	48	48
③	Liaison with classification division for specific technology	32	32
④	Confirmation of the catch-all check sheet	48	48
⑤	Liaison with procurement/Import department	20	20
⑥	Liaison and related work with the sales department	20	20
⑦	Other miscellaneous affairs, meetings, etc.	24	24

Order (hereinafter referred to as the Ministry Ordinance). When commercially available personal computers are collated with the specifications in Article 7 of the Ministry Ordinance, those computers do not correspond to goods which require export permission. Moreover, commercially available personal computers do not correspond to the classifications of specified technologies.

However, wireless local area network (LAN) cryptographic equipment embedded in personal computers may correspond to goods which require export permission. Cryptographic equipment corresponds to "cryptographic equipment or electronic assemblies, modules or integrated circuits having cryptographic functionality" in row 9 of appended Table 1 of the Export Order. Cryptographic equipment embedded in ordinary personal computers corresponds to the regulation of "those which use a symmetric algorithm employing a key-length in excess of 56 bits."

However, the cryptographic functionality of cryptographic equipment embedded in a commercially available personal computer cannot be changed by its user. In this case, export permission is not required because its use does not need technical support by the supplier or sales agency.

Based on the above, the classification of personal computers is performed after collating the specifications of personal computers with the specifications provided in the Ministry Ordinance.

When a person temporarily leaves Japan with a personal computer equipped with cryptographic equipment for their own use, export permission is not required. In many cases, a certificate of non-applicability is not created for a company exporting personal computers, but the certificate is acquired from the manufacturer. Therefore, personal computers can be exported problem free. However, companies exporting personal computers bear export responsibilities due to the Compliance Standards for

Exporters and Persons Conducting Similar Transactions and are obliged to appoint a person in charge of confirming the company's non-applicability.

5.2 Applications for Export Permission and Catch-All Controls

Personal computers are subject to regulations on "weapons of mass destruction for catch-all controls" and "conventional weapons for catch-all controls." When the export of personal computers to countries and regions other than those on the "whitelist" corresponds to the informed, objective, end-use, and end-user conditions, applying to the Minister of Economy, Trade, and Industry for export permission is required.

Personal computers often correspond to goods subject to US re-export controls because they often contain software and embedded parts made in the United States. Exporters of personal computers to countries restricted by the federal government of the United States (Cuba, North Korea, Iran, Sudan, and Syria) must first get export permission from the federal government of the United States.

Taking specified technologies that are regulated by the Foreign Exchange and Foreign Trade Act out of Japan is subject to the Foreign Exchange and Foreign Trade Act. Removing specified technologies stored in personal computers or USB memories out of Japan for service transactions requires the permission from the Minister of Economy, Trade, and Industry.

5.3 Regulations in the Destination Countries of Exports

The export of personal computers may be restricted due to the regulations of importing countries. For example, the European Union has the following regulations: the Electromagnetic Compatibility Directive, Low Voltage Directive, Restriction of Hazardous Substances Directive, Waste Electrical and Electronic Equipment Directive, and Directive on Eco-Design of Energy-using Products. Exporters of personal computers must address each and every regulation.

6 Systems to Assist Shipping and Export Controls

As mentioned above, shipping operations may become a heavy burden for the export section of a manufacturing company due to the strengthened list and catch-all controls. When exports increase due to the relaxation of regulations at the macroeconomic level, such as the expansion of regional economic integration, shipping operations become more complicated. This study proposes a cross-sectional organizational system to supervise the entire international operation instead of a vertical sectioning system. To this end, an international logistics management supervisory group or section (a tentative name) should be established to assist the highly specialized export control section and to provide a bridge connecting export control, sales, import, and procurement sections, because these sections need to strengthen in-house collaboration.

6.1 Conceptual Organizational Model

According to Chester Barnard, organizational goals, willingness to serve, and information sharing must exist in an organization in a well-balanced manner. An international logistics management supervisory group (hereinafter referred to as the supervisory group), which is cross-sectionally constructed, will sufficiently satisfy the above-mentioned three elements of an organization proposed by Barnard.

Organizational goal

Due to the expansion of regional economic zones, customs clearance has been simplified. The supervisory group appropriately copes with complicated shipping matters, the amount of which has rapidly increased, and applications for export permissions. The supervisory group closely collaborates with the sales, procurement, and import sections, and it also has a monitoring function.

Willingness to serve

The supervisory group will have to acquire sufficient practical knowledge to cope with the list control, the catch-all controls, and the Act against Delay in Payment of Subcontract Proceeds, and so forth, to subcontractors. Therefore, the supervisory group's contribution to corporate activities is high. The supervisory group's willingness to serve is highly stimulated by always being involved in various important procedures that are related to export restrictions.

Information sharing

By providing a bridge connecting export control, procurement, import, and sales sections, the supervisory group plays a key role in information sharing.

6.2 Organizational Reform Related to Foreign Trade

Company B has been established for more than 100 years. With the introduction of a new information system, this company undertook significant organizational reform related to export controls, including the list and catch-all controls. Major problems encountered during its organizational reform were: (1) complicated examination routes, (2) wasted time due to the distribution of jobs, and (3) operational errors and difficulties in understanding and sharing information in a timely manner.

Company B has the three divisions: medical services, science, and visual content. These divisions handle products subject to the list and catch-all controls. The route to approving a project was long, many business activities were redundant, and the database was not shared among divisions. To solve these three problems, the organization was reformed, and a new information system was introduced. As a result, examination times were shortened by 25–33%, personnel assignments were efficiently performed, the business affairs of each division were visualized, and information was properly collected.

The introduction of a new information system is essential for organizational reform. Many of company C's products are subject to the list control due to their characteristics. Therefore, company C constructed a system that can automatically apply the results of past transaction screenings to a new transaction and connected the function of summarizing the classification results of similar products to the SCM support system. Through this system, company C performs process management from order acceptance to shipping.

However, many manufacturing companies cannot introduce expensive systems. It may therefore be more realistic to improve business efficiency through organizational reform before introducing new information systems.

6.3 Establishment of a Cross-Sectional Organization

The person in charge of business related to the list and catch-all controls may cover the export control section, the classification section of the list and catch-all controls, the classification section of specified technologies, the confirmation section of catch-all check sheets, the sales section, the procurement section, and the import section. Because it is difficult for that person to concentrate on the businesses of existing sections, the establishment of a cross-sectional organization is required.

The amount of export-related business depends on the handling volume of goods to be exported. In the case of companies listed on the first section of the Tokyo Stock Exchange whose annual turnover is between 50 and 100 billion yen, the following organization is proposed as a standard prototype:

(1) Number of staff: six.
(2) Shifts: Staff members assist the section that is responsible for the particular day, in the form of half-day units, such as morning and afternoon shifts.
(3) Assistive duties consist of the following (a)–(f):
    (a) Communication with the export control section and METI, and communication-related duties
    (b) Communication with the classification section of the list and catch-all controls
    (c) Communication with the classification section of specified technologies

(d) Confirmation of catch-all check sheets
(e) Communication with the procurement and import sections
(f) Communication with the sales section, and communication-related duties.

In addition to the above six duties, staff members would perform miscellaneous duties and preliminaries. If necessary, work shifts would be arranged every week based on the requests of each staff member responsible.

6.4 Construction of a Scheduling Management System

Staff members of the above-mentioned organization would schedule work shifts every week and take charge of all the duties described in (a)–(f). To reduce the burden on each staff member, scheduling management would be performed. To create a work shift table, the following conditions are considered:

(1) Constraint conditions for shifts.
Conditions related to the composition of staff members (satisfaction with working status).

(a) Keep the minimum and maximum total working hours of each work shift (assistive duties) within the target period.
(b) Keep the minimum and maximum number of staff members for each day, time zone, and work shift (assistive duties).

(2) Constraint conditions for the staff members responsible.
Conditions related to the workload and work restrictions of each staff member.

(c) Keep the number of duties of each staff member in each work shift (assistive duties) in the target period within the range of the minimum and maximum numbers of duties.
(d) Consider each staff member's desired duties in charge at the day and time zone levels.

6.5 Formulation

On the premise of the constraint conditions in the previous section, the formulation is performed as follows:

Formula (1) is an objective function, which minimizes the sum of penalties against the maximum total working hours of each work shift, with the constraint conditions of (a) above.

$$\text{Minimize} \quad \sum_{d \in D} \sum_{n \in N} \sum_{s \in S} y_s \tag{1}$$

where D represents the aggregate of days in the target period, N represents the aggregate of staff members responsible, S represents the aggregate of work shifts (assistive duties), variable y_s represents penalties against the maximum total working hours of each work shift with the constraint conditions of (a) above. In other words, a penalty is imposed on the number of hours that exceed the maximum total working hours in work shift s.Inaddition, y_s is defined using Formula (11).

Formula (2) expresses that each staff member is assigned to shift s when the member works in each time zone h on each day d.

$$\sum_{s \in S} x_{dhns} = 1, d \in D, h \in H, n \in N \tag{2}$$

where H represents the aggregate of time zones, and variable x_{dhns} is a 0/1 variable, which is 1 when a duty assigned to each responsible staff member n in each time zone h on each day d is s and that is 0 in other cases. In addition, x_{dhns} is defined using Formula (10).

Formulae (3) and (4) express constraint conditions of (a) above and indicate that the total working hours of each shift s are within the range between the minimum total working hours $c1$ and the maximum total working hours $c2$. Formula (5) allows a breach (penalty), and variable y_s represents the deviation amount (the number of hours exceeding the maximum total working hours).

$$\sum_{d \in D} \sum_{h \in H} \sum_{n \in N} x_{dhns} \geq c1_s, \quad s \in S \tag{3}$$

$$\sum_{d \in D} \sum_{h \in H} \sum_{n \in N} x_{dhns} \leq c2_s + y_s, \quad s \in S \tag{4}$$

Regarding the constraint conditions of (b) above, Formulae (5) and (6) restrict the number of staff members required for shift s in each time zone h on each day d by the minimum number of people $c3_s$ and the maximum number of people $c4_s$.

$$\sum_{n \in N} x_{dhns} \geq c3_s, d \in D, h \in H, s \in S \tag{5}$$

$$\sum_{n \in N} x_{dhns} \leq c4_s, d \in D, h \in H, s \in S \tag{6}$$

Regarding the constraint condition of (c) above, Formulae (7) and (8) restrict the number of duties of each staff member in shift s in the target period by the minimum and maximum numbers of duties ($c5_{ns}$ and $c6_{ns}$, respectively).

$$\sum_{d \in D} \sum_{h \in H} x_{dhns} \geq c5_{ns}, \quad n \in N, \quad s \in S \tag{7}$$

$$\sum_{d \in D} \sum_{h \in H} x_{dhns} \leq c6_{ns}, \quad n \in N, \quad s \in S \tag{8}$$

Formula (9) expresses the constraint condition of (d) above and restricts shift s of each staff member n in the time zone h on the specific day d using the desired duty ${L^+}_{dhns}$.

$$ {L^+}_{dhns} - x_{dhns} \leq 0, d \in D, h \in H, n \in N, s \in S \tag{9}$$

Variable x_{dhnb} is a 0/1 variable, which is 1 when a duty assigned to each staff member responsible n in each time zone h on each day d is s and which is 0 in other cases. This value is defined using Formula (10).

$$x_{dhns} \in \{0, 1\}, d \in D, h \in H, n \in N, s \in S \tag{10}$$

Variable y_s expresses the deviation amount (the number of hours exceeding the maximum total working hours of each shift s), and is defined using Formula (11).

$$y_s s \in S \tag{11}$$

In these formulae, all of $c1$–$c6$ are constants.

$c1$: Minimum total working hours of each shift in the target period.

$c2$: Maximum total working hours of each shift in the target period.

$c3$: Minimum number of people in each shift in each time zone on each day.

$c4$: Maximum number of people in each shift in each time zone on each day.

$c5$: Minimum number of duties of each staff member in each shift in the target period.

$c6$: Maximum number of duties of each staff member in each shift in the target period.

6.6 Numerical Experiment

The target period was set to five days and the time zone was divided into two. These were between 9 a.m. and 1 p.m. (four hours including a break) and between 2 p.m. and 6 p.m. (four hours). The minimum and maximum total working hours in each shift were set, as shown in Table 1. The required number of people were set, as shown in Table 2. The number of duties of each staff member in each shift in the target period were set, as shown in Table 3, and values shown in this table were applied to all staff members. Each staff member's desired duty was set, as shown in Table 4. Table 5 shows the results obtained in the numerical experiments. As shown in Table 5, a solution that satisfied all the constraint conditions could be obtained. The sum of penalties was 0.

Table 2 Required number of people

	Assistant work	Minimum number of people	Maximum number of people
①	Liaison and related work with export control departments and the ministry of economy, trade and industry	0	2
②	Liaison with list control/catch-all control classification department	0	2
③	Liaison with classification division for specific technology	0	2
④	Confirmation of the catch-all check sheet	0	2
⑤	Liaison with procurement/Import department	0	1
⑥	Liaison and related work with the sales department	0	1
⑦	Other miscellaneous affairs, meetings, etc.	0	1

Table 3 Minimum times and Maximum times

	Assistant work	Minimum times	Maximum times
①	Liaison and related work with export control departments and the ministry of economy, trade and industry	2	2
②	Liaison with list control/catch-all control classification department	2	2
③	Liaison with classification division for specific technology	1	2
④	Confirmation of the catch-all check sheet	2	2
⑤	Liaison with procurement/Import department	0	1
⑥	Liaison and related work with the sales department	0	1
⑦	Other miscellaneous affairs, meetings, etc.	1	1

Table 4 Desired working

Staff no.	Desired work
1	Day 1 AM assistant ②
4	Day 4 assistant PM ⑤
5	Day 3 AM assistant ④

Table 5 Work shift

		1	2	3	4	5	
	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Staff	AM PM	AM PM	AM PM	AM PM	AM PM	AM PM	AM PM
1		2 5	1 2	1 3	6 4	4 7	
2		7 1	4 2	2 3	1 4	6 5	
3		6 2	1 1	3 2	7 3	4 4	
4		1 4	6 7	4 1	3 5	2 2	
5		4 1	7 3	4 2	1 2	5 6	
6		2 2	4 1	5 4	3 1	7 3	

*Gray shading indicates desired work

6.7 Discussion

To improve the efficiency of shipping and export operations, a cross-sectional supervisory organization must be established, and its operations must be assisted so that no heavy workload is placed on individual staff members. To this end, the scheduling management of the staff members responsible for any activities is indispensable. It is desirable to link a scheduling management system with a search system, which can automatically apply the results of transaction screening in the past to new transactions and the SCM support system. With this system, process management from order acceptance to shipping can be performed.

7 Conclusion

In this paper, we have considered, in detail, a series of export control processes. It is undeniable that the time and burden required to establish whether to determine the specific cargo/technology and to confirm it with the catch-all check sheet is enormous, and this burden is a new trade barrier that replaces customs procedures such as tariffs. The strengthening of global export control has been promoted, while each country is greatly influenced by the United States; however, ASEAN countries lack a sufficient legal system to comply with list regulations, catch-all regulations, and the like. Therefore, many countries do not have a legal system for exports management. It has been pointed out that although legislation is being developed, for example in China and India, judicial issues remain due to security restrictions. Although reducing the number of procedures is difficult, the smoothness of shipping operations will be hindered by the effects of new barriers created by the globalization of the economy.

Prior to 1993, Japan invited export managers from ASEAN countries to hold the "Asia Export Control Seminar" every year to deepen the understanding of ASEAN countries about the importance of export control. The seminar hosted by the Security and Trade Center (CISTEC) is attended by Japan's METI, Ministry of Foreign Affairs, leading companies, among others. For practitioners of shipping and export control, discussions with government officials tend toward institutional theory and ideal theory but still reflect the voices of businesspeople, including knowledge about business.

As described above, it has become clear that while customs operations are being reduced due to the expansion of the economic zone, export-related shipping operations are becoming more complicated due to regulations.

In addition, to promote the efficiency of shipping and export operations by showing a model in this paper and simulation, a cross-sectional control department was newly established to assist operations without imposing a heavy labor load on the newly established organization. For that purpose, schedule management of the person in charge is indispensable. Furthermore, linking the schedule management system with a search system and SCM support system that can automatically apply past transaction examination results from ordering to shipping is critical.

Bibliography

Beck M (2000) Reforming the multilateral export control regimes. Nonprolif Rev 7(2):91–103

Black S, Holle M (2015) Satellite industry perspectives on export control regulations. Astropolitics Int J Space Politics Policy 13(2–3)

CISTEC (2018) Export control compliance and American academia. Yushutukanri No Johoshi 173:94–99

Gill B, Ebata K, Stephenson M (1996) Japan's export control initiatives: meeting new nonproliferation challenges. Nonprolif Rev 4(1)

Holm K (2006) Europeanising export controls: the impact of the European union code of conduct on arms exports in Belgium, Germany and Italy. Eur Secur 15(2):213–234

Mathias C (1982) A new U.S. export control policy. Wash Q

Nayan R (2005) Emerging frontiers of US dual-use export control laws. Strateg Anal 29(1)

Noble MJ (2008) Export controls and United States space power. Int J Space Politics Policy 6(3)

Peterson D, Goorevich RS, Hooper R, Scheinman L, Tape JW (2008) Export controls and international safeguards. Nonprolif Rev 15(3):515–527

Rajeswari PR (1998) US export control policy and Wassenaar arrangement. Strateg Anal 22(3)

Rajeswari PR (1999) Economics of export controls: a study of US export control mechanism. Strateg Anal 23(7):1199–1213

Roberts B (1998) Export controls and biological weapons: new roles. New Chall Crit Rev Microbiol 24(3):235–254

Rudney R, Anthony TJ (1996) Beyond CoCom: a comparative study of five national export control systems and their implications for a multilateral nonproliferation regime. Comp Strateg Future Russia 15(1):41–57

Sato H (2019) Export control and international system. J World Aff 67(4):53–67

Sato T (2020) Issues based on the historical backgrounds and developments in export law and policies before introducing the U.S.export control reform act (ECRA) about check and balance by separation of powers and dual uses etc. Aoyama Law Rev 61(4):403–419

Seyoum B (2017) Export controls and international business: a study with special emphasis on dual-use export controls and their impact on firms in the US. J Econ Issues 51(2017):45–72

Suzuki K, Murayama Y (2021) A study on hybrid solving of scheduling problems by swarm intelligence based on business trends, report A of the research institute of industrial technology, Nihon University Number 54, vol 1, pp 1–7

Suzuki K, Murayama Y, Wakabayashi K, Watanabe A (2019) Efficiency of crew assignment in truck freight operation from the view of logistics, environmental sustainability in Asian logistics and supply chains, international federation of logistics and SCM systems. Springer, pp 219–231

Xing Y, Suzuki K, Murayama Y, Wakabayashi K, Watanabe A (2021) A study on a series of processes in export control. J Jpn Soc Direct 19(1):44–51

Two Echelon Vehicle Routing Problem for Disaster Mapping Process Using Cooperated Vehicles Assignment

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1 Introduction

A natural disaster is a phenomenon that is caused by natural forces and potentially leads to significant damages and loss of life (WHO 2002). According to Djalante et al. (2017), Indonesia is one of the countries with the highest risk of natural disasters globally, and one of the most common disasters that occur in this country is floods (Djalante et al. 2017). This disaster has a significant impact on Indonesia, especially on Bekasi City at the beginning of 2020. The damages caused by floods affected some infrastructures such as residences, roads, bridges, medical facilities, and others, resulting in potential obstacles in distributing disaster relief. Therefore, the availability of accurate maps to provide up-to-date information on the affected area condition is needed so that the disaster aid can be distributed quickly and precisely (Sarma et al. 2020).

Mapping disaster-affected areas are one of the disaster management activities (Das et al. 2013). Disaster management is a series of activities that aim to prevent,

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mitigate, prepare, emergency response to disasters and recover the affected areas. However, practically mapping or recording disaster-affected areas in Indonesia is relatively time-consuming. This is due to the limited number of mapping methods providing accessible routes to reach affected areas. In practice, mapping can be done by using satellite imagery and drone. Mapping using satellite imagery enables one to record large areas because of its ability to record from thousands of kilometres from the ground. However, using this tool costs a lot and requires a long time for image processing, so this method is rarely used for disaster management purposes (Kerle and Oppenheimer 2002). This method is also inflexible since the image resolution is strongly affected by weather conditions, and it is difficult to record in the exact location (Zulkipli and Tahar 2018). Meanwhile, mapping with drones has advantages such as having high speed and accessing areas without being affected by road infrastructure conditions (Kitjacharoenchai et al. 2020). Furthermore, drones can generate actual data using sensors such as the Global Positioning System (GPS), Inertial Navigation System (INS), and infrared (Zulkipli and Tahar 2018). Disaster mapping using drones also increases logistics activities efficiency and reduces disaster risk, early warning, and flood monitoring (for the Coordination of Humanitarian Affairs (OCHA 2014).

Despite its advantages in disaster mapping operation, drones have a limited range in capturing affected areas. Therefore, a suitable mechanism and planning are needed to execute mapping with drones to reach all affected areas. Based on the previous research, using a combination between ground vehicles and drones could extend the mapping range (Marinelli et al. 2018). However, practically using this combination for disaster-affected areas mapping is rarely found, especially in Indonesia. Therefore, this topic becomes the focus to discuss.

This research will focus on using a combination of ground vehicles and drones to record the flood disaster-affected area in Bekasi, January 2020. The problem will be modelled into 2E-VRP (Two-Echelon Vehicle Routing Problem), which is a simplification of Multi-Echelon VRP (Crainic et al. 2010). Since it is still categorized as a VRP model, this model will determine the route of vehicles with the most minimum possible time. However, this model is able to cover a problem with two different types of vehicles in different echelons. The first echelon determines the route for ground vehicles carrying drones, while the second echelon determines the route for drones to record the areas. A study has discussed the application of the 2E-VRP model with the drone that moves in a round trip called 2E-VRP-MOD (Liperda et al. 2020). This study modifies the drone movement into cooperative movement with the same objective: record the entire affected area with the minimum time. This is based on previous research that says that a combination of ground vehicles and drones that work cooperatively finish the tasks more efficiently and at lower costs. Based on the description mentioned, this study aims to build a mathematical model for mapping the affected areas with a combination of ground vehicles and drones that move cooperatively.

2 Problem Description and Mathematical Model

This research problem is formulated in a mathematical model, namely 2ECOVRP-MOD (Two Echelon Cooperated Vehicle Routing Problem—Mapping Operation with Drone), which describes disaster mapping operation with two types of routes (echelons) and these routes are accessed by ground vehicles and drones. The ground vehicle used in this research motorcycle due to its flexibility to reach the affected areas. A motorcycle carries one drone. The operation starts in the first echelon, from the depot point where these motorcycles take the drones to each stopover point. These stopover points are also where the drones will be launched to the affected areas to map the second echelon. The drones will return to stopover points, and they will be carried back to the depot by motorcycles after capturing the images of all affected areas. This model is modified from prior research with a similar case and is called 2E-VRP-MOD (Liperda et al. 2020). This model allows a drone to return to the stopover point once it has captured an image of a mapping point. However, in this research, the drones move cooperatively where they are able to visit more than one affected area as long as the flight time does not exceed the battery capacity. Cooperative movements between ground vehicles and drones are more efficient with lower costs compared to when these vehicles do not move cooperatively (Murray and Chu 2015). The illustration of the model can be seen in Fig. 1.

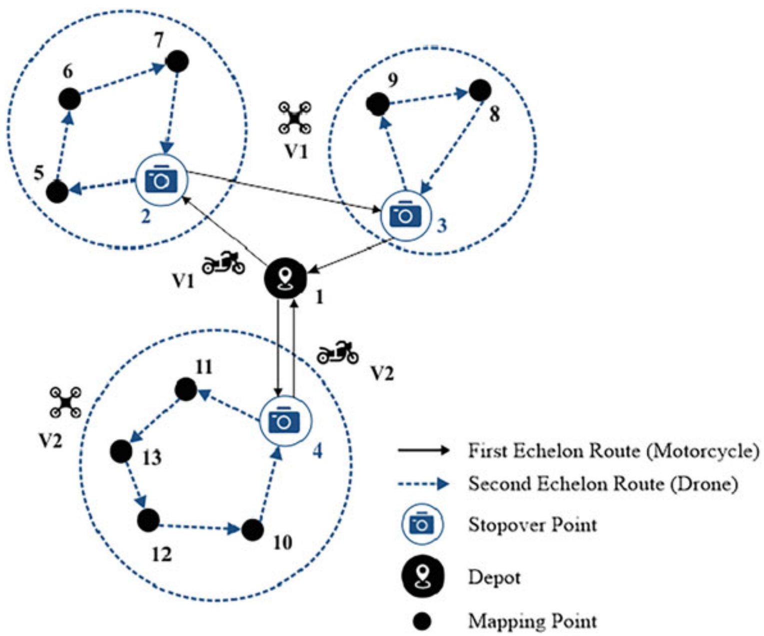

Fig. 1 Illustration of 2ECOVRP-MOD

Model 2ECOVRP-MOD has an objective to minimize the total time required to record all the affected areas. The details of the 2ECOVRP-MOD model is define as follows.

Set:

S Set of all nodes in the first echelon (includes depot)
S_0 Set of all stopover points where $S_0 = \{1 \ldots |S|\}$
C Set of all mapping points
V Set of all vehicles in the first echelon
K Amount of the drone routes in the second echelon

Parameter:

Cs_{ij} Travel time of vehicle from gathering point or stopover point i to stopover point j includes depot) in the first echelon
Cc_{ij} Travel time of drone from stopover point i to mapping point j in the second echelon
D_i Required mapping time for capturing the area of a mapping point i
Qd_v Maximum flight time of a drone
L A sufficiently large number

Decision variables:

x_{ijv} A binary variable equals one if vehicle v is travelled from node i to j where edge $(i, j) \in E1$ Otherwise zero.
z_i A binary variable equals one if the stopover point i is visited where $i \in S$ Otherwise zero.
y_{ijk} A binary variable that equals to one if *drone* routes k is travelled from node i to j where edge $(i, j) \in E2$ Otherwise zero.
Q_j The total amount of time needed for taking pictures in a stopover point i where $i \in S$
QK_{jk} The total amount of time needed for taking pictures in a stopover point i at each route k where $i \in S$
T_{jk} The total amount of time needed for travelling in a stopover point i where $i \in S$
U_j The total amount of time needed for drone travelling in $E2$ where $j \in S_0$
a_{iv} The total accumulated amount of information gathering time has been used up to stopover point i using vehicle v where $i \in S$ and $v \in V$
b_{iv} The total accumulated amount of transportation time has been used up to mapping point i using vehicle v where $i \in C$ and $v \in V$
c_{jk} The total accumulated amount of mapping time has been used up in a stopover point j at routes k where $j \in S_0 \cup C$ and $k \in K$

Objective

$$MinZ = \sum_{i \in S} \sum_{j \in S} \sum_{v \in V} Cs_{ij} x_{ijv} + \sum_{i \in S_0 \cup C} \sum_{j \in S_0 \cup C} \sum_{k \in K} Cc_{ij} y_{ijk}$$

$$+ \sum_{j \in S_0 \cup C} \sum_{i \in C} \sum_{k \in K} D_i y_{ijk} \tag{1}$$

Subject to

$$\sum_{i \in S} \sum_{v \in V} x_{ijv} = z_j \quad \forall j \in S_0 \tag{2}$$

$$\sum_{j \in S} \sum_{v \in V} x_{ijv} = z_i \quad \forall i \in S_0 \tag{3}$$

$$\sum_{i \in S} x_{ilv} - \sum_{j \in S} x_{ljv} = 0 \quad \begin{array}{c} \forall l \in S_0 \\ \forall v \in V \end{array} \tag{4}$$

$$\sum_{j \in S_0} x_{1jv} \leq 1 \quad \forall v \in V \tag{5}$$

$$\sum_{i \in S_0} x_{i1v} \leq 1 \quad \forall v \in V \tag{6}$$

$$\sum_{j \in S_0 \cup C} \sum_{k \in K} y_{ijk} = 1 \quad \forall j \in C \tag{7}$$

$$\sum_{j \in S_0 \cup C} y_{ijk} \leq 1 \quad \begin{array}{c} \forall i \in S_0 \cup C \\ \forall k \in K \end{array} \tag{8}$$

$$\sum_{j \in S_0 \cup C} y_{jik} = \sum_{j \in S_0 \cup C} y_{ijk} \quad \begin{array}{c} \forall i \in S_0 \cup C \\ \forall k \in K \end{array} \tag{9}$$

$$\sum_{i \in S_0 \cup C} y_{ilk} - \sum_{j \in S_0 \cup C} y_{ljk} = 0 \quad \begin{array}{c} \forall l \in C \\ \forall k \in K \end{array} \tag{10}$$

$$QK_{jk} \geq c_{ik} \cdot y_{ijk} \quad \begin{array}{c} \forall j \in S_0 \\ \forall i \in C \\ \forall k \in K \end{array} \tag{11}$$

$$Q_j \geq \sum_{k \in K} QK_{jk} \quad \forall j \in S_0 \tag{12}$$

$$\sum\nolimits_{j \in S_0} Q_j = \sum\nolimits_{i \in C} D_i \tag{13}$$

$$Q_j \leq L \cdot z_j \quad \forall j \in S_0 \tag{14}$$

$$b_{ik} = 0 \quad \begin{array}{l} \forall i \in S_0 \\ \forall k \in K \end{array} \tag{15}$$

$$c_{jk} = 0 \quad \begin{array}{l} \forall j \in S_0 \\ \forall k \in K \end{array} \tag{16}$$

$$c_{jk} \geq 0 \quad \begin{array}{l} \forall j \in C \\ \forall k \in K \end{array} \tag{17}$$

$$T_{jk} \geq b_{ik} + Cc_{ij} \quad \begin{array}{l} \forall j \in S_0 \\ \forall i \in C \\ \forall k \in K \end{array} \tag{18}$$

$$U_j \geq \sum_{k \in K} T_{jk} z_j \quad \forall j \in S_0 \tag{19}$$

$$a_{iv} + Q_j - L\left(1 - x_{ijv}\right) \leq a_{jv} \quad \begin{array}{l} \forall i \in S \\ \forall j \in S_0 \\ \forall v \in V \end{array} \tag{20}$$

$$b_{ik} + Cc_{ij} - L\left(1 - y_{ijk}\right) \leq b_{jk} \quad \begin{array}{l} \forall i \in S_0 \cup C \\ \forall j \in C \\ \forall k \in K \end{array} \tag{21}$$

$$c_{ik} + D_j - L\left(1 - y_{ijk}\right) \leq c_{jk} \quad \begin{array}{l} \forall i \in S_0 \cup C \\ \forall j \in C \\ \forall k \in K \end{array} \tag{22}$$

$$\sum_{i \in S} \sum_{j \in S_0} x_{ijv}\left(Q_j + U_j\right) \leq Qd_v \quad \forall v \in V \tag{23}$$

The objective function (1) is the sum of total travel time in the first echelon, which is a motorcycle, total travel time in the second echelon, and the total duration time of recording Constraints (2) and (3) restrict the ground vehicles to visit the stopover points more than once on the first echelon. Constraint (4) aims to ensure the consecutive movement of vehicles on the first echelon. Constraints (5) and (6) ensure the ground vehicle to start and return the depot. Constraint (7) ensures that all mapping points are visited, while constraint (8) limits any mapping point to be visited only once. Constraint (9) validates the vehicle routes on the second echelon. Constraint (10) ensures the consecutive movement of the vehicles on the second echelon. Constraint (11) denotes the duration on the route k if the mapping point is visited. Constraint (12) denotes the accumulated mapping time of each mapping point at the route k. Constraint (13) signifies that the accumulated total recording time on each stopover point equals the accumulated total required to record for that area. Constraint (14) calculates each mapping point is accumulated recording time at the stopover point and indicates that the stopover point has unlimited capacity.

Constraint (15) ensures that the calculation of drones' total travelling time starts from 0. Constraint (16) ensures that the mapping duration of drones from 0 and constraint (17) shows that the operation time of mapping points of each route k can be equal to more than 0. Constraint (18) denotes the accumulation of drones' travelling time and constraint (19) calculates the total flight time of all drones from the stopover points. Constraints (20) and (21) are the sub-tour elimination of the first and second echelon, respectively. Constraint (22) signifies the validation of the mapping process. Constraint (23) limits the drones' mapping operations and flight time so it do not exceed the battery capacity.

3 Computational Study

The areas of Bekasi City which was affected by floods in January 2020 are the object research, and these are illustrated using Google Maps by marking the points of a depot (black icon), stopover points (blue icons), and the affected areas (red and orange icons). The coordinates of these places on the Google Maps are used in QGIS as inputs to measure the distances between points and then converted into travelling time with the speed of motorcycles equals 20 km/h. The illustration of the affected areas can be seen in Fig. 2.

This also applies to travelling time calculation in the second echelon. The drone used in this research is DJI Phantom 4 Pro V2.0, with a constant speed of 5.56 m/s and a maximum flight capacity of 30 min. Two batteries are used for a drone so that the maximum flight time is 60 min without considering the time needed to charge the battery. Secondary data of the affected locations were obtained from the regional disaster management agency of Bekasi City Regional Disaster Management Agency (BPBD). It is also needed to know the duration of mapping on each affected point, and this duration depends on the area. The larger the area, the more time is needed for the drone to do the mapping process. The areas of these affected places were then used to calculate the mapping duration. This duration calculation was also done by referring to research conducted by Boccardo et al. (2015) in mapping a 400 m $\times$ 400 m area, and this was done within 13 min at the altitude of 70 m. In this study, the mapping duration is assumed to be 8125×10^{-5} min/m^2 when the drone is 70 m above the ground. After calculating the travelling time on the first echelon, the drones' flight times on the second echelon and the mapping durations, these data then were categorized into eight to ten small instances. The model is verified using AMPL with the computer specifications as an Intel® Core ™ i7-7500U processor with 8 GB RAM and a 64-bit operating system.

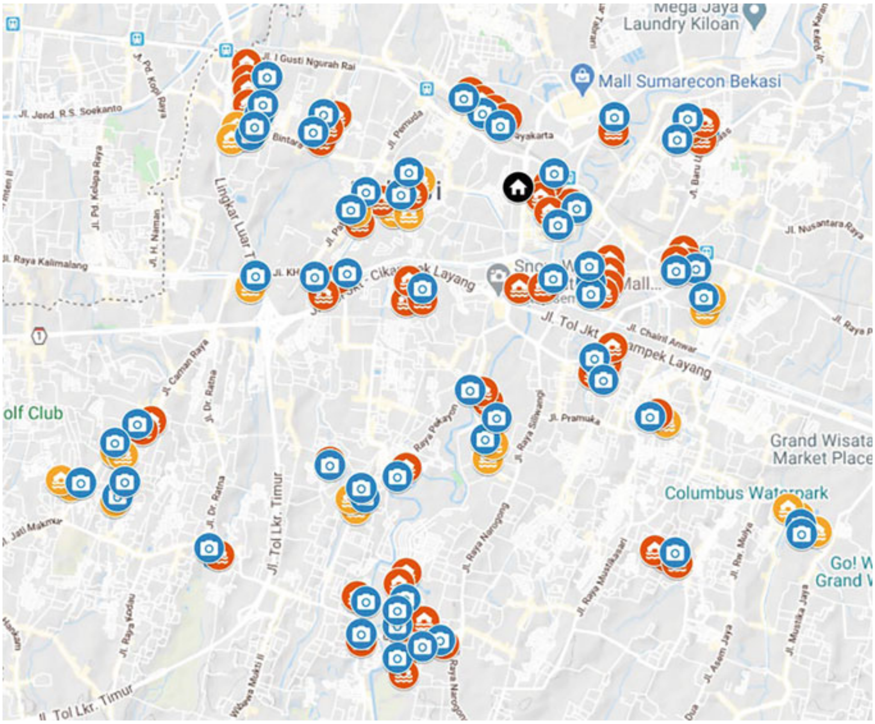

Fig. 2 Flood affected areas in Bekasi City, January 2020

4 Discussion

The computational results can be seen in Table 1. The results shown a feasible result with all drones utilize to visits all mapping points. The results show that the problem can be solved using 2ECOVRP-MOD with the objective value of mapping time from 19 to 48 min. The solution can be obtained with a computational time from 0.25 to 1.2 s. This result is considerably efficient in terms of obtaining the optimal solution. Furthermore, the detailed route can be seen in Table 2. However, due to the small size of the instance being used, there is a need to further investigate in a larger size instance.

5 Conclusion

This study proposes an integer linear programming model for ground vehicles and drones to conduct mapping operations in the post-disaster situation denoted as 2ECOVRP-MOD (Two Echelon Cooperated Vehicle Routing Problem—Mapping

Table 1 The computational results

Data	Stopover point	Mapping point	Objective value (min)	Solve time (s)
Small 1	2	7	19,851	0.20313
Small 2	3	8	35,167	0.29688
Small 3	3	8	30,32	0.25
Small 4	3	8	39,074	1.01562
Small 5	3	10	29,371	1.1875
Small 6	2	7	25,782	0.25
Small 7	3	8	31,136	0.35938
Small 8	2	9	36,457	0.34375
Small 9	2	10	38,632	0.29688
Small 10	2	6	23,23	0.15625
Small 11	2	7	22,797	0.328125
Small 12	2	7	33,606	0.140625
Small 13	3	10	46,964	0.703125
Small 14	2	10	40,637	0.546875
Small 15	3	10	48,22	0.5625
Small 16	2	8	19,872	0.34375
Small 17	3	8	25,336	0.25

Table 2 The detailed routes

Data	1st echelon routes	2nd echelon routes	Total routes
Small 1	1–3, 3–1	3–6-7–5-4–3	1–3-6–7–5–4-3–1
Small 2	1–4, 4–1	4–7-8–5-6–4	1–4-7–8-5–6-4–1
Small 3	1–4, 4–1	4–6-5–8-7–4	1–4-6–5-8–7-4–1
Small 4	1–4, 4–1	4–8-6–7-5–4	1–4-8–6-7–5-4–1
Small 5	1–2, 2–1	2–10-8–9-5–7-6–2	1–2-10–8-9–5-7–6-2–1
Small 6	1–3, 3–1	3–6-5–4-7–3	1–3-6–5-4–7-3–1
Small 7	1–3, 3–1	3–6-8–4-5–7-3	1–3-6–8-4–5-7–3-1
Small 8	1–3, 3–1	3–4-9–7-8–6-5–3	1–3-4–9-7–8-6–5-3–1
Small 9	1–2, 2–1	2–7-8–9-10–4-6–5-2	1–2-7–8-9–10-4–6-5–2-1
Small 10	1–2, 2–1	2–5-6–4-2	1–2-5–6-4–2-1
Small 11	1–2, 2–1	2–4-5–6-7–2	1–2-4–5-6–7-2–1
Small 12	1–2, 2–1	2–7-5–6-4–2	1–2-7–5-6–4-2–1
Small 13	1–2, 2–3, 3–1	2–6-7–8-9–5-2, 3–10-3	1–2-6–7-8–9-5–2-3–10-3–1
Small 14	1–2, 2–1	2–8-9–7-10–6-5–4-2	1–2-8–9-7–10-6–5-4–2-1
Small 15	1–3, 3–1	3–5-10–9-8–7-6–3	1–3-5–10-9–8-7–6-3–1
Small 16	1–3, 3–1	3–8-7–6-4–3	1–3-8–7-6–4-3–1
Small 17	1–2, 2–1	2–7-8–5-4–6-2	1–2-7–8-5–4-6–2-1

Operation with Drone). The model is applied to solving a mapping operation in a real case of flood disaster mapping in Bekasi, Indonesia. It is shown that the model can be effectively used to provide an optimal solution for small size data. However, further investigation is needed to verify the model's ability to solve a larger data size. Further research needs to investigate the possibility of using cruise speed optimization to get the best result among different cruise speeds. Moreover, the application of heuristics or meta-heuristics approaches enables finding a solution for more significant size instances of as 2ECOVRP-MOD is needed.

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References

Boccardo P, Chiabrando F, Dutto F, Tonolo F, Lingua A (2015) UAV deployment exercise for mapping purposes: evaluation of emergency response applications. Sensors 15(7):15717–15737. https://doi.org/10.3390/s150715717

Crainic TG, Perboli G, Mancini S, Tadei R (2010) Two-echelon vehicle routing problem: a satellite location analysis. Proc Soc Behav Sci 2(3):5944–5955

Das K, Lashkari RS, Biswas N (2013) Disaster assessment and mitigation planning: a humanitarian logistics based approach. Ind Eng Manag Syst 12(4):336–350

Djalante R, Garschagen M, Thomalla F, Shaw R (2017) Introduction: disaster risk reduction in Indonesia: progress, challenges, and issues. In: Disaster risk reduction in Indonesia. Springer, pp 1–17

Kerle N, Oppenheimer C (2002) Satellite remote sensing as a tool in Lahar disaster management. Disasters 26(2):140–160. https://doi.org/10.1111/1467-7717.00197

Kitjacharoenchai P, Min B-C, Lee S (2020) Two echelon vehicle routing problem with drones in last mile delivery. Int J Prod Econ 225:107598. https://doi.org/10.1016/j.ijpe.2019.107598

Liperda RI, Pewira Redi AAN, Sekaringtyas NN, Astiana HB, Sopha BM, Maria Sri Asih A (2020) Simulated annealing algorithm performance on two-echelon vehicle routing problem-mapping operation with drones. In: IEEE international conference on industrial engineering and engineering management. https://doi.org/10.1109/IEEM45057.2020.9309923

Marinelli M, Caggiani L, Ottomanelli M, Dell'Orco M (2018) En route truck–drone parcel delivery for optimal vehicle routing strategies. IET Intel Transport Syst 12(4):253–261

Murray CC, Chu AG (2015) The flying sidekick traveling salesman problem: optimization of drone-assisted parcel delivery. Transp Res Part C Emerg Technol 54:86–109

Office for the Coordination of Humanitarian Affairs (OCHA) (2014) Unmanned aerial vehicles in humanitarian response

Sarma D, Das A, Bera UK (2020) Uncertain demand estimation with optimization of time and cost using Facebook disaster map in emergency relief operation. Appl Soft Comput 87:105992

WHO (2002) Disasters & emergencies; definitions training package. In: WHO/EHA training package (Issue March). http://apps.who.int/disasters/repo/7656.pdf

Zulkipli MA, Tahar KN (2018) Multirotor UAV-based photogrammetric mapping for road design. Int J Opt 2018:1–7. https://doi.org/10.1155/2018/1871058

A Relief Aids Distribution Model for the Pre-cooked Meals: The Case of the Probable Disasater During Fasting Periods in Padang City, Indonesia

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1 Introduction

Disaster phenomena are increasingly recognized as a serious considerable concern due to their tremendous effects on societies and environments. Among several types of disasters, the tsunami is known as the sudden-onset natural disaster characterized by its massive impacts. From 1992 to 2016, there are at least 290 tsunamis occurrences registered (Gusiakov et al. 2019). During this 25-year period, the 2004 Indian Ocean tsunami was acknowledged to be one of the deadliest catastrophes in history. In Indonesia alone, this trans-oceanic mega-tsunami has led to 221,000 people death or missing, half of million people being affected, as well as damages to infrastructures and surroundings (Ali et al. 2019). The hazards with a similar potential magnitude that may take place in the future must be recognized as an essential issue in order to minimize the possible consequences of the upcoming calamities.

The severities and complexities carried out by a disaster substantially require a thorough deliberation in enhancing the capability of the disaster countermeasure. In order to come up with the effects of this casualty, disaster management is widely

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known as the fundamental strategy for providing decent assistance to the beneficiaries. Disaster management mainly consists of four stages including mitigation, preparation, response and recovery (Altay and Green III 2006). The mitigation stage involves the efforts of either preventing or reducing the impacts of the disaster onset. Meanwhile in the preparedness stage, the community is prepared to respond when a disaster occurs. In the response stage, the activities of resources' employment as well as the implementation of the emergency procedures are performed to preserve lives, properties, the environments, and the socio-economic structures of the community. Subsequently, the recovery stage implicates the long-term activities aiming to facilitate the community to recover from a disaster.

In humanitarian operations, the level of preparedness significantly affects to the effectiveness of relief response (Van Wassenhove 2006). The preparedness strategies must be comprehensively managed to provide a successful response since the lack of preparation may result with delays and losses in the response stage. During the preparedness stage, the process of organizing effective humanitarian logistics decisions to be applied in the response stage is crucial. With regards to its vital role in assisting about 80% of the disaster relief activities (Van Wassenhove 2006), humanitarian logistics has been thought of as a key factor in determining the successful or failed operations.

The central issue arising at the relief logistics operations is to ensure that the beneficiaries' basic needs are sufficiently fulfilled during the initial response, particularly in the first 72 h after the disaster occurrence. Within these periods, an adequate amount of relief aids must be distributed to the demand points in a timely moment (Ahmadi et al. 2015). The decisions on the relief delivery must take into account the trade-offs between the increment of the required demands over the planning periods (Inca and Nikorn 2019) and the scarce availability of resources in the first 72 h of the emergency periods. The other problems related to network failures are also critical to be addressed in defining the appropriate relief distribution decisions (Ahmadi et al. 2015). Another constraint regarding the foods that are being delivered during these crucial periods must be taken into deliberation since it is very difficult, if not impossible, to establish a kitchen facility that can serve the meals to the recipients. Delivering the pre-cooked meals becomes a feasible alternative so that the recipients can consume them directly after their arrival. Furthermore, particularly in the majority of Muslim-populated countries, the disaster that occurs in the fasting periods may lead to another distinctive challenge in the relief delivery efforts. In the fasting periods, Muslims are obligated to eat or drink only between sunset and dawn (Azizi 2002). The emerging challenge regarding the relief aids delivery during these periods is to send the relief foods within the specified duration in order to keep the freshness of the foods as well as to ensure that the beneficiaries receive the basic needs at the right time with the right amount of aids.

This research intends to develop a multi-period multi-trip relief delivery for a two-tier relief distribution network in order to distribute the pre-cooked meals by taking into account the possibility of disaster occurrence during the fasting periods. This research addresses several substantial considerations: (1) the distinctive demands throughout the first 72 h of emergency periods, (2) the scarcity of relief vehicles, (3) the expected network failures and (4) the specified delivery duration. In this work, the expected network failures due to the effects of the disaster impacts are modelled in the Geographic Information Systems (GIS) environment to obtain the expected passable roads to be further utilized in the optimization process. A Mixed Integer Linear Programming (MILP) model is then proposed to minimize the transportation costs regarding the routing decisions as well as the lateness and the shortage penalty costs due to the late-satisfied and unsatisfied fulfilment. A case study of the predicted upcoming hazard Mentawai Megathrust in Padang City, Indonesia is used to demonstrate the numerical experiments of our model.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literatures related to the intended problem. Section 3 presents the problem description and model development. Section 4 provides the observed case study. Section 5 presents the computational results and analyses. Section 6 presents the conclusions obtained from this research.

2 Literature Review

In recent years, a number of studies have sought to formulate the distribution models related to the relief aids fulfilment in the post-disaster aftermath. Tzeng et al., conducted a fuzzy multi-objective programming model for minimizing the total costs and maximizing the minimal satisfaction level in relief distribution (Tzeng et al. 2007). Balcik et al., formulated the last mile distribution model for distributing the emergency relief supplies in order to minimize the transportation costs and maximizing benefits to the beneficiaries (Balcik et al. 2008). A two-stage vehicle routing model for both the planning stage and operational stage is proposed by Shen et al. (2009). In their research, the mathematical formulation for both stages is used to solve the large-scale bioterrorism case. Liberatore et al., concerned on the damaged distribution infrastructures to generate the delivery planning of the emergency goods in the aftermath of a disaster (Liberatore et al. 2014). Ahmadi et al., developed a multi-depot location-routing problem by taking into account the probability of network failures, the use of multiple vehicles and the consideration to standard relief time in the last mile distribution (Ahmadi et al. 2015). Patrisina et al., considered a three-tier relief distribution network including warehouses, local distribution centres, and refugee camps to propose a two-stage programming model applied in the humanitarian operations (Patrisina et al. 2018). Maghfiroh and Hanaoka presented multi-modal transportation with multi-trip delivery for the three-tier relief chain in the disaster response (Maghfiroh and Hanaoka 2020). By considering the condition of network infrastructures and accessibility of supplies and modes of transport, their work determined the location of the logistics operational areas as well as the assigned modes of transport along with its allocated loaded amount over the planning horizon. Mahtab et al., proposed a decision model for pre-disaster and post-disaster events which is multi-objective stochastic programming applied to a case study of flood in Bangladesh. The results of the model can support optimal resource allocation in humanitarian logistics. Sources of uncertainty in the model were considered such as demand, node reachability under a specific mode of transport, etc. The model solutions provide the location of temporary facilities, the amount of commodity to be prepared, the distribution schedules with the dispatched vehicles (Mahtab et al. 2021). Nezhadroshan et al., designed a humanitarian logistics network integrating multiple central warehouses with local distribution centers based on a probabilistic-stochastic programming approach. Their model was intended to be robust and resilient. It guarantees the delivery of the crucial supplies to the beneficiaries under both operational and disruptive risks. The proposed model was focused on the transportation network's routes after an earthquake which took a real case study of Mazandaran province in the north of Iran to validate the model (Nezhadroshan et al. 2021). Boostani et al., proposed a sustainable relief logistics network model under the strategic and tactical levels. The model describes a three-tier chain network in the pre-disaster and post-disaster phases, focusing on facility location, procurement, and resource allocation. It was designed as a multi-objective mixed-integer stochastic programming model with minimizing the total costs of the relief supply chain, maximizing the social welfare, and minimizing the environmental impacts. Two solution methods, which are the Compromise Programming (CP) technique and Lexicographic Optimization Method (LOM), were compared under two numerical examples based on surveying data of probable Tehran earthquakes (Boostani et al. 2021). Shiripour et al., conducted an empirical study of the earthquakes in the city of Tehran, Iran. They devised the integrated mathematical model of the casualties' transportation to uncover the temporary locations of aid stations and their capacities, the percentage of the casualties under various severities allocated to each station, as well, to discover the different routes and the number of vehicles in order to minimize the total relief time. An approach, called the circle-based approach, was developed and solved by an evolutionary algorithm based on simulated annealing and a discrete version of the imperialist competitive algorithm (Shiripour and Mahdavi-Amiri 2021). Garcia-Alviz et al., purposely studied the performance of post-disaster relief operations under the transportation networks disruption. They aimed to propose the strategic plans which can aid the victims promptly. The occurrence of heterogeneous types of roads disruptions was incorporated into the mathematical model with coordinating road network restoration and relief activities. The objective of the developed model was to acquire a restoration plan supporting the relief operations under the set of scheduling, routing restoration machines, and relief vehicles. The heuristic algorithm was built and applied with a realistic case study of flooding in the Mojana region of northern Colombia in 2010–2011 (García-Alviz et al. 2021). Moddassir et al., proposed a robust optimization model to enclose the uncertainty situations in the relief distribution centers (RDCs), mainly are RDCs' capacity and relief demand. The key idea in the study was focused on the occurrence of the second disaster which is relatively in time and location with the first disaster. It can result in more misery to the victims and more difficulties to the relief distribution. The proposed model to minimize the total transportation cost, additional RDC cost, and shortage of commodities were formulated and solved, effectively. Also, the sensitivity analysis was performed to support an insightful decision (Nayeem and Lee 2021). Zhang et al., constructed a distribution relief model by proposing a sustainable last mile relief network concentrating on three perspectives which are social factors, disaster relief efficiency, and the economic cost. A multi-objective model was formulated to maximize the fair supplies distribution and to minimize the transportation time and operating cost. Uncertainties in the model are including the disaster situation, transportation time, freight, road capacity, and demand. These uncertainty variables were considered as an ambiguity set incorporating the bounds, means, and mean absolute deviations. With the solution method of a revised multi-choice goal programming, the answer were attained and verified with a case study of the Banten tsunami (Zhang et al. 2022).

3 Problem Description and Model Development

This section firstly describes the problem description of the observed system. Afterward, we present the modelling approach as well as the mathematical formulation.

This research addresses a two-tier relief distribution network consisting of a permanent warehouse and its associated demand points whereas a warehouse is allowed to deliver the relief items to a number of demand points. We consider the variation of demand requirements over the first 72 h of the initial response phase to obtain the appropriate relief delivery decisions. In particular, this work deliberates the essential conditions related to the delivery duration in the fasting periods regarding the pre-cooked meals distribution, as shown in Fig. 1. During the fasting periods, the recipients are allowed to have a meal after sunset, which is further defined as the delivery targeted time. The process of delivery will be started before the targeted time. However, late-delivery that exceeds the targeted time is permitted by adding an additional lateness penalty reflecting the recipients' suffering time to wait for the late-arrival delivery. In order to keep the freshness of the foods on its arrival, the late delivery is only allowed to be performed within a specific duration. The shortage penalty will be charged if the available vehicles are not able to fulfil the demand needs during the assigned duration. With regards to the possibility of road disruptions, the GIS environment is employed to generate safe candidate routes that avoid the expected damaged roads. Furthermore, this study takes into account the scarcity of the available vehicles in the post-disaster occurrence by allowing the vehicles to perform multi-trip delivery according to their allocated capacities during the assigned duration in each day of emergency periods. In summary, the operational decisions related to the intended problem involve: (1) the number of pre-cooked meals to be delivered to each demand point, (2) the vehicle routing and (3) the number of the assigned vehicles along with their allocated trips.

The modelling approach encompassed in this research consists of three phases, which is basically modified from the work of (Balcik et al. 2008), as shown in Fig. 2. Phase 1 is intended to generate the travel time and distance matrix of each location by considering the avoidance of the undesired road networks by utilizing GIS environment. Next, the determination of the possible delivery routes including the cost and duration for each vehicle along with the demand points visited by each

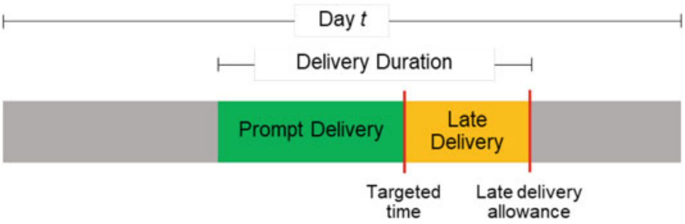

Fig. 1 Illustration of delivery duration

route is enumerated in Phase 2. Finally, the optimization process is employed in Phase 3 to obtain the daily delivery routing including the assigned vehicles along with their associated trips and the daily delivered amount to be sent to each demand points.

The proposed model regarding the relief aids distribution is presented in the following notations:

Sets

T set of days in the planning horizon
K set of vehicles
R set of route candidates
H set of trips
N set of demand locations
N set of demand locations visited on route $r \in R$

iments of the case study.

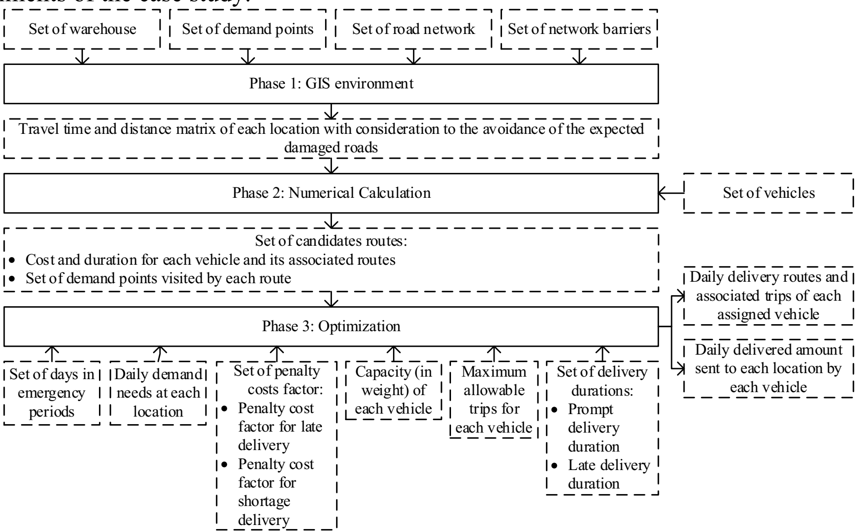

Fig. 2 Modelling approach

Routing Parameters

c_{rk} cost of route $r \in R$ for vehicle $k \in K$
q_k capacity of vehicle $k \in K$ (weight)
E_{rk} travel time (in hour) required by vehicle $k \in K$ to use route $r \in R$
F duration allowance (in hour) to perform prompt delivery
G delivery duration span (in hour)

Demand parameters

d_i^t demand required (in weight) by location $i \in N$ on day $t \in T$
P penalty cost factor for late delivery.
U penalty cost factor for unsatisfied fulfilment

Routing decision variables

$$X_{rhk}^t = \begin{cases} 1 \; if \; router \in R \, is \, visited \, by \, vehicle \, k \in K \, using \, trip \, h \in H \, on \, period \, t \in T \\ 0 \qquad otherwise \end{cases}$$

Lateness decision variables

$$A_k^t = \begin{cases} 1 \; if \; \sum_{r \in R} \sum_{h \in H} X_{rhk}^t E_{rk} \leq F \\ 0 \; otherwise \end{cases}$$

Delivery decision variables

Y_{irhk}^t amount of demand delivered to location $i \in N$ by vehicle $k \in K$ using route $r \in R$ on trip $h \in H$ on day $t \in T$
L_k^t penalty cost associated with the late delivery using vehicle $k \in K$ on day $t \in T$
S_i^t penalty cost associated with the unsatisfied fulfilment at location $i \in N$ on day $t \in T$
B_i^t fraction of unsatisfied demand at location $i \in N$ on day $t \in T$

Objective function

$$Minimize \, Z = \sum_{r \in R} \sum_{h \in H} \sum_{t \in T} \sum_{k \in K} c_{rk} X_{rhk}^t + \sum_{t \in T} \sum_{k \in K} L_k^t + \sum_{i \in I} \sum_{t \in T} S_i^t \tag{1}$$

Constraints

$$L_k^t = PA_k^t \left(\left(\sum_{r \in R} \sum_{h \in H} X_{rhk}^t E_{rk} \right) - F \right) \qquad \forall t \in T, k \in K \tag{2}$$

$$\sum_{r \in R} \sum_{h \in H} X_{rhk}^t E_{rk} \leq G \qquad \forall t \in T, k \in K \tag{3}$$

$$S_i^t = UB_i^t \qquad \forall i \in N, t \in T \tag{4}$$

$$B_i^t = \left(d_i^t - \sum_{r:i \in N(r)} \sum_{h \in H} \sum_{k \in k} Y_{irhk}^t \right) / \left(d_i^t \right) \qquad \forall i \in N, t \in T \tag{5}$$

$$\sum_{r:i \in N(r)} \sum_{h \in H} \sum_{k \in K} Y_{irhk}^t \leq d_i^t \qquad \forall i \in N, t \in T \tag{6}$$

$$\sum_{i \in N(r)} Y_{irhk}^t \leq q_k X_{rhk}^t \qquad \forall r \in R, h \in H, t \in T, k \in K \tag{7}$$

$$0 \leq B_i^t \leq 1 \qquad \forall i \in N, t \in T \tag{8}$$

$$Y_{irhk}^t \geq 0 \qquad \forall i \in N, r \in R, h \in H, t \in T, k \in K \tag{9}$$

$$x_{rhk}^t \in \{0, 1\} \qquad \forall r \in R, h \in H, t \in T, k \in K \tag{10}$$

$$A_k^t \in \{0, 1\} \qquad \forall t \in T, k \in K \tag{11}$$

The objective function (1) aims to minimize total routing cost, total lateness penalty cost and total shortage cost over the planning periods. Constraint (2) defines the lateness penalty cost due to the late delivery performed by each vehicle on each day. Constraint (3) guarantees that the total travel time of each assigned vehicle on each day does not exceed the delivery duration. Constraint (4) determines shortage penalty cost regarding the unsatisfied fulfilment at each location on each day. Constraint (5) deliberates the fraction of the unsatisfied fulfilment for each location on each day. Constraint (6) ensures that the total amount of items delivered is less or equal to the required demand in each location on each day. The vehicle capacity constraint is defined in Constraint (7). Constraint (8) guarantees that the fraction of unsatisfied fulfilment is between zero and one. Constraint (9) is the non-negativity constraint. Constraint (10) and (11) define the binary value of the routing variable and the lateness delivery variable, respectively.

The proposed model however consists of non-linear formula particularly in the lateness decision variables. A linearization technique suggested in the optimization tool is employed by converting the non-linear function to a series of linear, mathematically equivalent expression (Lindo, 2020). The resulted Mixed Integer Linear Programming (MILP) model is then used to solve the computational experiments of the case study.

In order to solve the proposed MILP model, the Branch and Boundary Algorithm is employed. This algorithm is widely known for its efficiency to generate the exact solutions of the non-convex and combinatorial problems that cannot be solved in polynomial time (Huang et al. 2021). Prior to commencing the investigation, the problems are iteratively split into smaller sub-problems by creating a search tree. The divide-and-conquer algorithm is implemented by removing the integral conditions of a problem to compute the linear programming (LP) relaxation.

4 The Case Study

This research takes into account the case study of the probable hazard Mentawai Megathrust in Indonesia to demonstrate the effectiveness of our modelling approach. The predicted ruptures that may suddenly displace along the Megathrust faults are expected to generate great earthquakes triggering a large volume of tsunami waves (Sieh 2006). Padang is becoming the most threatened area due to its flat topography and the high population living in this city (Liperda et al. 2021). In this study, a two-tier relief distribution network is deliberated by allowing direct delivery from a warehouse to its demand points. Table 1 represents the location of each node as well as the required demands over the three days of emergency periods. The demand needs are calculated based on the expected arrival of the refugees in each day referring to the recent contingency planning data developed by the West Sumatra's local authority for disaster countermeasure (BPBD Kota Padang 2017). This research assumes that a refugee will require a package of pre-cooked meals with an associated weight of 0.59 kg.

This work considers four developed scenarios according to the substantive conditions in the real-world case study, as depicted in Table 2. With regards to the scarce availability of the vehicles that is common in the post-disaster occurrence, this study takes into account the use of the limited number of vehicles with multiple trips allowance to perform an efficient delivery. The set of homogenous vehicles is represented in scenarios 1 and 3 while the set of heterogeneous vehicles is defined in scenarios 2 and 4, respectively. In addition, this work presumes that the worth consuming span of the pre-cooked meals is five hours. This assumption is adopted to restrict the delivery duration allowance in order to ensure that the beneficiaries receive

Table 1 Location of depot and demand points

ID	Locations	Latitude	Longitude	Demand Requirements (ton)		
				Day 1	Day 2	Day 3
Depot						
0	UPT BNPB Pusdalops PB	−0.953111	100.428493	–	–	–
Demand points						
1	Sungai Sapih	−0.902755	100.39697	9.43	14.34	18.38
2	Kubu Marapalam	−0.950678	100.383768	25.22	43.91	59.32
3	Ship Loading Point	−0.961905	100.39454	1.92	5.78	8.96
4	Banuaran nan XX	−0.968938	100.384775	5.32	14.81	22.64
Total				41.89	78.84	109.3

Table 2 Developed scenarios

Scenario	Vehicle, capacity		Max trips	Delivery duration (hr)	Duration of prompt delivery (hr)	Duration of late delivery (hr)	Penalty Cost factor for late delivery ($/hr)	Penalty cost factor for unsatisfied fulfilment ($/% of unsatisfied
	6 Wheel	4 Wheel						
1	3 (6 ton)	0	4	5	2	3	10	1000
2	3 (6 ton)	1 (4 ton)	4	5	2	3	10	1000
3	3 (6 ton)	0	4	5	4	1	10	1000
4	3 (6 ton)	1 (4 ton)	4	5	4	1	10	1000

decent-consumable meals. Moreover, different sets of the prompt delivery allowance are investigated in this work by setting up the different values for the prompt delivery span. Ultimately, the criticality between the late-satisfied and unsatisfied fulfilment is interpreted by the discrepancy of the penalty amount charged.

5 Computational Results and Analyses

This section demonstrates the computational results and analyses of the observed case study. The route candidates are firstly determined by considering the expected network failures. Next, the optimization tool is employed to generate the routing assignments based on the developed scenarios. Subsequently, the trade-offs between the obtained solutions and the late-satisfied as well as unsatisfied fulfilment are described to show how the components of the problem affect the routing decisions. In this work, the computer specifications utilized to obtain both GIS-based analysis and optimization solutions are CPU core i5 with 4 GB of RAM.

The depiction of the Origin–Destination Matrix by considering the expected network failures is mapped in Fig. 4. This work utilizes ArcMap 10.2 to obtain the straight-line representation of the OD Matrix in Padang City. The Network Analyst Extension in ArcMap 10.2 is employed to conduct the least-distance measurements between multiple nodes using Dijkstra's Algorithm. As illustrated in Fig. 3, OD matrix analyst allows users to specify the number of origins and destinations to be measured by including several intended constraints and parameters such as the restricted road to be avoided during delivery activities. The route candidates are then generated by taking into account the travel time for each candidate as well as the distribution cost for each vehicle type, as shown in Table 3. As indicated in Table 3, we restrict the number of route candidates to nine candidates in order to decrease the computational time in the optimization phase by limiting the total travel time. However, further investigation may be carried out by considering all of the feasible candidates.

The optimization phase of the proposed model is performed by utilizing LINGO 18.0 that employs the branch-and-bound algorithm to generate the optimization results. The proposed MILP model of each developed scenario results with the global optimal solutions. Table 4 presents the results of the routing decisions as well as the number of delivered items for each test problem over the three days of emergency periods. In each scenario, the model primarily chooses the full truckload shipment to maximize the assigned capacity constraints. From Table 4, it is observed that the daily routing assignments are immensely affected by the increment of the demand requirements over the three days of emergency periods. Further analysis shows that the multi-trip delivery assignments are essential to be applied in the emergency periods to come up with the scarce availability of vehicles. Consequently, the report on the total costs of the associated test problems is presented in Table 5. With regards to the model objective for minimizing the sum of total costs, Table 5 reveals that

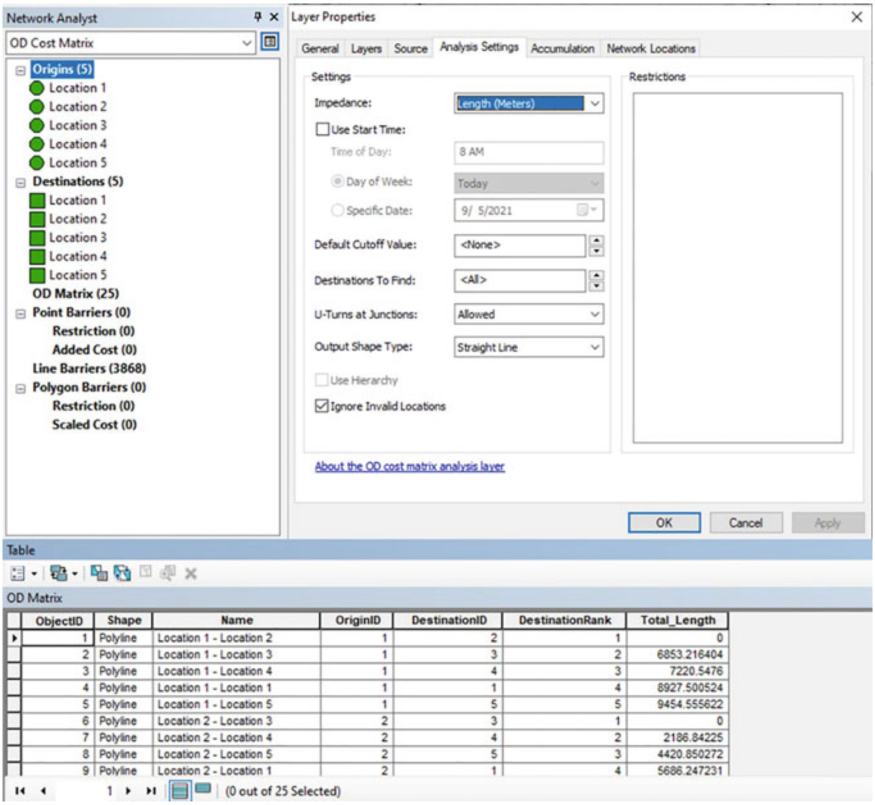

Fig. 3 Illustration of Network Analyst Interface

Fig. 4 OD Matrix Representation by Considering Expected Damaged Roads

Table 3 Route candidates

Route candidates	Tours	Travel time (hr)	Cost ($)	
			6 Wheel	4 Wheel
R1	0, 1, 0	0.95	9	8
R2	0, 2, 0	0.78	8	8
R3	0, 3, 0	0.82	8	8
R4	0, 4, 0	0.71	8	7
R5	0, 1, 2, 0	1.29	13	12
R6	0, 1, 3, 0	1.37	13	12
R7	0, 1, 4, 0	1.26	12	12
R8	0, 2, 3, 0	1.16	12	11
R9	0, 2, 4, 0	1.05	11	11

the optimal solutions are achieved by balancing the late-delivery penalty costs, the shortage penalty costs and routing costs. These relative values changes accordingly with the changes of the input parameters. As presented in Table 5, it is observed that scenario 4 result with the least total costs. Moreover, this scenario gives us the least penalty costs regarding the late-delivery and unsatisfied fulfilment. Due to the dynamic and uncertain circumstances that might occur in the disaster aftermath, the solutions may turn into different possible outcomes.

Table 4 Routing assignments and amount of delivered items

Vehicle	Assigned route	Trip	Amount delivered in day 1 (ton)			
			Node 1	Node 2	Node 3	Node 4
Scenario 1						
6 Wheel A	R1	1	6			
	R9	1		3.14		2.86
6 Wheel B	R8	1		4.08	1.92	
	R2	2		6		
6 Wheel C	R7	1	3.43			2.46
	R2	1		6		
Scenario 2						
6 Wheel A	R2	1		6		
	R4	1				5.32
6 Wheel B	R1	1	6			
	R2	1		6		
6 Wheel C	R8	1		4.08	1.92	
	R2	1		6		
4 Wheel A	R1	1	3.43			
	R2	1		3.14		
Scenario 3						
6 Wheel A	R1	1	6			
	R8	1		4.08	1.92	
	R2	1		6		
6 Wheel B	R2	1		5.89		
	R9	1		3.25		2.75
	R7	1	3.43			2.57
6 Wheel C	R2	1		6		
Scenario 4						
6 Wheel A	R8	1		4.08	1.92	
	R7	1	3.43			2.57
6 Wheel B	R1	1	6			
	R9	1		3.25		2.75
6 Wheel C	R2	2		6		

(continued)

The detailed information on the lateness and shortage percentage values as well as the amount of relief aids delivered for the developed scenarios are presented in Table 6 and Table 7, respectively. The lateness time is acknowledged when the total routing time exceeds the prompt delivery limit in order to delineate the refugees' suffering time waiting for the late-arrival delivery. Meanwhile, the shortage percentage values

Table 4 (continued)

Vehicle	Assigned route	Trip	Amount delivered in day 1 (ton)			
			Node 1	Node 2	Node 3	Node 4
	R2	1		5.89		
Vehicle	Assigned route	Trip	Amount delivered in day 2 (ton)			
			Node 1	Node 2	Node 3	Node 4
Scenario 1						
6 Wheel A	R2	3		6		
	R3	1			5.78	
6 Wheel B	R1	1	6			
	R2	2		6		
	R4	2				6
6 Wheel C	R1	1	2.34			
	R1	1	6			
	R2	1		4.72		
	R2	1		6		
	R9	1		3.19		2.81
Scenario 2						
6 Wheel A	R1	2	6			
	R2	1		6		
6 Wheel B	R2	3		6		
	R3	1			5.78	
	R4	1				6
6 Wheel C	R2	3		6		
	R4	1				6
4 Wheel A	R5	1	2.34	1.66		
	R4	1				2.81
Scenario 3						
6 Wheel A	R2	4		6		
	R3	1			5.78	
6 Wheel B	R2	2		6		
	R2	1		5.29		
	R4	2				6
6 Wheel C	R1	2	6			
	R1	1	2.34			
	R9	1		2.62		2.81

(continued)

Table 4 (continued)

Vehicle	Assigned route	Trip	Amount delivered in day 2 (ton)			
			Node 1	Node 2	Node 3	Node 4
Scenario 4						
6 Wheel A	R1	1	6			
	R2	1		6		
	R9	1		3.19		2.81
	R3	1			5.78	
6 Wheel B	R1	1	6			
	R2	2		6		
	R4	2		6		
6 Wheel C	R2	3		6		
	R2	1		4.72		
4 Wheel A	R1	1	2.34			
Vehicle	Assigned route	Trip	Amount delivered in day 3 (ton)			
			Node 1	Node 2	Node 3	Node 4
Scenario 1						
6 Wheel A	R1	1	6			
	R2	4		6		
	R3	1			6	
6 Wheel B	R8	1		3.04	2.96	
	R2	2		6		
	R4	1				4.64
	R4	2				6
6 Wheel C	R1	2	6			
	R2	3		6		
	R4	1				6
Scenario 2						
6 Wheel A	R2	4		6		
	R9	1		5.32		0.68
	R3	1			6	
6 Wheel B	R1	1	5.34			
	R1	1	6			
	R2	2		6		
	R4	1				6
6 Wheel C	R1	1	6			
	R2	3		6		
	R4	2				6
4 Wheel A	R4	1				3.96
	R6	1	1.04		2.96	

(continued)

Table 4 (continued)

Vehicle	Assigned route	Trip	Amount delivered in day 3 (ton)			
			Node 1	Node 2	Node 3	Node 4
Scenario 3						
6 Wheel A	R8	1		3.04	2.96	
	R2	2		6		
	R4	3				6
6 Wheel B	R1	2	6			
	R2	3		6		
	R4	1				4.64
6 Wheel C	R1	1	6			
	R2	4		6		
	R3	1			6	
Scenario 4						
6 Wheel A	R1	1	6			
	R2	3		6		
	R4	1				6
6 Wheel B	R2	4		6		
	R4	2				6
6 Wheel C	R1	1	6			
	R2	2		6		
	R2	1		5.32		
	R4	1				4.64
4 Wheel A	R1	1	4			
	R3	1			3.34	
	R3	1			4	
	R6	1	2.38		1.62	

Table 5 Total costs

Scenario	Total cost ($)	Transportation cost ($)	Penalty cost of late delivery ($)	Penalty cost of unsatisfied fulfilment ($)
Scenario 1	546.61	337	150.50	59.11
Scenario 2	468.19	347	115.50	5.69
Scenario 3	423.01	337	26.90	59.11
Scenario 4	356.40	351	5.40	0

are yielded as a result of the insufficient fulfilment regarding the lack of capability in delivering the required amount of the relief items within the given duration limit. The relative values of the penalty cost factor charged for both late satisfied and unsatisfied fulfilment emphasize the criticality between these decisions. As a consequence, the model will prioritize the late-delivery rather than the shortage fulfilment. However, we should notify that the late-satisfied and unsatisfied degrees regarding the victims' suffering are difficult to be quantified into the real costs. A further study with more focus on investigating the vulnerabilities of the disaster victims particularly in the immediate aftermath of a disaster is therefore suggested.

Table 8 shows the solution statistics for each scenario using LINGO 18.0. As shown in Table 8, scenario 4 results with the longest run time to generate the global optimal solutions. It can be implied from these results that the scale of the model as well as the components of the problems obviously affect the computational time. In addition, the computer specifications used in this research may also lead to the length of the required running time. With regards to its classification as an *NP-hard* problem, this is becoming an important issue for future research to provide a practical methodology in order to effectively solve the larger instances within reasonable computational time.

6 Conclusions

This paper was aimed to develop the analytical approach for a multi-period multi-trip relief delivery for optimizing routing decisions for distributing the pre-cooked meals during fasting periods. This study has shown that the proposed modelling approach has the capability to be applied in the humanitarian logistics operations by enabling the relief stakeholders to address several substantial issues of the real-world problems. Several noteworthy contributions of this paper are considering the distinct demand requirements over the planning horizon, utilization of the scarce resources, avoidance of expected network failures and limited delivery duration. In this study, GIS environment was employed to the generate the expected passable roads between each node by considering the possible network failures. Furthermore, the MILP model was developed to minimize the total transportation cost as well as the late-satisfied and unsatisfied fulfilment. The computational results of the case study Mentawai Megathrust hazard in Padang City, Indonesia was used to highlight the relationship between various decisions with the changes in the model parameters. The findings in this report are subject to at least three limitations. First, the solutions may change according to dynamic and uncertain condition occurring in the real-case. Second, the degrees of the victims' vulnerabilities in the post-disaster aftermath must be further investigated. Third, the problems with larger instances may increase the solution times which require practical methodology approach to effectively solve this *NP-hard* problem within reasonable computational time. Particularly for the last

Table 6 Routing time and lateness time

Vehicle		Day		
		Day 1	Day 2	Day 3
Scenario 1				
6 Wheel A	Routing time (hr):	2	3.16	4.89
	Lateness (hr):	0	1.16	2.89
6 Wheel B	Routing time (hr):	3.10	3.93	4.85
	Lateness (hr):	1.10	1.93	2.85
6 Wheel C	Routing time (hr):	2.04	4.51	4.95
	Lateness (hr):	0.04	2.51	2.95
Scenario 2				
6 Wheel A	Routing time (hr):	1.49	2.68	4.99
	Lateness (hr):	0	0.68	2.99
6 Wheel B	Routing time (hr):	1.73	3.87	4.17
	Lateness (hr):	0	1.87	2.17
6 Wheel C	Routing time (hr):	1.94	3.05	4.71
	Lateness (hr):	0	1.05	2.71
4 Wheel A	Routing time (hr):	1.73	2	2.08
	Lateness (hr):	0	0	0.08
Scenario 3				
6 Wheel A	Routing time (hr):	2.89	3.94	4.85
	Lateness (hr):	0	0	0.85
6 Wheel B	Routing time (hr):	3.09	3.76	4.95
	Lateness (hr):	0	0	0.95
6 Wheel C	Routing time (hr):	0.78	3.90	4.89
	Lateness (hr):	0	0	0.89
Scenario 4				
6 Wheel A	Routing time (hr):	2.42	3.60	4
	Lateness (hr):	0	0	0
6 Wheel B	Routing time (hr):	2	3.93	4.54
	Lateness (hr):	0	0	0.54
6 Wheel C	Routing time (hr):	2.34	3.12	4
	Lateness (hr):	0	0	0
4 Wheel A	Routing time (hr):	0	0.95	3.96
	Lateness (hr):	0	0	0

Table 7 Amount of delivered relief aids

Node (s)		Day		
		Day 1	Day 2	Day 3
Scenario 1				
Node 1	Delivery amount (ton):	9.43	14.34	18
	Shortage percentage (%):	0%	0%	2.07%
Node 2	Delivery amount (ton):	25.22	43.91	57.04
	Shortage percentage (%):	0%	0%	3.84%
Node 3	Delivery amount (ton):	1.92	5.78	8.96
	Shortage percentage (%):	0%	0%	0%
Node 4	Delivery amount (ton):	5.32	14.81	22.64
	Shortage percentage (%):	0%	0%	0%
Scenario 2				
Node 1	Delivery amount (ton):	9.43	14.34	18.38
	Shortage percentage (%):	0%	0%	0%
Node 2	Delivery amount (ton):	25.22	43.66	59.32
	Shortage percentage (%):	0%	0.57%	0%
Node 3	Delivery amount (ton):	1.92	5.78	8.96
	Shortage percentage (%):	0%	0%	0%
Node 4	Delivery amount (ton):	5.32	14.81	22.64
	Shortage percentage (%):	0%	0%	0%
Scenario 3				
Node 1	Delivery amount (ton):	9.43	14.34	18
	Shortage percentage (%):	0%	0%	2.07%
Node 2	Delivery amount (ton):	25.22	43.91	57.04
	Shortage percentage (%):	0%	0%	3.84%
Node 3	Delivery amount (ton):	1.92	5.78	8.96
	Shortage percentage (%):	0%	0%	0%
Node 4	Delivery amount (ton):	5.32	14.81	22.64
	Shortage percentage (%):	0%	0%	0%
Scenario 4				
Node 1	Delivery amount (ton):	9.43	14.34	18.38
	Shortage percentage (%):	0%	0%	0%
Node 2	Delivery amount (ton):	25.22	43.91	59.32
	Shortage percentage (%):	0%	0%	0%
Node 3	Delivery amount (ton):	1.92	5.78	8.96
	Shortage percentage (%):	0%	0%	0%
Node 4	Delivery amount (ton):	5.32	14.81	22.64
	Shortage percentage (%):	0%	0%	0%

Table 8 Solution statistics

Scenario	Extended solver steps	Total solver iterations	Computational time (hr)
Scenario 1	619,950	8,924,534	1.29
Scenario 2	1,501,469	26,743,764	4.50
Scenario 3	1,044,432	12,291,150	1.91
Scenario 4	5,751,805	84,720,971	27.03

limitation addressed in this research, we are developing a metaheuristic algorithm to provide good solutions with reasonable computational time in our current research.

References

Ahmadi M, Seifi A, Tootooni B (2015) A humanitarian logistics model for disaster relief operation considering network failure and standard relief time: a case study on San Francisco district. Transp Res Part E Logist Transp Rev 75:145–163. https://doi.org/10.1016/j.tre.2015.01.008

Ali MSS, Arsyad M, Kamaluddin A, Busthanul N, Dirpan A (2019) Community based disaster management: Indonesian experience. IOP Conf Ser Earth Environ Sci 235(1). https://doi.org/10.1088/1755-1315/235/1/012012

Altay N, Green III WG (2006) Interfaces with other disciplines OR/MS research in disaster operations management 175(December 2004):475–493. https://doi.org/10.1016/j.ejor.2005.05.016

Azizi F (2002) Review article. Res Islamic Fasting Health 22:186–191

Balcik B, Beamon BM, Smilowitz K (2008) Last mile distribution in humanitarian relief. J Intell Transp Syst Technol Plan Oper 12(2):51–63. https://doi.org/10.1080/15472450802023329

Boostani A, Jolai F, Bozorgi-Amiri A (2021) Designing a sustainable humanitarian relief logistics model in pre- and postdisaster management. Int J Sustain Transp 15(8):604–620. https://doi.org/10.1080/15568318.2020.1773975

BPBD Kota Padang (2017) Dokumen Rencana Kontijensi Tsunami Kota Padang. BPBD Kota Padang, Padang

García-Alviz J, Galindo G, Arellana J, Yie-Pinedo R (2021) Planning road network restoration and relief distribution under heterogeneous road disruptions. OR Spect 43. Springer, Berlin, Heidelberg. https://doi.org/10.1007/s00291-021-00644-x

Gusiakov VK, Dunbar PK, Arcos N (2019) Twenty-five years (1992–2016) of global tsunamis: statistical and analytical overview. Pure Appl Geophys 176(7):2795–2807. https://doi.org/10.1007/s00024-019-02113-7

Huang L, Chen X, Huo W, Wang J, Zhang F, Bai B, Shi L (2021) Branch and bound in mixed integer linear programming problems: a survey of techniques and trends (November), pp 1–29. Retrieved from http://arxiv.org/abs/2111.06257

Inca LR, Nikorn S (2019) The location-allocation decision under the dynamic increment of demand for selecting the local distribution centers to face sumatra megathrust : study case of Padang. City 9(1):293–299

Liberatore F, Ortuño MT, Tirado G, Vitoriano B, Scaparra MP (2014) A hierarchical compromise model for the joint optimization of recovery operations and distribution of emergency goods in humanitarian logistics. Comput Oper Res 42:3–13. https://doi.org/10.1016/j.cor.2012.03.019

Lindo. (2020). LINGO: the modeling language and optimizer. 1415 North Dayton Street Chicago, Illinois 60642: LINDO Systems, Inc. Retrieved from https://www.lindo.com/downloads/PDF/LINGO.pdf

Liperda RI, Aulya AR, Sukarno I, Lusiani M, Sirivongpaisal N (2021) Geological behavior (GBR) a GIS—based optimization for the fuel location-allocation to face the probable tsunami: case of Padang city 5(1):13–16. https://doi.org/10.26480/gbr.01.2021.13.16

Maghfiroh MFN, Hanaoka S (2020) Multi-modal relief distribution model for disaster response operations progress in disaster science multi-modal relief distribution model for disaster response operations. Progr Disaster Sci 6(April):100095. https://doi.org/10.1016/j.pdisas.2020.100095

Mahtab Z, Azeem A, Ali SM, Paul SK, Fathollahi-Fard AM (2021) Multi-objective robust-stochastic optimisation of relief goods distribution under uncertainty: a real-life case study. Int J Syst Sci Oper Logist. https://doi.org/10.1080/23302674.2021.1879305

Nayeem MK, Lee GM (2021) Robust design of relief distribution networks considering uncertainty. Sustainability (switzerland) 13(16):1–23. https://doi.org/10.3390/su13169281

Nezhadroshan AM, Fathollahi-Fard AM, Hajiaghaei-Keshteli M (2021) A scenario-based possibilistic-stochastic programming approach to address resilient humanitarian logistics considering travel time and resilience levels of facilities. Int J Syst Sci Oper Logist 8(4):321–347. https://doi.org/10.1080/23302674.2020.1769766

Patrisina R, Sirivongpaisal N, Suthommanon S (2018) A logistical relief distribution preparedness model : responses to a probable tsunami case study in West Sumatra, Indonesia. Ind Eng Manag Syst 17(4):850–863

Shen Z, Dessouky M, Ordónez F (2009) A two-stage vehicle routing model for large-scale bioterrorism emergencies. Networks 54(4):255–269

Shiripour S, Mahdavi-Amiri N (2021) Disaster relief on destructive transportation networks using a circle-based approach. Transp Lett 13(8):568–590. https://doi.org/10.1080/19427867.2020.1742417

Sieh K (2006) Sumatran megathrust earthquakes : from science to saving lives (June), pp 1947–1963. https://doi.org/10.1098/rsta.2006.1807

Tzeng GH, Cheng HJ, Huang TD (2007) Multi-objective optimal planning for designing relief delivery systems. Transp Res Part E Logist Transp Rev 43(6):673–686. https://doi.org/10.1016/j.tre.2006.10.012

Van Wassenhove LN (2006) Blackett memorial lecture humanitarian aid logistics: supply chain management in high gear. J Oper Res Soc 57(5):475–489. https://doi.org/10.1057/palgrave.jors.2602125

Zhang P, Liu Y, Yang G, Zhang G (2022) A multi-objective distributionally robust model for sustainable last mile relief network design problem. In: Annals of operations research, vol 309. Springer US. https://doi.org/10.1007/s10479-020-03813-3

The Impact of the Use of Intelligent Supply Chain Tools on the Transport, Forwarding and Logistics Industry

Sylwia Konecka and Anna Łupicka

1 Introduction

The analysis of the benefits and costs of using intelligent solutions for the implementation of transport processes is of great importance not only due to the innovative nature of these tools—although they require ordering and closer examination, but also due to the great importance of the activities of Polish carriers in the European Union (EU). The TFL industry (transport-forwarding-logistics) significantly contributes to the development of the Polish economy, carriers support the operation of the industry and the production sector, and also generate a considerable part of GDP (6%). 40% of cabotage and 17% of all transports in the EU are handled by Polish transport companies, which have been consistently in the first place in terms of the number of tonnes of cargo transported in international transport since 2012 (Zysińska 2019). Nevertheless, there are some problems in the industry. Experts recognize, first of all, the dangers of the regulations currently being introduced at the EU level, which may result in:

- an increase in the costs of transport networks (due to a reduction in their efficiency), fuel costs and wages,
- reduction of revenues related to the restriction of market access—in the field of cross-trade and cabotage services, and consequently also handling the import and export of goods,
- increased risk and barriers to doing business, especially in the case of small carriers, due to the increased complexity of the rules,

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- forcing the internationalization of carriers—who operate today in many foreign markets from Poland,
- an increase in the concentration level—as a result of the collapse of small enterprises that do not have an adequate share of transport in the country and on foreign markets in their activities.

It should be noted that with the low level of margins in the road haulage transport segment, an increase in costs may lead to the elimination of the least effective entities from the market. In turn, the scientific community focuses on the growing requirements in the field of environmental protection regarding lower CO_2 emissions and other pollutants, the use of more ecological drives and local restrictions on the movement of internal combustion vehicles, which for entrepreneurs may also contribute to an increase in costs. Attention is also drawn to the insufficient level of development of national law in the field of new technologies.

It is also worth recognizing the area of implementing intelligent tools facilitating transport management, which could be helpful in overcoming the above-mentioned problems and supporting carriers in maintaining a competitive advantage in the international dimension. In addition, transport processes connect all links in the supply chain and are of great importance in the EU in the light of the Sustainable and Smart Mobility Strategy. The aim of the article is to propose a theoretically based conceptual framework for studying the impact of identified intelligent solutions on the TFL industry. The study used a qualitative descriptive method referring to a critical analysis of domestic and foreign studies in the field of intelligent solutions, and made a short review of selected theoretical approaches in the field of costs and benefits. The potential benefits and costs of introducing intelligent solutions in the transport industry were also identified.

The presented issues, due to their topicality and dynamics of development as well as very poor research in the field of science, require in-depth research. The conclusions obtained are of practical importance, as they allow for the identification and assessment of benefits and costs for entities in the TFL industry, which are brought by solutions of intelligent supply chains. Although research in the field of transport is common and more and more studies also deal with industry 4.0, the review of Polish literature carried out in 2020 (Młody and Weiner 2021) shows that no studies linking the subject of road haulage transport with the latest IT solutions have been conducted, 7 out of 68 of analyzed publications was related to logistics and supply chains. There is also a lack of studies using quantitative methods and case studies. Taking up a popular but new, poorly recognized, dynamically developing topic allows to signal possible economic, social and environmental consequences, becoming the basis for a more adequate socio-economic policy and creating strategies for entrepreneurs in the TFL industry.

The article is theoretical and constitutes a kind of research reconnaissance. The method of systematic literature review was used for its preparation. The following databases were selected for the study: WoS, Scopus and Google Scholar. In the first phase, the literature was reviewed in terms of solutions used in intelligent supply chains, then the identified solutions were confronted with the transport activity related

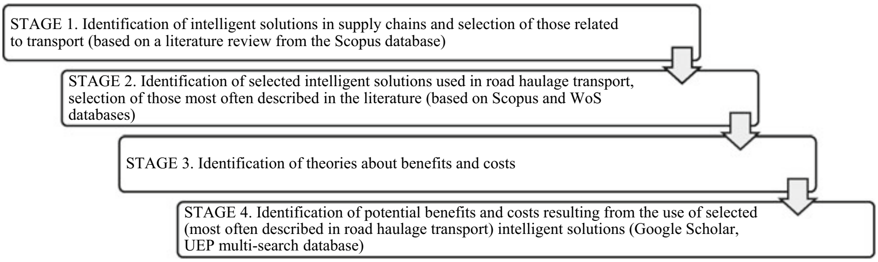

Fig. 1 Diagram of the identification steps carried out as part of the literature review. *Source* Own study

to the transport of goods. The Google Scholar database was used to review the literature in terms of the theory of benefits and costs and to search for potential benefits and costs for the transport industry from the use of selected IT solutions. Details of the search keywords used are provided in each subsection. The method of operation aimed at achieving the set goal is reflected in the theoretical model presented in Fig. 1.

2 Intelligent Solutions Used in Road Transport

According to the Dictionary of the Polish Language (www.sjp.pl 2021), intelligence is "the ability to understand, learn and use the possessed knowledge and skills in new situations". Therefore, it can be ascribed not only to personal entities, but also to organizations that are constantly operating in new situations today. Apart from the term "intelligent organization", there is also a "learning organization". According to Penc (2003), the main difference between a learning organization and an intelligent organization is the desire (the last of the mentioned ones) to fully use the intellectual potential of all employees.

Smart organizations are characterized by: agility (speed in action), adaptability, self-regulation and self-optimization (adapting key business indicators to short-term changes in the business climate), smooth borders and a network structure (enabling restructuring and changing the scale of the organization's operations depending on the needs, e.g., by outsourcing or insourcing), as well as the ability to transform into new, better forms in the long term (Kemal et al. 2002).

It seems that intelligent organizations should strive to maintain a balance between acquired knowledge and shared knowledge. The formation of an intelligent organization is a process that consists in constantly increasing knowledge and changing the mentality of its members, who learn to be more responsible, independent and entrepreneurial related to their tasks (Kaczmarek 2013). The development of such an enterprise may result from taking independent actions by managers and members of

Table 1 Number of publications on intelligent supply and transport chains (Scopus database)

The selected tool of intelligent supply chain	Number of articles
RFID (Radio-frequency identification)	50
ITS (Intelligent transport systems)	35
IoT (Internet of things)	27
ICT (Information and communication technologies)	14
AI (Artificial intelligence)	13
Automation	12
TMS (Transport management systems)	1

Source Own study

the organization, but it may also take place as a result of implementing the concept of a virtual organization, strategic alliances or coopetition. (Romaniuk 2017)

The literature review shows that intelligent solutions applicable in a broader context than a single enterprise, i.e., supply chains, are discussed in the literature on the subject in such areas as types of algorithms—genetic or fuzzy-logical systems, in the field of reverse logistics, intelligent systems in intermodal transport, in transport urban and extra-urban, ITS system and security of their use, intelligent warehouse management systems, Cloud of Things, RFID, autonomous vehicles (Konecka 2019). Initial research and literature review indicate that a significant part of these tools relates to transport activities. The literature most often states that transport companies can use evolutionary versions of ITS, RFID, cloud of things, blockchain, IoT (Konecka and Maryniak 2020) (Table 1).

Knowledge of the impact of technology on the activities of companies in the TFL industry is based mainly on industry reports. Only in one Polish publication appeared a direct connection of transport activities with solutions of the so-called industry 4.0 in the form of the use of the concept of transport 4.0 (Brach 2019). There are few publications dealing only with transport, in particular road transport, and only goods, with the exception of passenger transport.

The preliminary assessment of the state of knowledge based on the number of publications in the databases: Web of Science (WoS) and Scopus in the last five years, i.e., from 2017 to 2021, shows that for the entry in the title or summary “road AND transport” a pool of 43 902 publications was obtained in WoS, while looking for the “road transport” version—2,624. In the Scopus database it was 13,898 and 3440 publications, respectively. Among these results, the following keywords were checked: “Industry 4.0”, “Telematics”, “Internet of Things”, “Automation”, “Big Data”, “Information and Communication Technologies”, “Artificial Intelligence”. Only one article concerned a study on the impact of digitization on road haulage transport using the example of Sweden, the study was carried out using the scenario method and based on the opinions of 52 experts. The results of the number of publications obtained are presented in Table 2.

Table 2 Number of publications on road transport and selected smart tools

Tool/Solution	WoS		Scopus	
	Road and transport	Road transport	Road and transport	Road transport
Industry 4.0	75	4	110	24
Automation	461	53	1259	294
Telematics	91	19	230	65
IoT (Internet of things)	179	11	457	77
Big Data	610	31	828	168
ITS (Intelligent transport systems)	967	145	1446	240
ICT (Information and communication technologies)	56	11	280	70
AI (Artificial intelligence)	323	16	1358	272

Source Own study

The industry literature review shows that in practice, carriers use the following IT solutions: freight exchanges, cargo tracking systems, TMS systems, tachographs, electronic toll collection systems, telematics, sensors, GPS, translators, cargo securing and monitoring, information on CO_2 emissions. Thus, it can be assumed that the solutions indicated in the literature are used rather by public entities or industry leaders and not by carriers, but e.g., by logistics operators. Before the potential benefits and costs resulting from the use of intelligent solutions are identified, those most often discussed in the literature on the subject were selected, i.e., automation (for transport, autonomous vehicles will be considered here), ITS, AI, Big Data and IoT.

3 The Concept of Benefit and Cost in the Light of Selected Theories

There is no doubt that the emerging intelligent IT tools affect the concept of human capital, production, consumption and exchange of goods both in theoretical and practical terms. Human labor ceased to be the basic factor of production, and human capital takes on an intellectual dimension. There is a concern among economists about the need for humans to fight robots for jobs (Rifkin 1995). A reference to the revolution based on ICT techniques and the current economic thought is the concept of the process of creative destruction of Schumpeter. Since "information techniques (ICT) are a fundamental element of most systems, the feature of which is constant and dynamic development, often of a subversive nature" (disruptive technologies), a Schumpter approach to innovation suggests itself (Goliński 2013). Currently, a scientific theory is expected to be able to explain the processes taking place and to be reliable in predicting the future. It is also expected to be able to properly analyze emerging trends and use a huge amount of data, which fits perfectly into the concept of the latest revolution. The equilibrium models that have been in force for many years, being a certain photograph of the optimal state on the market or, more broadly, in the economy, cease to be applicable in the world of constant changes (Olender-Skorek 2017). Hence the idea to take a closer look at the concept of benefits and costs in theory in order to compare them to the benefits and costs of implementing intelligent solutions in road transport of goods. Similarly, if modern IT solutions are to be considered revolutionary in the transport industry, then one should also refer to the classic concept of Kuhn's revolution (2009). Nevertheless, first the considerations were focused on the concept of benefits and costs, wondering who will benefit from this revolution and who will lose.

When looking for a definition of benefits in economic terms, we can meet the two most popular approaches:

- external benefits, i.e. benefits obtained from the production and consumption of goods by people not directly involved in their production, consumption or exchange, and
- economies of scale that occur in the long term and relate to the phenomenon of lowering the average total costs along with increasing the scale of production and introducing new technologies.

For example, according to Bentham, the essence of pleasure and unpleasantness obtained from various sources is the same. The only difference between them lies in the circumstances surrounding their creation, and therefore they should be the subject of a *felicific calculus* of happiness for the individual and society. The property of an object or activity by which it promotes the production of benefit or the prevention of harm to the interested party, Bentham called utility. The benefit derived from the decisions made should be regarded as an expression of the utility of an action or object, rather than its utility, since the latter is merely a property of the object or action by which it favors the production of benefits (Betham 1958/1780).

The meaning of the term "favorable decision" is related to the scope of the expression "rational decision". And making a rational decision is associated with the demands of perfect information, consistency and maximization. The first of them, assuming that the model decision maker knows all the possibilities of using the available resources, and that the expected benefit (utility) will be (utility) actually realized as a result of taking these actions, is of particular importance in the context of the current development of "big data". In addition, Bentham's original idea concerns the concept of utility, allowing the benefits achieved by market participants to be located both in the sphere of consumption and in the sphere of production. By analogy with consumers benefiting from the consumption of goods, one can speak of producers benefiting from their production. Exposing the benefits as a category expressing the most universal goal of actions undertaken by market participants is a procedure that precisely formulates the starting point for further analysis of the behavior of market entities. The benefits that people strive for are a polymorphic category and very often completely immeasurable quantitatively, economists over the centuries have tried to find replacement variables for which they assumed that they changed in the same direction as satisfaction, satisfaction or benefit resulting from the undertaken activities. For example, there are proxy variables such as wealth, utility, preferences, profit, income, reciprocity, entropy, and well-being.

In the analysis of the result achieved by the producer from business activity, two elements are juxtaposed: the costs of undertaken activities and the resulting benefits. The costs are subjective and their magnitude depends on the personal characteristics of the decision-maker. Hidden income is an expression of satisfaction (benefits) resulting from running a business and may include, for example, such elements as: social prestige, a sense of social security (peaceful life), membership of environmental organizations such as associations, clubs or chambers, a sense of professional independence and decision-making freedom as well as opportunities for self-realization.

Among the theories regarding the concept of benefits and costs, there are also:

- Homans' theory of social exchange (1967), which is a sociological and anthropological theory, referring to behaviorism and economics, from which the notion of exchange was adopted, social relations explained by the exchange of goods (rewards and punishments) between individuals participating in the interaction;
- the theory of consumption chains of goals and means, developed by Newell and Simon (1972), the idea of which is that the attributes of products inform the consumer whether the desired goals, namely values and direct benefits, will be met by the products;
- the theory of public goods and the theory of groups, in which Olson (2012) presents the fundamental problem of the limitations of the effectiveness of collective action undertaken by various types of groups or organizations. Rejects as untrue the judgment that if a group has any collective goal or benefit, the individuals making up that group will automatically seek to achieve it;
- the theory of comparative advantages, formulated by Ricardo and Hartwell (1971) and based on the claim that international exchange can be beneficial for both partners, when one produces most of the goods cheaper than the other. To obtain such benefits, it is sufficient that there are relative differences in the production costs in both countries. Trade between two countries can be beneficial for both countries if each of them exports a good in the production of which he has a comparative (relative) advantage;
- the theory of absolute costs formulated by Smith, the theory of international trade, according to which the basis for the development of international specialization and the source of benefits from international trade is the fact that there are absolute differences between production costs and labor inputs. The benefits of exchange mean an increase in the production capacity of both trade partners from international exchange and explain the reasons why individual countries trade with each other (Milewski 2003).
- the theory of distributive justice, the most general concept of the fair distribution of Sena's goods regarding equality and benefits (Kwarciński 2011) and

- cost–benefit analysis.

Cost–benefit analysis (CBA) is perhaps the most useful in the context of using intelligent solutions in transport. It is a method of assessing the effectiveness of investments and projects, taking into account all expected benefits and costs, including quantitative and qualitative elements, allowing to determine the degree of investment effectiveness in a complex environment. The cost–benefit analysis also takes into account social, cultural and environmental aspects, expressed as external costs. CBA is particularly useful in assessing projects, the implementation of which is associated with a large number of benefits and costs incurred by various groups of stakeholders, and where the main selection criterion is not necessarily the maximization of financial profit. The theoretical basis of the CBA is welfare economics (Becla et al. 2012).

According to Paprocki (2017), the development of technology and technology, as well as changes in the behaviour of participants in social and economic processes, are factors causing the need to correct the theory describing the functioning of transport. Changes in social and economic policy, as well as in climate, ecological and energy policy, necessitate further research work devoted to the analysis of possible and acceptable scenarios. Thus, the deliberate behavior of researchers is to indicate possible system solutions together with a description of the anticipated benefits and costs that may occur in the case of applying any of them.

4 Potential Benefits of Implementing Intelligent Transport Solutions

The implementation of intelligent supply chain solutions has both potential benefits and costs. They can be divided into three groups—social, environmental and economic. They can be perceived differently by small companies and large logistics operators, employers and employees. In the article, the authors will try to answer research questions: Are intelligent supply chain tools perceived as a source of benefits or costs in companies from the TFL industry?

4.1 Internet of Things

In the report "IoT in the Polish economy" (2019), prepared by the Working Group for the IoT at the Ministry of Digital Affairs, it was estimated that in 2022 almost USD 590 million will be allocated to IoT in transport. The Internet of Things is used in many areas of logistics, including traffic management and transport fleet. Then the telematics systems play the main role. The foundation of their functioning is the skilful use of GPS, GSM, BLE and Wi-Fi technologies. The solutions based on them offer the opportunity to improve both the efficiency and safety of road transport.

They enable the collection and analysis of data on the efficiency and effectiveness of traffic and transport fleet management in the enterprise, and thus, reducing the costs of vehicle operation, detecting potential problems and more effective planning of subsequent routes. IoT supports such processes as: property protection, employee safety, control and optimization.

The Internet of Things is also used in supply chain management. For example, in the case of shipment tracking, RFID tags connected to the data cloud, thanks to which the only activity performed by employees is loading the goods. Also when it comes to the course of delivery, the use of GPS and RFID technology allows to minimize the risk of delays in transport resulting from unfavourable weather conditions or poor road condition. Drivers are informed on an ongoing basis about the expected difficulties, which gives them the opportunity to take action to prevent the extension of deliveries. In addition, a network of sensors installed in trucks monitors their technical parameters, such as load stability and tire pressure.

According to (Trzop 2020), the most important benefits of implementing IoT solutions include:

- monitoring the state of material resources of the company and the status of shipments as well as supervision over employees,
- measuring the effectiveness of the use of material and human resources of the company,
- controlling the work of the company's resources and influencing its course,
- automation of business processes,
- optimization and coordination of mutual cooperation of people, systems and material resources,
- learning about areas that can be improved and applying best practices.

4.2 Big Data

In a global economy where data is expected to be used to make better decisions and allocate resources faster, algorithms with large data sizes can perform tasks more efficiently than humans, the transportation industry has a lot to gain, if only because it is fragmented. Transport resources, senders, recipients, intermediaries form a network that is difficult to handle effectively using manual processes. Transport generates huge amounts of data that can be used to optimize its performance. The use of telematics allows you to send information about the location and condition of vehicles, TMS collect data on the content, quality and purpose of the load, beacons are installed in the loads themselves, data is collected by toll collection devices, drivers' mobile phones are integrated with electronic exchanges, electronic documents are used, e.g., e-CMR, intelligent tachographs control the driver's working time, driving speed, data on the driving style of individual drivers, the degree of tire wear and fuel are collected. These data, properly processed by algorithms, can contribute to a better use of existing resources: matching loads to means of transport, using the capacity of semi-trailers and planning the length of routes. Especially when they cannot be enlarged enough.

Possibilities resulting from the use of big data analytics include (Trzop 2020):

- comprehensive evaluation of the course of processes,
- process planning improvement,
- optimization of transport processes,
- improving risk prediction and management processes,
- the ability to define priorities in everyday tasks,
- improving customer relations.

4.3 *Intelligent Transport Systems*

The use of ITS is one of the priorities in the implementation of the city's transport policy. The most important effects of using ITS include:

- general improvement in the efficiency of the transport system operation (in particular, shortening the travel time, reduction of the number of stops and road incidents),
- increasing the level of road safety, and
- reduction of the emission of harmful exhaust components, dust and noise.

Regardless of the development of ITS solutions related to road infrastructure, electronic systems for communicating vehicles with the environment, including other vehicles, the so-called C-ITS systems (Cooperative ITS). As a development of this concept, works are also carried out on Connected and Automated Driving vehicles, which will cooperate with road ITS solutions in order to effectively use data, access current information and respond to current needs and threats.

The concept of MaaS (Mobility as a Service) is also being developed, which consists in providing a transport service with the use of various means of transport, but without the need to have any of them. The goal of the ongoing development of MaaS is to better respond to market demand by linking booking, purchasing and payment systems in the transport chains and providing real-time information on timetables, weather and traffic conditions, as well as available carrying capacity and available solutions. MaaS is therefore the user digitized transport interface. Its aim is also to optimize the use of transport capacity. This solution reduces travel costs and air pollution, especially where it is very important—in cities. It also significantly increases the use of means of transport, which under traditional solutions (vehicle ownership) are used on average in about 5%. The vehicles are not used for the rest of the day (Kamiński 2020).

Basically, the above-mentioned solutions concern the concept of digitization, collecting large amounts of data and their use or sharing via the cloud and creating IoT would not be possible without it. TMS and FMS class systems, online service purchase platforms, ITS based on telematics can reduce the time-consuming administrative activities of drivers and office workers and are the result of digitization.

There are several forms of transport digitization. Today, digital information is already used in many ways in vehicles, including technologies and services that support car driving, rail traffic control, aviation and vessel traffic management. The digitization of passenger and cargo information is another area that is used on a daily basis. Finally, robots are widely used in terminal operations in freight logistics.

The digitalisation of mobility of people and goods transport has many potential benefits, such as

- ease of access and convenience for passengers,
- increasing efficiency, productivity and safety in freight transport,
- greater traffic safety, especially advanced automation increases transport safety by reducing the frequency of human error.
- emission reduction.

The impact of transport on the climate and the environment depends on many factors. Replacing fossil fuels with low carbon fuels, electricity or hydrogen is another important way to reduce emissions. The implementation of electric vehicles and the expansion of smart electric grids are closely related to transport automation. The environmental impact is not only related to transport, but also to the life cycle of vehicles. Repatriating production and implementing a circular economy and close loop supply chains approach reduce the impact of the life cycle.

4.4 Artificial Intelligence

The area of application of AI in logistics is supply chain planning (SCP) systems supported by machine learning. In the area of transport, AI solutions are also used. An example is autonomous trucks that independently control their work and react to external conditions, and even form integrated convoys (truck platooning).

When it comes to AI, the main benefits of its application in the area of logistics include (Trzop 2020):

- increasing the efficiency of processes,
- shortening the time of performing tasks,
- streamlining the information flow process,
- improving the customer service process,
- the ability to prioritize tasks,
- avoiding empty runs: both in internal and external transport processes,
- optimization of the way the goods are distributed.

4.5 Automation

The benefits of automation in transport processes include, among others, reducing the shortage of employees. It is estimated that after 2025, autonomous vehicles will reduce transport costs by up to 28% compared to 2016. By replacing labor costs (drivers) with software costs, telematics and remote control. Most economic, social or political and legal factors are likely to drive up costs in the industry, so autonomy may be one of the few ways to reduce them. However, it will take 5–10 years for technological solutions in this area (PwC 2017). As many as 78% of representatives of global transport and logistics companies plan to take actions to automate tasks and positions in order to ensure the effective achievement of goals. Kantar's researchers interviewed 1300 people over the age of 15 from Polish cities over 50,000. residents. They asked, among others about the advantages of autonomous cars. Among the greatest advantages, half of the respondents indicated greater mobility of people who cannot drive a car, e.g., young people and the elderly. Another benefit is the reduction of parking spaces (21% of responses) if the autonomous car returns to the owner's garage after reaching its destination or, as in the case of shared vehicles, will pick up another person, he will not need a parking space in the city center. In addition, the popularization of shared mobility may cause many people to give up driving their own cars in favor of autonomous cars. 8% of city residents indicated that autonomous vehicles will provide the opportunity to rest or work while traveling (2%). In any case, they will allow more efficient use of travel time. Autonomous mobility can also make car users healthier and calmer, as driving in a crowded city can be a source of stress. Meanwhile, in the case of autonomous cars, the vehicle itself takes care of everything. (www.transport-publiczny.pl)

The results of pilot research carried out among road transport operators in Greater Poland in 2019 for the purposes of the thesis will be presented below (Różniewicz 2019). According to 58% of respondents, by 2030 autonomous cars will normally functioning on Polish roads, only 16% were skeptical about such implementation prospects. 76% of respondents declared their willingness to participate in courses enabling better understanding of the topic of autonomous vehicles. 82% of respondents are willing to replace trucks and vans in their own fleet with self-steering ones. Among the benefits that the respondents saw in the introduction of autonomous cars, cost optimization was 58% first. It was to consist of getting rid of the costs of drivers' salaries, faster covering the route—without mandatory breaks in accordance with the Act on the driver's working time, timely delivery. 32% of respondents noticed the benefit of being able to constantly monitor a vehicle, its location and, technical parameters. Only 14% of respondents saw the benefit of eliminating a significant number of accidents caused by drunk drivers.

Questions about the potential benefits of using autonomous vehicles as well as threats were multiple-choice questions. Respondents perceived threats more often. They considered the biggest threat to the lack of trust in the 36% system, they are also afraid of software errors and the inability to respond to such obstacles from vehicles. 64% of respondents indicated that autonomous vehicles were not adapted to the psychological aspects of other road users—for example, the behavior of drunk pedestrians. Another threat is what has also been indicated as an advantage, i.e., reduced employment of drivers—44%, also in the context of retraining or acquiring new skills, piloting an autonomous vehicle.

The number of technological solutions used in enterprises employing respondents may also affect the perception of automation. The vast majority of respondents declared that their enterprises use the most popular solutions, i.e., GPS (Global Positioning System)—satellite navigation system, working time controller and driving speed controller. 23 people indicated that they worked with the help of cargo tracking, and three people less—with a fuel consumption meter. The least respondents got acquainted with the functioning of the tire pressure sensor and temperature sensor. Awareness and ability to use individual tools also results in answering previous questions. People who worked with the fuel consumption meter, work time controller, GPS indicated that they are in favor of the introduction of autonomous cars because it will facilitate their work because the above devices will cease to need them.

96% of respondents would like to use the latest technologies at work. 60% of respondents believe that autonomous transport is an expensive solution. In this issue, the most important were the responses of employees who use the latest technologies at work. They are the ones who have the greatest awareness and have broader knowledge than others. After careful analysis, it was this group of people who fully opted for autonomous transport. And 40% of those surveyed believe that an investment in autonomous rolling stock will pay off and begin to bring benefits in a few years.

From a bibliometric analysis it follows that (Astarita et al. 2019; Bechtsis et al. 2018; Khondaker and Kattan 2015; Li et al. 2015; McGinley 2014; Sovacoola and Axsenc 2018; Vleugel and Bal 2018; Yigitcanlar, Wilson and Kamruzzaman 2019):

- the future is bringing increasing demands for greater efficiency and for more sustainable designs in cargo handling technologies;
- automated transport systems also play an important role in the creation of urban mobility and have an important influence on the shaping of urban space;
- attention should also be paid to the safety of autonomous vehicle traffic (AV) as part of both ITS and sharing economics;
- information security management is critical to protect the users of autonomous vehicles;
- the potential of autonomous vehicles to implement sustainable development can also be seen in the wider context of linking autonomous vehicles to sustainable supply chain development.

5 Potential Costs of Implementing Intelligent Transport Solutions

One of the most frequently indicated potential social costs related primarily to automation is the elimination of human labor. The change in the nature of human work will certainly lead to the elimination of professions in transport, such as: driver, train driver or operator of reloading equipment—crane, forklift. However, automation does not have to lead to the elimination of work, as the dynamics of economic processes must be taken into account. According to Götz and Gracel (2017), the effects of digitization on the labor market should be positive on balance, as in Germany one-third of enterprises subject to digitization processes plan to increase employment, and only one-tenth expect a reduction in employment as a result of digitization. On the other hand, OECD studies show that as a result of automation, about 12% of jobs in Germany are at risk, and about 7% in Poland (Brandt 2016). Workstations where 70% of work can be replaced by machines are considered such. In Great Britain this figure reaches 10%, in the USA—9%, and in Japan—7%. Some studies even mention the disappearance of more than 200 professions, new ones will surely emerge. According to Paprocki (2017), just as computerization did not cause structural unemployment, robotization does not have to cause this phenomenon.

However, the barriers to implementing the above-mentioned tools should be taken into account: high investment costs, lack of experts, well-qualified and understanding market needs, mentality, data security, fragmentation—95% of Polish transport companies are micro-enterprises with a fleet of up to 20 vehicles. Such companies have approx. 60% of the fleet resources in Poland.

Both in terms of individual users and enterprises, the development of intelligent technologies in transport and the resulting costs should be viewed in terms of the development of social media and the concept of Zuboff (2015) surveillance capitalism. And by analogy, consider the possibilities of extending it also to the discussed solutions. Structural asymmetries of knowledge and rights made it impossible for people and small organizations to learn about practices of leading tech companies. In this concept "the new tools, networks, apps, platforms, and media thus became requirements for social participation". In the same way, the use of intelligent transport tools becomes a prerequisite for the continued existence of transport companies. In this new regime, a global architecture of computer mediation turns the electronic text of the bounded organization into an intelligent world-spanning organism that Zuboff (2015) call Big Other. One of the main challenges is the detailed recognition of a new business model in which service providers, i.e., carriers of people and goods, are completely cut off by virtual platform operators from their customers, i.e., passengers and shippers. When analyzing this model, it is necessary to take into account a specific scenario in which one operator occupies an unprecedented position in the market, becoming a monopsony. In economic theory, the operation of monopsons has so far been analyzed in a very narrow range. It is possible to emancipate virtual platform operators, who will take over the role of architects of the entire mobility support system for individuals and the entire society, as well as for the distribution system of things and goods devoid of material form. Nowadays, the source of the leader's advantage is the intellectual advantage obtained thanks to the use of the so-called narrow AI. (Paprocki 2017) So, perhaps we should consider the scenario of a specific exclusion of enterprises that do not efficiently use the most modern IT solutions.

The need to introduce new types of digital platform-based business models is linked to the need to create a supportive and enabling environment and, through a regulatory framework, a level playing field for businesses. Market leaders (logistics operators) are already implementing technological innovations, but there are no regulatory provisions. When introducing intelligent IT tools, concerns are raised not only about work, but also security, privacy and the environment.

When it comes to security, there is a growing concern about cybersecurity, which will be one of the key aspects of transport security. It applies not only to vehicles, but also to the infrastructure that supports, controls and manages them. The main challenge may be to de facto accountability in the event of an accident, given the role of digital systems and the involvement of several entities such as vehicle manufacturers and owners and infrastructure managers. New safety risks are due to the limited ability of sensors to recognize shapes, malfunctions, internet disruptions, and new types of human error such as software error. Of course, all these protections will generate costs, but the final effect is still assessed as positive.

Concerning the need for privacy and greater data exchange, concerns are raised about continuous monitoring, shape recognition. The management of non-personal data, especially data generated by sensors and smart devices, also requires explanation and regulation. When considering the issue of ease of access and re-use of data, it is worth noting that generally it is not the data itself that gives a competitive advantage, but rather it is improved by tools, innovation resources and market power.

Paradoxically, autonomous transport may lead to more use of private cars due to greater passenger comfort. But car sharing (along with the use of autonomous public transport) can reduce the number of private cars. Consumer preferences will play a decisive role. They will depend on the possibility of travel planning, encouraging passengers to make environmentally friendly choices, price incentives for the use of electricity infrastructure. However, it should not be forgotten that new digital and digitized infrastructure, new services are needed to enable access to traffic information as well as for reservations and payments for mobile services and they require electricity, the way to get it will be environmental impact (EKES 2017).

The implementation of intelligent IT solutions is associated with large financial outlays, which not every enterprise, especially small or medium-sized, can decide to do. In addition, their use is often associated with the need to entrust an external entity with valuable information resources of the enterprise. There is also no doubt that the implementation of such advanced technologies is associated with significant changes in the organization of processes, requiring appropriate change management skills from the managerial staff. However, it is clear that this process cannot succeed if technology alone is driving progress. Ideally, development should be driven by societal demand.

6 Conclusions

Technology offers many opportunities, but progress cannot be based solely on it. It requires an appropriate degree of availability, ease of access and free flow of data. At the same time, adequate data protection must be ensured. In order to be able to respond to new developments, it is also necessary to strengthen cybersecurity capacities and to address liability issues. Close links with other policy areas such as digital single market, energy, industrial development, innovation and skills policies. As climate change mitigation objectives and requirements also contribute to the development of digital transport, there is also a close link with environmental sustainability.

It is difficult to unequivocally identify and estimate the scale of benefits and the scale of threats posed by the described IT solutions. The problem of the redistribution of these benefits and costs remains open, both between enterprises in the country and in enterprise networks and in the international dimension. A question arises—Are these benefits and costs the same for all entities? It is worth considering the dependence of perceiving the same tools as a cost or benefit depending on the type of entity, e.g., its size in the transport industry.

Each of the analyzed solutions—digitization, autonomization, IoT, big data, telematics, could be studied separately in a more detailed way. In the sciences of management and quality, it is expected to continue work on dynamic changes in the behavior of market participants. It is also possible to conduct research as part of the so-called Uberization and amazonization taking place in the supply channels, they adapt to the requirements imposed on them by entities gaining market dominance thanks to the use of the latest digital technologies.

As part of megatrends, e.g., connected living or big data clouds, it is possible to study the decision-making model at the enterprise level, which will have the opportunity to achieve effects so far in theory considered achievable only on a macro scale. The topics that require separate research are: electromobility, including vans and trucks, sharing economy and instant pricing, blockchain and cybersecurity in transport.

However, it is important to adequately address these structural changes by developing strategies to ensure a fair and efficient transition, reduce negative social impact and respond to skills mismatches, with appropriate monitoring of progress, that is, considering the achievements and consequences of intelligent IT transport solutions from an end-to-end perspective. society, including enterprises, workers, consumers, and looking at the balance of benefits and losses in both economic, social and environmental terms.

References

Astarita V, Giofrè VP, Guido G, Vitale A (2019) A single intersection cooperative-competitive paradigm in real time traffic signal settings based on floating car data. Energies 12:409

Bechtsis D, Tsolakis N, Vlachos D, Srai JS (2018) Intelligent autonomous vehicles in digital supply chains: a framework for integrating innovations towards sustainable value networks. J Clean Prod 181(20):60–71

Becla A, Czaja S, Zielińska A (2012) Analiza kosztów-korzyści w wycenie środowiska naturalnego, Difin, Warszawa

Betham J (1958/1780) Wprowadzenie do zasad moralności i prawodawstwa, Państwowe Wydawnictwo Naukowe, Warszawa

Brach J (2019) Kształtowanie się Transportu 4.0 i Systemu Transportu 4.0 w kontekście wpływu Rewolucji 4.0 na współczesny transport drogowy. Economics of the 21st Century 1(21):87–101

Brandt M (2016) Automatisierung bedroht Millionen Arbeitsplätze. http://ap-verlag.de/automatisierung-bedroht-millionen-arbeitsplaetze/23457/

Europejskiego Komitetu Ekonomiczno-Społecznego (EKES) (2017) Wpływ cyfryzacji i robotyzacji transportu na kształtowanie polityki UE. TEN/632, Bruksela

Goliński M (2013) Informacja i techniki informacyjne jako przyczyna zmiany. Nierówności Społeczne a Wzrost Gospodarczy 32:37–48

Götz M, Gracel J (2017) Przemysł czwartej generacji (Industry 4.0) – wyzwania dla badań w kontekście międzynarodowym. Kwartalnik Naukowy Uczelni Vistula 1(15):217–235

Grupa robocza do spraw Internetu Rzeczy przy Ministerstwie Cyfryzacji (2019) IoT w polskiej gospodarce

Homans G (1967) The nature of social science. New York

https://www.gov.pl/web/cyfryzacja/grupa-robocza-ds-internetu-rzeczy-internet-of-things-iot

Kaczmarek B (2013) Tworzenie organizacji inteligentnej jako nowej wartości firmy, Zeszyty Naukowe Uniwersytetu Szczecińskiego, 786. Finanse, Rynki Finansowe, Ubezpieczenia 64(1):157–162

Kamiński T (2020) Kooperacyjne Inteligentne Systemy Transportowe (C-ITS) jako rozwiązania podnoszące bezpieczeństwo i efektywność transportu drogowego. Gospodarka Materiałowa i Logistyka, LXXII 6:10–18

Kemal A, Delic KA, Dayal U (2002) The rise of the intelligent enterprise, Ubiquity, 6

Khondaker B, Kattan L (2015) Variable speed limit: a microscopic analysis in a connected vehicle environment. Transp Res Part C Emerg Technol 58:146–159

Konecka S (2019) Intelligent supply chains from the perspective of benefits and costs for transport-forwarding-logistics industry. Ekonomika i Organizacja Logistyki 4(4):49–59

Konecka S, Maryniak A (2020) Intelligent and innovative solutions in supply chains, advances in intelligent systems and computing. Springer 1026:854–859

Kuhn TS (2009) Struktura rewolucji naukowych. Aletheia, Warszawa

Kwarciński T (2011) Równość i korzyść: Amartyi Kumar Sena: koncepcja sprawiedliwości dystrybutywnej, Monografie: prace doktorskie, Uniwersytet Ekonomiczny w Krakowie, 11

Li Z, Chitturi MV, Yu L, Bill AR, Noyce DA (2015) Sustainability effects of next-generation intersection control for autonomous vehicles, special issue on smart and sustainable transport, 15, 30(3):342–352

McGinley K (2014) Preparing port container terminals for the future: making the most of intelligent transport systems (ITS), Urban Transport XX

Milewski R (2003) Podstawy ekonomii. PWN, Warszawa, p 585

Młody M, Weiner A (2020) The importance of technological anxiety for the digital transformation of industrial processing companies in Poland. In: Contemporary organisation and management. Challenges and trendsPublisher, Łódź University Press

Newell A, Simon HA (1972) Human problem solving. Prentice Hall, Englewood Cliffs

Olender-Skorek M (2017) Czwarta rewolucja przemysłowa a wybrane aspekty teorii ekonomii. Nierówności Społeczne a Wzrost Gospodarczy 51:38–49

Olson M (2012) Logika działania zbiorowego. Dobra publiczne i teoria grup, Wydawnictwo Naukowe Scholar
Paprocki W (2017) Role of virtual platform operators in transforming consumer goods market. J Manag Financ Sci XI(27):25–37
Penc J (2003) Zarządzanie w warunkach globalizacji, Difin, Warszawa
PriceWaterhouseCoopers (2017) A decade of digital keeping pace with transformation, 2017 Global Digital IQ® Survey: 10th anniversary edition. https://www.pwc.com/sk/en/publikacie/assets/2017/pwc-digital-iq-report.pdf
Ricardo D, Hartwell RM (1971) On the principles of political economy, and taxation. Penguin Books, Harmondsworth
Rifkin J (1995) The end of work. The decline of the global labor force and the dawn of the post-market era, New York
Retrieved June 20, 2021, from https://www.transport-publiczny.pl/wiadomosci/jakie-korzysci-z-auto-autonomicznych-dostrzegaja-polacy-61220.html
Retrieved July 30, 2021, from https://sjp.pwn.pl/szukaj/inteligencja.html
Romaniuk K (2017) Implikacje koopetycji dla organizacji inteligentnej w perspektywie teorii gier i teorii kosztów transakcyjnych. Przegląd Organizacji 7(930):11–18
Różniewicz E (2019) The prospect of autonomous transport development, praca dyplomowa pod kierunkiem Konecka S., UEP, Poznań
Schumpeter JA (2008) Capitalism, socialism and democracy. Harper Collins Publ, UK
Sovacoola BK, Axsenc J (2018) Functional, symbolic and societal frames for automobility: implications for sustainability transitions. Transp Res Part A 118:730–746
Trzop A (2020) Przegląd rozwiązań z zakresu przemysłu 4.0 stosowanych w obszarze logistyki. Organizacja i Zarządzanie 81:233–247
Vleugel JM, Bal F (2018) More space and improved living conditions in cities with autonomous vehicles. Int J Des Nat Ecodyn 12(4):505–515
Yigitcanlar T, Wilson M, Kamruzzaman M (2019) Disruptive impacts of automated driving systems on the built environment and land use: an urban planner's perspective. J Open Innov Technol Mark Complex 5:24
Zuboff S (2015) Big other: surveillance capitalism and the prospects of an information civilization. J Inf Technol 30:75–89
Zysińska M (2019) Ocena przedsiębiorstw TSL działających w Polsce – dylematy metodyczne badań. Studia i Prace Kolegium Zarządzania i Finansów 173:141–162