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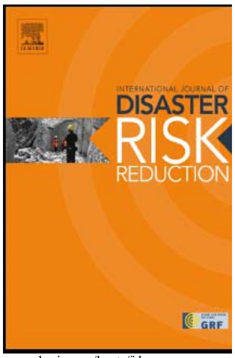

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Location and Allocation Optimization for Integrated Decisions on Post-Disaster Waste Supply Chain Management: On-site and Off-s Separation for Recyclable Materials

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Abstract

Post-disaster waste management is one of the most important operational management systems that have been developed to help affected communities recover and restore conditions back to a stable situation after a disaster. An effective post-disaster waste management strategy still needs to be further developed for optimum efficiency. Hence, this paper aims to present the developed system of post-disaster waste supply chain management strategy (PWSCM) along with the integrated decision-making system for the on-site and off-site separation of recyclable materials. A mathematical model of mixed-integer linear programming is proposed in which the objective aims are to minimize the financial effects through assessment of the fixed costs and variable costs, RSR (Reduction, Separation and Recycling) costs, and the penalty costs associated with the negative environmental and human effects of post-disaster scenarios and to maximize revenue from any sellable waste. The proposed model considers all networks in the debris operation process that consists of waste collection and separation sites, processing and recycling sites, disposal sites and market sites. Moreover, the RSR technologies have also been considered in the proposed model. Due to the limitations of competence of an exact solution method for such a large problem, this study also presents two effective metaheuristic approaches with particular encoding and decoding schemes; Particle Swarm Optimization (PSO) and Differential Evolution (DE) to solve PWSCM. Finally, the numerical tests for PWSCM improvement will be discussed. The performance of the proposed PWSCM improvement system was superior to both the on-site separation model and the off-site separation model.

Keywords: location-allocation optimization, post-disaster waste management, mathematical model, metaheuristic

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1. Introduction

Disaster is any occurrence that causes damage, destruction, ecological disruption of human life, human suffering, or the deterioration of health and health services scale sufficient to warrant an extraordinary response from outside the af community or area [1]. Since the 1950s, the magnitude and number of disasters

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(DM)" with the objective of helping at-risk persons to avoid and recover fro effects of a disaster [4]. The activity of DM consists of four major stages: mitig preparation, response, and recovery. One of the most important stages is the rec stage. This stage was defined as the act of restoring the affected community o back to a normal situation after a disaster [5]. Two of the initial and most signi perspectives of disaster recovery management involve the removal and dispo debris from the affected communities or areas [6]. This activity is a significant on often an overlooked aspect that is associated with post-disaster debris management Post-disaster debris or waste management is a discipline associated with the cont the concepts of the generation of debris, storage collection, transport and tra processing, recycling, reuse, and disposal. The post-disaster debris or management is considered a lengthy, economic, public health engineering, conser of nature, aesthetics, and environmental challenge with a need to consider the attit the public. Currently, the U.S. Federal Emergency Management Agency (FEMA focused exclusively on reimbursing the costs of post-disaster debris operations with the transportation costs, disposal costs, and collection costs [8]. Therefore, F has changed its policies and announced a program offering financial incentiv municipalities in order to encourage the reuse and recycling of disaster debris [6] is considered an opportunity to reduce the costs associated with post-disaster s chain management and the negative effects on environment. According to the pc and timeline employed by FEMA, before the disaster occurs, each commun required to provide potential waste management facilities such as waste collection processing sites, recycling plants, disposal sites and market sites [9]. Generall recovery stage involves debris collection, where the disaster debris is transferred the road and curb sides to temporary processing facilities, where it may go th containment processes such as separation, sorting, grinding incineration, co crushing and wood chipping. After that, all or parts of the disaster debris m transferred to the landfill or incinerator for disposal, whereas parts of it m processed further to be recycled and either reused or sold. However, many cou have also established different strategies that are more appropriate for their circumstances. To comprehend the structure of a post-disaster waste manag system, see Appendix A.1 in the Supplementary data section.

Currently, post-disaster waste management is being developed in many cou Concepts of economic development, social development, and environmental prot are the main dimensions of sustainability with regard to waste management. Prot both the environment and productive resources are among the most significant f of sustainability [10]. Post-disaster waste presents a significant threat to bot environment and society. Hence, post-disaster waste management is becoming an of great interest on a global scale. To achieve a level of sustainable managemer main goal of an effective post-disaster waste management system is not or minimize system costs within the network, but also to minimize any negative effe the environment, humans and society that are present in proximity to the network Many of the negative effects on the environment, humans and society are a fac certain activities associated with post-disaster waste management systems su

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facilities that can effectively process post-disaster waste can have an impact c environment and the people that are in the immediate area of the proposed management facilities.

Several processes of post-disaster waste management systems have been us develop and enhance the network in order to respond to the purposes of sustai waste management. Waste separation is an important component of the main stru of a waste management system since it can affect the economy and the environm the area. This is all pertinent to the feasibility of recycling for the purpos sustainable waste management [13], see Appendix A.1 with regard to sepa approach presented in the Supplementary data section. To reach these goals, separation is used to enhance the management of the post-disaster waste supply (In this study, the optimization technique has been utilized. Optimization is becon powerful approach that is used to solve problems in waste management. Va published research studies have proposed that this technique be applied to management such as those of [10], [14], [15], etc.

In order to enhance and fulfill the research gaps that exist within sustainable disaster waste management, we aim to propose a developed post-disaster waste s chain management strategy by using the location and allocation optimization under the integrated decision-making system for the on-site and off-site separati recyclable materials. There are two goals of this paper. Our first goal is to develo post-disaster debris supply chain management strategy under an integrated dec making system for on-site and off-site separation in handling recyclable materials the optimization technique. The network structure considers waste collection separation sites, processing sites, disposal sites and market sites. Our pro mathematical model aims to select the suitable sites for post-disaster waste manag system, including the collection and separation sites, processing sites and landfi order to provide a debris flow decision-making system as a supply chain minimizing the total costs incurred in that the supply chain. The total costs cons fixed and variable costs associated with the debris collection process, RSR, the dis process, environmental penalty costs and takes into account revenue incurred fror sellable waste. Our second goal is to propose solution algorithms for the larger pro and this paper aims to propose solutions that are representative of two metaheu (Particle Swarm Optimization: PSO and Differential Evolution: DE) to addres problem.

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The remainder of this paper is organized as follows: Section 2 presents an overvi the existing literature. Section 3 presents the conceptual model of the post-di waste supply chain management (PWSCM) strategy and formulates a mathem model for the proposed system. Section 4 presents the solution algorithms of PS(DE intended to address the problem. Section 5 proposed computational experimen the PWSCM model. Finally, a conclusion is given in Section 6.

2. Literature review

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of past experiences [7]. Lin [20] proposed an analysis on policies, political pr priorities, problems and aspects of the waste removal process after Katrina, Brandon et al. [21] proposed an analysis of a case history of the waste recycling e of the US Army Corps of Engineers in Mississippi. Additionally, Karunasena et al proposed an analysis of post-disaster debris management in developing countries on a case study in Sri Lanka, and Brown and Milke [13] studied recycling disaster management based on the past experiences of five international disaster even developed countries. Moreover, this study also proposed an analysis of the benefit comparison of on-site and off-site separation. Ultimately, Brown and Milke recommended that it is possible to have an integrated model where selected mat are separated on-site while the rest would go to an off-site separation facility. No have these academic papers described potential management techniques, but organizations have also proposed guidelines for the post-disaster debris operations as FEMA (2007) [8], USEPA [23], UNEP [24] and EPA [25]. Notably, an inte summary article has been published and presented by [26-29].

According to the facility location and allocation problems that exist and the fact th flow debris decision-making process has been based on post-disaster debris s chain management, an optimization technique has been proposed that can poten overcome this challenge. The optimization technique has been applied to addres relevant humanitarian logistics problems and to attempt to achieve positive results Table 1 presents the important characteristics of the existing studies in this comprising the objective function, mathematical model, exact approach, algo solution, structure of network, and type of separation. Fetter and Rakes [6] propo mixed-integer linear programming model for decision-making with regard t location of the processing sites, aspects of processing availability, and the flo disaster waste from each affected community to the relevant site and proce networks. This study aims to minimize the total costs of the debris manage operations with consideration of the fixed and variable costs of debris collection, costs (Reduction, Separation and Recycling Operations) and disposal costs including the potential revenue of saleable debris. The method of separation employed uses the off-site separation model. A case study in Chesapeake has proposed for validating this model. Hu and Sheu [31] proposed the linear program model in which this study focuses on the transportation, recycling, storage of di waste throughout the disaster recovery stage. The objective function aims to min the reverse logistical costs, psychological cost and risk penalty. Hu and Sheu [31] recommended that the storage and separation techniques should be employed at th site stage of management. The system employed in Wenchuan City in China has proposed in this study. Pramudita et al. [32] presented a location-capacitated arc ro problem that emphasizes the debris collection sites. The goal of this model minimize the travel costs and the costs of establishing intermediate depots in which search meta-heuristics have been proposed to find an acceptable solution. Kim et a proposed selecting a temporary debris management site for the effective d operation system by using both geographical analysis and optimization analysis objective of this was to minimize the total hauling distance for the transpor

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and linear programming method have been applied in this study. Onan et al proposed the employment of a framework to determine the location of a temp disaster management facility with the objective of cost minimization and minimization from hazardous waste exposure. They determined the criteria fo planning of the collection and transportation of disaster debris. This paper pro NSGA-II to find the solution. Wakabayashi et al. [36] presented a strategy of eco and environmental evaluation of a disaster debris management system that conside spatial distribution of temporary storage sites and treatment facilities. This study a linear programming to find solutions and has been tested with a real case study i Prefecture, Japan. This strategy is provided as an example of an off-site sepa system. Lorca et al. [7] proposed a decision-support tool for a post-disaster management system. The mathematical model being proposed optimizes the sel of the processing site, processing capacities, and debris flow decision-making th related to the collection, transport and disposal systems. Moreover, this study ha considered balancing the costs and duration of the relevant disaster waste ope systems. Moreover, Habib and Sarkar [37] presented a two-phase framewor sustainable waste management in the response phase of disasters in whic Analytical Network Process (ANP), fuzzy TOPSIS and Optimization technique been proposed to identify the suitable temporary disaster debris management si another related paper, but one that did not employ the optimization appr Kawamoto and Kim [38], Tabata et al. [12], Gabrielli et al. [39], and Cheng Thompson [40] proposed a system of post-disaster waste management.

Following on from the previous research studies, an effective post-disaster management strategy still needs to be further developed for optimum efficiency. S studies have considered addressing a number of problems associated with devel the effective post-disaster debris operations such as those by [13] and [31] integrated decision-making process for the on-site and off-site separation of recy materials is an issue that has been recommended by many research papers in or develop an effective post-disaster waste supply chain management system. Accord the previous research studies, the merits of the on-site and off-site separation sy for recyclable materials in an overall post-disaster waste supply chain manag system are not well known [13]. Integrating the on-site and off-site separation sy for recyclable materials can balance the advantages of both approaches efficiently maintaining regard for the economic view, environmental perspective, time constr resource availability, degree of mixing of the waste and human and public hazards [13]. To this point, see the advantages of both approaches in Appendi (Table A1). The post-disaster debris supply chain management system now employed that uses the optimization technique is lacking in consideration integrated decision-making process for the on-site and off-site separation of recy materials and the consideration of all networks simultaneously (debris collection processing sites, disposal sites and market sites). Furthermore, an algorithm that be employed to solve the larger problems in this study is lacking due to c competence limitations of the exact solution method. Recently, Particle S Optimization (PSO) and Differential Evolution (DE) have been successfully appl

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making system for the on-site and off-site separation of recyclable materials, as w
a solution algorithm that would solve any larger related problems via the PSO an

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tudy of the optimization model for post-disaster debris management.

Objective	Math model	Multiple/Single Objective	Exact approach	Algorithm	FLP				On/Off site separation
					J	K	L	M	
Total cost (The fixed and variable costs of debris collection, RSR, and disposal and revenue)	MILP	Single	Excel	-		*			Off-site separation
Total transport cost	LP	Single	LINGO	-		None			On-site separation
Total reverse logistical costs, psychological cost, risk penalty	LP	Multiple	CPLEX	-		None			On-site separation
Total hauling distance	MILP	Single	-	Shortest path algorithm/ GIS		*			On-site separation
Total cost (Financial cost, Environmental cost, revenue), total time (Collection time and disposal time) and land usage.	MILP	Multiple	GLPK	-		*			Mixed model separation
Total cost and risk	MILP	Multiple	-	NSGA-II	*				Off-site separation
Total cost (The travel cost and the cost of establishing intermediate depots)	MILP	Single	-	Tabu search	*				None
Shortest distance	LP	Single	Simplex method	Warshall-Floyd		None			On-site separation
Total distance, total transport cost, and treatment and environmental cost	LP	Single and Multiple	Exact method	-		None			Off-site separation
Total cost (The fixed and variable costs of debris collection, RSR, disposal, environmental penalty cost, and revenue)	MILP	Single	LINGO	PSO and DE (Large problem)	*	*	*		Mixed model separation

and separation site, K = processing and recycling site, L = landfill, M = market, LP = linear programming, MILP = mixed gramming, FLP = facility location problem.

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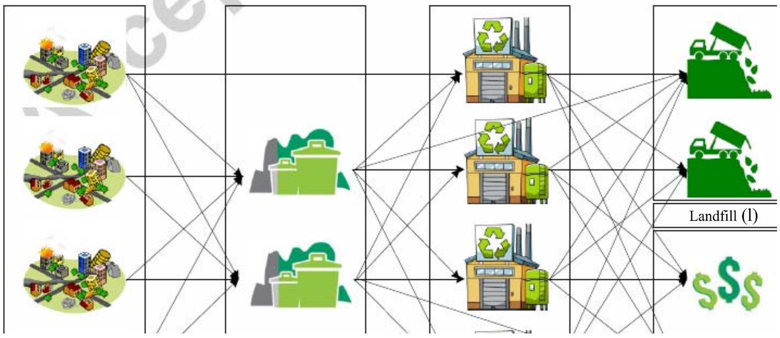
3. Post-disaster waste supply chain management (PWSCM) model

3.1 Conceptual model

The framework of the PWSCM model is designed with respect to a hierarchical r as is shown in Fig. 1. This conceptual model is developed and modified from [6 [7]. The structure of this study considers all networks in the supply chain consist the affected zones, temporary disaster waste collection and separating c (TDWCSC), temporary disaster waste processing and recycling centers (TDWI landfills, and markets. According to [13], it has been proposed that the on-site an site separation should be simultaneously applied since both approaches have dif advantages. When both approaches are merged, the post-disaster waste manag process will be able to balance the advantages and disadvantages of both appro This integrated strategy was employed and succeeded in the 2011 Great East Earthquake and the Canterbury earthquakes (see more details of assessment in Thus, this criterion is taken to apply in the PWSCM model. In our conceptual n the process is separated into three stages that consist of: (1) collection and on-site site separation, (2) off-site processing and recycling, (3) waste disposal and selling. Fig. 1 reveals that in Stage 1, debris removal is initiated after the emer access routes are cleared. The waste is assigned from the affected zones to TDW or TDWPRCs for collection and separation by manual or preliminary technologi this stage, the mixed model of on-site and off-site separation is applied. The wa some affected communities is separated on-site by a TDWCSC, while the r transferred to an off-site separation facility identified as TDWPRC. In Stage separated waste at the TDWCSCs is divided into three parts. The first part is trans to TDWPRCs for processing and recycling; the second part is transferred to landfi waste disposal; the third part is transferred to markets for selling (reuse). After the is processed and recycled using a variety of technologies at the TDWPRCs, the operation will be started. In stage 3, the waste at the TDWPRCs is classified int separate stages for the disposal of the remaining waste and the selling of the sella reusable waste. The remaining waste at the TDWPRCs is allocated to the landf disposal, while the rest is transferred to the market for selling, respectively.



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3.2 Proposed mathematical model

According to the conceptual model, we have modified the general facility lo model and distribution model to formulate a model for the PWSCM strategy proposed mathematical model is formulated as a mixed-integer linear progran problem (MILP), and its basic assumptions are listed as follows:

- The structure of PWSCM strategic consists of affected zones, TDW(TDWPRCs, landfills, and markets.
- To protect bafflement of assignment, this study provides the assumptio debris flow decisions as follows; each affected zone can be served by one from TDWCSC or TDWPRC, each TDWCSC can be served by one landfi one market, the waste from each TDWCSC that need to be treated with RSR technology can be served by one TDWPRC and each TDWPRC c served by one market.
- The capacity of the market is assumed to be infinite.
- All saleable waste types can be sold at all markets.
- All waste needs to be separated before it is assigned for recycling, disposa sale.
- All used parameters are known, constant and deterministic.

Based on the relevant functions of sustainable post-disaster waste management th described in Section 1, this proposed mathematical model aims to consider an eco perspective and an environmental perspective, simultaneously. From an eco perspective, this mathematical model aims to minimize the total costs that are asso with establishing the specific cost of each facility, the operational cost of each p and the transportation cost of each stage, as well as to maximize the potential rev obtained from the saleable waste. From an environmental perspective, this mathem model aims to minimize the negative effects on the environment and humans. value is determined as a penalty cost. The output of this model aims to TDWCSCs, TDWPRCs, and landfills, minimize financial costs, minimize the effe humans and the environment, maximize revenue and provide debris flow dec throughout the supply chain.

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The following notions and parameters are used:

I:	Number of affected zones (i = 1, 2, …, I)
J:	Number of possible TDWCSC facility locations (j = 1, 2, …, J)
K:	Number of possible TDWPRC facility locations (k = 1, 2, …, K)
L:	Number of possible landfill facility locations (l = 1, 2, …, L)
M:	Number of markets (m = 1, 2, …, M)
N:	Number of RSR technologies (n = 1, 2, …, N)
H_i:	Volume of debris in affected zone i
γ_n:	Proportion of debris from affected zone that is eligible to be treated with RSR technology n

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P_T: Fraction of penalty cost from transporting debris
P_O: Fraction of penalty cost from operating debris
F_j^{TDWCSC}: Fixed cost of opening and closing TDWCSC at location *j*
F_k^{TDWSRC}: Fixed cost of opening and closing TDWPRC at location *k*
$F_l^{Landfill}$: Fixed cost of opening and closing landfill at location *l*
V_j^{TDWCSC}: Fixed cost of making separated technology at TDWCSC location *j* (On-site)
V_{kn}^{TDWSRC}: Fixed cost of making RSR technology *n* at TDWPRC location *k* (Off-site)
O_j^{TDWCSC}: Operating cost at TDWCSC location *j*
O_{kn}^{TDWSRC}: Operating cost RSR technology *n* at TDWPRC location *k*
$O_l^{Landfill}$: Operating cost at landfill *l*
C_j^{TDWCSC}: Capacity of TDWCSC at location *j*
$C_l^{Landfill}$: Capacity of landfill at location *l*
C_{kn}^{RSR}: Capacity of RSR technology *n* at TDWPRC location *k*
δ_m: Revenue from saleable portion of debris at market *m*
Ca_{ij}: Cost of transporting debris from affected zone *i* to TDWCSC *j*
Cb_{ik}: Cost of transporting debris from affected zone *i* to TDWPRC *k*
Cc_{jk}: Cost of transporting debris from TDWCSC *j* to TDWPRC *k*
Cd_{jl}: Cost of transporting debris from TDWCSC *j* to landfill *l*
Ce_{jm}: Cost of transporting debris from TDWCSC *j* to market *m*
Cf_{kl}: Cost of transporting debris from TDWPRC *k* to landfill *l*
Cg_{km}: Cost of transporting debris from TDWPRC *k* to market *m*

The following decision variables are used:

$x_j = \begin{cases}1, & \text{If TDWCSC is opened at location } j\\ 0, & \text{Otherwise}\end{cases}$

$y_k = \begin{cases}1, & \text{If TDWPRC is opened at location } k\\ 0, & \text{Otherwise}\end{cases}$

$z_l = \begin{cases}1, & \text{If landfill is opened at location } z\\ 0, & \text{Otherwise}\end{cases}$

$w_{kn} = \begin{cases}1, & \text{If RSR technology } n \text{ is available at TDWPRC } k\\ 0, & \text{Otherwise}\end{cases}$

a_{ij}: Volume of debris from affected zone *i* to TDWCSC *j*
b_{ik}: Volume of debris from affected zone *i* to TDWPRC *k*
c_{jkn}: Volume of debris from TDWCSC *j* to TDWPRC *k* for recycling by RSR technology *n*
d_{jl}: Volume of debris from TDWCSC *j* to landfill *l*
e_{jm}: Volume of debris from TDWCSC *j* to market *m*
f_{kl}: Volume of debris from TDWPRC *k* to landfill *l*
g_{km}: Volume of debris from TDWPRC *k* to market *m*
$\xi a_{ij} = \{1,$ If the volume of debris from affected zone *i* is assigned to TDWCS

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Otherwise

$\xi d_{jl} = \begin{cases} 1, & \text{If the volume of debris from TDWCSC } j \text{ is assigned to landfill } l \\ 0, & \text{Otherwise} \end{cases}$

$\xi e_{jm} = \begin{cases} 1, & \text{If the volume of debris from TDWCSC } j \text{ is assigned to market } m \\ 0, & \text{Otherwise} \end{cases}$

$\xi g_{km} = \begin{cases} 1, & \text{If the volume of debris from TDWPRC } k \text{ is assigned to market } m \\ 0, & \text{Otherwise} \end{cases}$

The following auxiliary variables are used:

FC:	Total fixed cost
TC:	Total transport cost
OC:	Total operation cost
PC:	Total penalty cost for activities with environmental impact
R:	Total revenue

The mathematical model of the problem is formulated as follows:

Minimization of Total Cost:

Min $Z = FC + TC + OC + PC - R$

Subjected to constraints;

$$FC = \sum_j F_j^{TDWCSC} x_j + \sum_k F_k^{TDWSRC} y_k + \sum_l F_l^{Landfill} z_l + \sum_j V_j^{TDWCSC} x_j + \sum_k \sum_n V_{kn}^{TDWSRC} w_{kn}$$

$$TC = \sum_j \sum Ca_{\ j} a_{ij} + \sum_i \sum_k Cb_{\ k} b_{ik} + \sum_j \sum_k Cc_{jk} c_{jk} + \sum_j \sum_l Cd_{jl} d_{jl} + \sum_j \sum_m Ce_{jm} e_{jm} + \sum_k \sum_l Cf_{kl} f_{kl} + \sum_k \sum_m Cg_{km} g_{km}$$

$$OC = \sum_j \sum O_j^{TDWCSC} a_{ij} + \sum_i \sum_j \sum_k \sum_n O_{kn}^{TDWSRC} (b_{\ k}\gamma_n + c_{jkn}) + \sum_j \sum_k \sum_l O_l^{Landf\ ll} (d_{jl} + f_{kl})$$

$$PC = P_T TC + P_O OC$$

$$R = \sum_j \sum_k \sum_m \delta_m (e_{jm} + g_{km})$$

$$\sum_j x_j \leq U^{TDWCSC}$$

$$\sum_k y_k \leq U^{TDWSRC}$$

$$\sum_l z_l \leq U^{Landfill}$$

$$\sum a_{\ j} \leq C_j^{TDWCSC} x_j \qquad \forall j \qquad ($$

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$$\sum_{j} a_{\,j} + \sum_{k} b_{\,k} = H \qquad \forall i \qquad ($$

$$\sum_{i} a_{\,j}\gamma_n = \sum_{k} c_{jkn} \qquad \forall j,n\ (n = 2,\dots,N) \qquad ($$

$$\sum_{i} a_{\,j}\,\eta_1\left(1-\sum_{n=2}^{N}\gamma_n\right) = \sum_{l} d_{jl} \qquad \forall j \qquad ($$

$$\sum_{i} a_{\,j}\,\rho_1\left(1-\sum_{n=2}^{N}\gamma_n\right) = \sum_{m} e_{jm} \qquad \forall j \qquad ($$

$$\sum_{i} b_{\,k}\,\eta_1\left(1-\sum_{n=2}^{N}\gamma_n\right) + \sum_{i}\sum_{n=2}^{N} b_{\,k}\gamma_n\eta_n + \sum_{j}\sum_{n} c_{jkn}\,\eta_n = \sum_{l} f_{kl} \qquad \forall k \qquad ($$

$$\sum_{i} b_{\,k}\,\rho_1\left(1-\sum_{n=2}^{N}\gamma_n\right) + \sum_{i}\sum_{n=2}^{N} b_{\,k}\gamma_n\rho_n + \sum_{j}\sum_{n} c_{jkn}\,\rho_n = \sum_{m} g_{km} \qquad \forall k \qquad ($$

$$\sum_{j} \xi a_{\,j} + \sum_{k} \xi b_{\,k} \le 1 \qquad \forall i \qquad ($$

$$\sum_{k} \xi c_{jkn} \le 1 \qquad \forall j,n \qquad ($$

$$\sum_{l} \xi d_{jl} \le 1 \qquad \forall j \qquad ($$

$$\sum_{m} \xi e_{jm} \le 1 \qquad \forall j \qquad ($$

$$\sum_{m} \xi g_{km} \le 1 \qquad \forall k \qquad ($$

$$a_{ij} \le LN\xi a_{ij} \qquad \forall i,j \qquad ($$

$$b_{ik} \le LN\xi b_{ik} \qquad \forall i,k \qquad ($$

$$c_{jkn} \le LN\xi c_{jk} \qquad \forall j,k,n \qquad ($$

$$d_{jl} \le LN\xi d_{jl} \qquad \forall j,l \qquad ($$

$$e_{jm} \le LN\xi e_{jm} \qquad \forall j,m \qquad ($$

$$g_{km} \le LN\xi g_{km} \qquad \forall k,m \qquad ($$

$$x_j, y\ , z_l, w\ _n, \xi a_{ij}, \xi b_i\ , \xi c_j\ , \xi e_{jm}, \xi f\ _l, \xi g\ _m \in \{0,1\} \qquad \forall j,k,l,m,n \qquad ($$

$$a_{ij}, b_{ik}, c_{jkn}, d_{jl}, e_{jm}, f_{kl}, g_{km} \ge 0 \qquad \forall i,j,k,l,m,n \qquad ($$

The objective of the proposed model is to minimize the total costs associated wi management of the debris removal supply chain in post-disaster scenarios as is sho equation (1). The objective function aims to balance the fixed costs, transport operational costs, penalty costs and potential revenue as is shown in equation equation (6), respectively. Equation (2) represents the fixed costs of the lo opening of TDWCSCs, TDWPRCs, and landfills and the investing RSR technolo each TDWPRC. Equation (3) represents the transport cost through the supply network. Equation (4) represents the operational cost of TDWCSCs, TDWPRC the landfills. Equation (5) presents the penalty costs for activities having environn impacts that are related to the transport and operational processes. In this study; thi is calculated by considering the total costs of transport and operations in whic fraction of the penalty cost (P_T and Po) is provided by the decision m

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revenue incurred from saleable waste obtained from the TDWCSCs and TDWI This is an opportunity to reduce the system costs within the post-disaster waste s chain. In the case of indirect action, this can reduce the negative effects o environment, humans and society in which the reusable wastes are sold instead of disposed of. Equation (7) – equation (9) state that the total number of selected loc cannot exceed the maximum limit of each location type, equation (7) enforces the of selected TDWCSCs, equation (8) enforces the limit of selected TDWPRC equation (9) enforces the limit of selected landfills. Equation (10) – equation (13) the volume of debris assigned to each location type. Equation (10) ensures th volume of debris assigned to TDWCSC cannot exceed the maximum capacity of TDWCSC. Equation (11) limits the volume of debris assigned to TDWPRC acc to the RSR technology capacity available at the TDWPRC. Equation (12) requires TDWPRC must be opened in order to make RSR technologies available. Equation ensures that the volume of debris assigned to the landfill cannot exceed the max capacity of each landfill. Equation (14) guarantees that the volume of debris in affected zone is collected and processed. Equation (15) – equation (17) state th collected debris in each selected TDWCSC is transported to processing (TDWPRC), landfills and markets. Equation (18) and equation (19) state that the in each selected TDWPRC is transported to landfills and markets. To protect a bafflement of the assignment, this study provides conditions according to the assumptions, the conditions are represented as equation (20) – equation (24). Equ (20) provides that each affected zone can be served by one node from TDWC TDWPRC. Equation (21) provides that the waste from each TDWCSC that needs treated with each RSR technology can be served by one TDWPRC. Equation (equation (23) provide that each TDWCSC can be served by one landfill and one m Equation (24) provides that each TDWPRC can be served by one market. Equation – equation (30) state that the binary variable of the assignment is set to 1 whe volume of debris in each node is assigned to each node. Lastly, equation (31) – equ (32) describe non-negativity and the binary conditions of the decision variables.

The solution of the proposed mathematical model is reached with consideration number of TDWCSCs, TDWPRCs, and landfills, the allocation of each node, the planning budget, the penalty of environmental and human effects and the revenue any sellable waste that can be calculated. An integrated model of on-site and o separation for recyclable materials can balance the benefits of both approach several ways [13]. This result can serve emergency management purposes. The f to help in the preparation stage and includes the spatial distribution of waste coll and separation sites, processing and recycling sites, and disposal sites, assignm waste in each affected community, and the expectations of the planning budget second way is to aid in the recovery stage in order to provide debris flow and dire at each step of the post-disaster waste supply chain management process and redu effects on humans and the environment in the post-disaster supply chain netw well.

3.3 Fundamental information

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potential facility location, (iv) the maximum selected location in each type, (v debris composition (reduction percentage) and (v) the fixed and variable penalty associated with transportation, RSR processing and disposal. All input data c determined, estimated and calibrated by the decision makers or experts government or emergency management agencies) before the disaster hits. Curr there are several guidelines and tools that can support the determination of the data in debris management operations. For instance, FEMA [8] has proposed the guic of how costs can be calculated, how the potential debris amounts can be determine so on. The steps involved with generating fundamental information in this study been followed according to the guidelines of FEMA [8].

In the first step, each community is required to generate potential disaster scenaric the potential debris amounts that depend on the severity of those disasters, the di types and the demographic and geographic properties of the affected area. In or guide the estimation process, FEMA [41] provides a set of guidelines for the estimation, along with easy-to-apply methods to estimate the debris amounts. Sim the U.S. Army Corps of Engineering (USACE) have proposed a guide for estimati debris amounts during hurricanes [42]. Moreover, Scawthorn et al. [43] have pro the debris estimation tool that is known as HAZUS-MH. As is presented in the the decision makers can apply those tools for debris estimation. In the second ste potential facility location of each type is considered. The decision makers s provide the potential facility location along with consideration of the environ risks, geographic properties, demographic properties and so on [8]. The pot facility location of each type should be located in an area that does not disrupt business operations or cause dangerous conditions for residents, schools, hospital sensitive areas. The decision makers should consider public lands first in order to costly land leases. The TDWCSCs, TDWPRCs, landfill sites and markets that close proximity to the affected area are all considered ideal locations. Areas TDWPRCs and landfill sites need to be evaluated for TDWCSCs. Furthermor vacant lots, parks and sports fields that will not incur extensive repair costs shou considered for TDWCSCs as well. According to the consideration of the pot facility location of each type, the decision maker should provide an estimate suitable capacity associated with the potential debris amounts that will need to be and processed. Finally, the maximum selected location of each type, the composition (reduction percentage) and the fixed and variable penalty cos transportation, RSR processing and disposal can be estimated and determined b decision makers. In particular, RSR parameters are common knowledge to the e in the recycling field (many of these may already be in use in the local area for eve solid waste management) [6]. For the expectation of obtaining that data, the de makers can use several tools to calculate those figures. Moreover, the historical da be applied to estimate that data as well. A matrix specifying the cost of transp debris between each location type can be created using the Euclidian metric meth which the transportation distance is used to calculate the cost of transporting based on negotiations with trucking contractors [6]. The scale of each facility lo type in this model is proposed for medium- and long-term planning (or annual

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strategy that needs to balance between on-site and off-site separation procedur recyclable materials. Also, the time condition has not been considered in this mode

To reach a possible solution under a variety of scenarios including an emer situation or an irregular situation, the proposed model should be used with s varying conditions in order to obtain results that are unique to each situation, su over-abundance of debris volume, high cost of installing RSR technology, ca shortage, installing the temporary incinerators, installing additional temporary st sites, unusable facility location (after disaster hit) and so on. After a disaster o some emergency situations might also occur. Consequently, the post-disaster supply chain management (PWSCM) model requires a new model solution bas those emergency situations.

According to the problems associated with the NP-hard system, the solution cann found by mathematical programming solution software when a larger probl presented. In the actual practice, the decision made on the operation for facility lo and allocation in the PWSCM problem involves an evaluation of a variety of scen including a range of possible data employed to reach an acceptable solution [44-4 the model, the computation time involves a lengthy amount of time to reach a so and this is not desirable in practice. Therefore, we aim to propose a solution algo by using a metaheuristic approach in this study that is represented in next section.

4. Solution algorithm

As mentioned in the introduction, this paper was motivated by the limitatio applying PSO and DE in solving post-disaster waste management problems. Henc research study has focused on applying two effective metaheuristics – Particle S Optimization (PSO) and Differential Evolution (DE) – to plan the post-disaster management process. The search procedures employed for each algorithm are desc in Appendix A.2 in the Supplementary data section. Details of the encodin decoding schemes, allocation solutions and local searches for PWSCM problen presented in the following sections.

4.1 Encoding and decoding scheme

4.1.1 Encoding

The encoding procedures used in this study start by providing the range of dimen that make up the overall dimensions of the maximal number of the selected locati each location type, the sequence of the location selection process at each location and the sequence of the assignment for allocation purposes. The total dimensions c calculated as 3+I+3J+2K+L where I is the number of affected zones, J is the num TDWCSCs, K is the number of TDWPRCs and L is the number of landfill site more easily understand this, consider an example with two locations within location type and two RSR technologies. For this example, the number of dimensi

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4.1.2 Decoding

To decode the random numbers in a dimension of this problem, a sorting list rul applied in this study. An example of the decoding method is presented in Fig. 3 3(a) presents a decoding example for the maximal number of selected locations in while Fig. 3(b) presents a decoding example for the sequence of location selectior the sequence of the assignments for allocations in Sets 2-7.

As is shown in Fig. 3(a), an example of the decisions for the maximal numb selected TDWPRCs is presented. The maximal number of selected locatio identified using a sorting rule with a choice of the maximal number of se locations. The choice for the maximal number of selected locations can be deter using the equation U+1, where U is the total number of locations that can be se from the candidate location. In this example, we assume that the U value is 2 in location type. Since there are three choices required to make the decision for TDV in this example problem, the three choices are equally ranged under the space betw and 1. Thus, each choice can be selected with a probability of 1/3. Accordingl random value of the maximal number of selected TDWPRCs in Fig. 2 is 0.41 random value is taken between 0.33 – 0.67. Therefore, the decoding solution f maximal number of selected TDWPRCs as provided is 1. The decision on the ma number of selected TDWCSCs and landfill sites in Set 1 can be decoded in the way.

To generate the sequencing in Sets 2-7, the decoding example for the sequer TDWPRC selection (Set 3) is proposed in Fig. 3(b). The sequence is deter according to the order of ascending values in a dimension, in which the seque ordered from the minimum random number to the maximum random number solution for the example for the sequence of the TDWPRC selection in Fig. revealed that TDWPRC 1 is determined as sequence number 2, while TDWPR(revealed as sequence number 1. The same procedure is applied to decod sequencing in Sets 2-7. After both decoding approaches are applied to this probler summary of all solution representations is presented in Fig. 4.

To identify the open/close decision of each location type, the decoding in Sets employed to make the decision. The decision method in each location type is gen following the sequence of the location selection along with the maximal numb selected locations. If the sequence number of the facility location is less than or eq the maximal number of the selected location, that facility location is selected as Otherwise, that facility location is indicated as being closed. The solution of open decision in this example is represented as shown in Fig. 5. As is illustrated in Fig. TDWCSC 1, TDWCSC 2, TDWPRC 2, and Landfill site 2 are opened, whil remaining locations are closed. Note that the value 1 is "open" and the value "closed".

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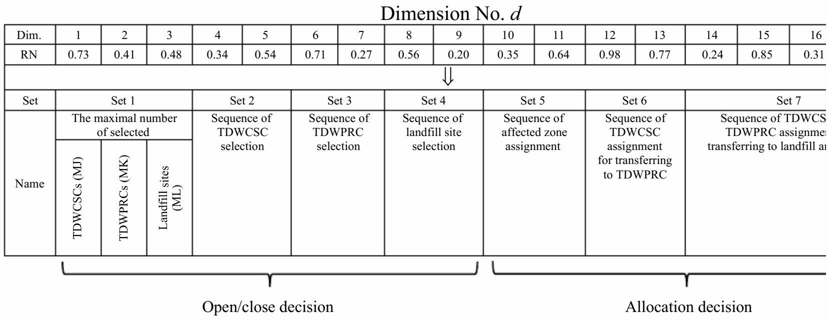


Fig. 2. An encoding scheme for PWSCM system.

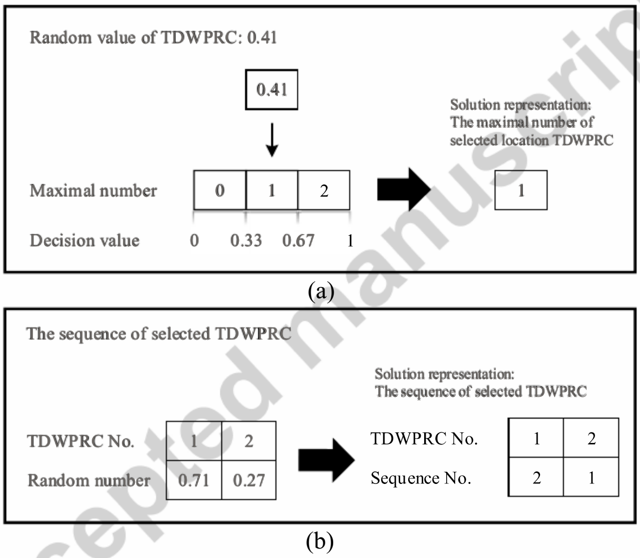
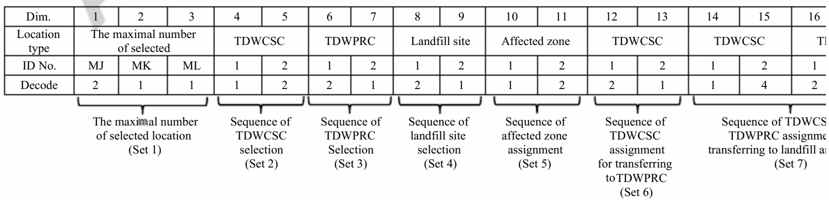


Fig. 3. An example of decoding scheme
(a) A decoding for the maximal number of selected TDWPRC;
(b) A decoding for the sequence of TDWPRC selection.



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4.2 Allocation solution

After the decisions on location selection (Open/Close) and the sequence of assigi at each stage is made, the method of allocation of PWSCM is proposed. The struct method is divided into three main stages: (1) allocating waste for collectioi separation; (2) allocating waste for processing and recycling; (3) allocating was disposal and sale. At each step in each stage, only one arc is added to the syste selecting an origin location with the highest priority and connecting it to a destii location considering the minimum total cost of transport and operation (*LC*) decoding in Sets 5-7 is employed to determine the priority of allocations in whic priority is sequenced from the minimal sequence number to the maximal seq number. The available locations in each location type are considered followin decoding scheme of the open/close decision. The pseudo code of the allocation m is presented in Fig. 6 and described as follows.

Stage 1: Allocating waste for collection and separation
The allocation algorithm is initiated from this stage. All affected zones are assigi the location of collection and separation. To consider the separation meth recyclable materials, both on-site and off-site separation are considered at this Materials from some affected zones are separated on-site, while the rest goes to a site separation facility. The decoding in Set 5 is employed to determine the prioi allocation at this stage. The pseudo code of this stage is listed in Appendix A.3 Table
Stage 2: Allocating waste for recycling
After the allocation of waste for collection and separation is completed, the proc allocating waste for recycling is then proposed for the next step. This stage operat processing and recycling by considering RSR technologies. The waste at TDWC allocated to TDWPRC by separating the debris for each RSR technology, whi waste that is separated at off-site (TDWPRCs) is not needed to make the allocatic complete the sequence of allocation for TDWCSCs, the decoding in Set 6 is ap The pseudo code of this stage is listed in Appendix A.3 Table A3.
Stage 3: Allocating waste for disposal and sale
Finally, allocation of waste for disposal and sale is proposed. The decoding in Se applied to determine the priority of TDWCSCs and TDWPRCs allocation at this In this stage, the waste at the TDWCSCs and TDWPRCs is divided into two poi disposal and sale. The waste is then assigned to landfill sites and markets, respect The pseudo code of this stage is listed in Appendix A.3 Table A4.

I. Allocate waste for collection and separation
$LC \leftarrow min\ \{\{Ca_{ij} + O_j^{TDWCSC}, i \in I, j \in J\}$ *(On-site separation)*
or $\{Cb_{ik} + O_{kn}^{TDWSRC}, j \in J, k \in K, n = 1\}\}$ *(Off-site separation)*
II. Allocate waste for recycling
$LC \leftarrow min\ \{Cc_{jk} + O_{kn}^{TDWSRC}, j \in J, k \in K, n = 2 \ldots N\}$
III. Allocate waste for disposal and sale
TDWCSC
Disposal: $LC \leftarrow min\ \{Cd_{jl} + O_l^{Landfill}, j \in J, l \in L\}$

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4.3 Local search

In general, a local search may be applied to a certain group of vectors or partic order to enhance the exploitation of the search space. The local search typ attempts to improve the quality of the solution by searching for better solutions a its neighbors. According to the above solution, some facility locations do not need opened with full capacity. Therefore, the local search is proposed to improve the q of the solution by providing the maximum capacity of each location. The encod decode are presented as Fig. 7. In this study, the TDWCSC and TDWPRC are pro to find the maximum capacity of each location in order to improve the quality of solution since those factors are able to threaten the next generated stage in finding or worse solutions.

Dimension No. λ

Dim.	1	2	3	4	5	6
RN	0.73	0.41	0.98	0.34	0.54	0.61

(a)

⇓

Dim.	1	2	3	4	5	6
Facility type	TDWCSC 1	TDWCSC 1	TDWPRC 1 with RSR 1	TDWPRC 1 with RSR 2	TDWPRC 2 with RSR 1	TDWPRC 2 with RSR 1
Capacity	8000	6000	10000	4000	6000	8000
	Example		(b)			

Fig. 7. Example of solution representation of local searches: (a) An encoding scheme, (b) A decoding scheme.

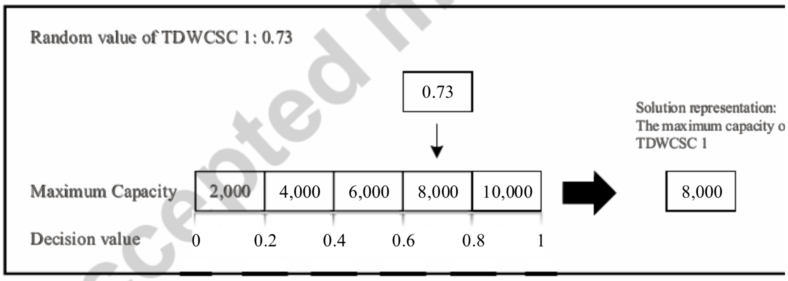

Fig. 8. Decoding example of TDWCSC 1 under the portion of capacity associated the decision value.

According to this example, two locations are considered in each location type an RSR technologies. The dimensions of the local search are set at 6 (J+(K×N)), whe the number of TDWCSCs, K is the number of TDWPRCs and N is the number of technologies. The encoding value in the dimensions is generated with a uniform ra number between [0, 1]. To decode the dimensions of this problem, a sorting list i applied to an individual value in order to generate the maximum capacity. Assum

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According to the random number shown in Fig. 7(a), the solution representation decoding process is illustrated in Fig. 7(b). After the maximum capacity is provide solution is improved using the proposed algorithm. If the fitness value is improve made better than the previous solution, then the new solution and the new fitness are updated.

5. Computational experiments

5.1 Parameter setting and test problems

The performance of the metaheuristic algorithms does not only depend on the sear mechanisms and solution representation procedures, but the parameter setting affects how good the solutions are and how they can be found and converged [4 In this study, two metaheuristic approaches are proposed to solve the PWSCM pro the Differential Evolution (DE) and Particle Swarm Optimization (PSO). In algorithms, the function evaluations are set as a fixed value of 300,000, so sufficient function evaluations are allowed in order to find the best solutio determine the appropriate parameters of PSO and DE; firstly, the prelim experiments are conducted with four different values of each parameter. Then, for parameter, while the values of the other parameters are fixed, the outstanding para values out of all other parameter values are identified according to the total obtained from the algorithm. The following combinations of the parameter's su values are further tested for each size of the specified instance.

A full factorial design is conducted to determine the best parameter setting as is s in Table 2. The average results obtained from the algorithm are then computed for parameter setting. The simple decision-making process is considered according results and they are employed to identify the suitable parameters [48]. The deta parameter experiments are described in Appendix A.5 in the Supplementary . The results indicate that the best solution quality is obtained from the parameter setting as is shown in Table 3. Hence, this method will be used in the follo computational study.

Table 2 Parameter experiments.

PSO	DE
Swarm size: 100, 150, 200	Population size: 100, 150, 200
w: [0.1, 0.5], [0.4, 0.9] (linearly increase)	F: [0.1, 0.5], [0.5, 1] (linearly increase)
c : 1, 1.6	C_r: [0.1, 0.5], [0.5, 1] (linearly increase)
c_g: 1, 1.6	

Table 3 Parameter setting.

PSO		DE	
Number of iterations	1500	Number of iterations	2000
Number of particles	200	Number of population	150
Inertia weight, w	[0.4, 0.9]	Amplification factor, F	[0.1, 0.

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The experiments of PWSCM are implemented using C# language of Microsoft \ Studio 2015. A personal computer with an Intel(R) Xeon(R) X5690 CPU @ 3.4 with 24GB RAM is used to execute and verify the algorithms. To determir performance of PSO and DE, LINGO 16 is proposed to evaluate the algorithm sol The numerical results obtained from the PSO and DE are compared with an oj solution and the PSO and DE are compared under the same conditions which a encoding and decoding schemes. The Gap of the solution (*Gap*) obtained from the or DE versus LINGO software solver and the Relative Improvement (*RI*) of the so obtained from the PSO versus DE is evaluated according to Equation 33 and Equ 34, respectively.

$$Gap = ((Sol_{PSOorDE} - Sol_{LINGO}) / Sol_{LINGO}) \times 100$$
$$RI = ((Sol_{DE} - Sol_{PSO}) / Sol_{DE}) \times 100$$

where Gap = the gap of solution (%) between proposed algorithm solut by using PSO or DE and optimal solution*,

RI = the relative improvement between Sol_{PSO} and Sol_{DE}**

Sol_{PSO} = the solution of proposed algorithm obtained from PSO,

Sol_{DE} = the solution of proposed algorithm obtained from DE,

Sol_{LINGO} = the optimal solution obtained from LINGO software solv

Note;
*The more negative *Gap* is the superior performance of PSO or DE to the LINGO software solver.
**The more positive *RI* is the superior performance of PSO to the DE.

In this study, twenty PWSCM problems were designed to investigate hov performance of the proposed algorithm works for real cases. Twenty instance presented in Table 4 including the number of the affected zones (I), TDWCS TDWPRC (K), landfills (L), markets (M), RSR technology (N), variables constraints. Twenty instances were divided into four categories consisting of smal problem (case 1-5), medium-size problem (case 6-10), large- size problem (case 1 and very large- size problem (case 16-20). The PWSCM problem was tested wit case groups; without a limit of locations and with a limit of locations. Some data been generated randomly based on a real-case problem from the work of Fette Rakes [6], such as the volume of debris, reduction proportion, proportion of re debris from RSR technology saleable as recycled material, cost of RSR techno disposal cost, and revenue. In order to verify the validity of the proposed n Instance 1 is employed to investigate which data is presented in Appendix A.4 results of the example data are provided in Table 5.

Table 6 and Table 7 show the results of the PWSCM problem without a lir locations and with a limit of locations such as the optimal (feasible) solution with computational time limit, the best, average and standard deviations of the total c PWSCM from ten runs of each algorithm for each case, the gap of the solution ar *RI* of the best and average solutions obtained from the PSO and DE. Moreo comparison of the total cost in the supply chain between LINGO software solver,

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Table 4 Experimental design for various cases.

Case	Test problem						Variables	
	I	J	K	L	M	N	Total	Integers
1	10	2	2	2	2	2	153	70
2	15	3	3	2	2	3	320	152
3	20	3	4	3	2	2	437	205
4	32	4	4	4	3	3	772	368
5	40	7	5	5	4	3	1,454	700
6	50	10	5	5	5	3	2,175	1,060
7	64	10	8	5	5	3	3,240	1,579
8	70	15	10	8	6	4	5,547	2,696
9	80	18	12	9	9	4	7,784	3,783
10	96	20	15	10	8	3	9,958	4,830
11	100	20	10	5	10	3	8,235	4,065
12	123	25	15	10	8	3	13,718	6,710
13	208	32	10	10	10	4	21,901	10,848
14	325	40	18	13	12	3	45,169	22,351
15	427	47	20	18	15	4	69,490	34,385
16	500	50	30	20	20	3	95,775	47,290
17	632	60	30	30	30	4	139,445	68,820
18	785	65	25	30	27	4	165,010	81,750
19	890	78	32	36	30	5	235,895	116,794
20	1000	100	50	45	30	5	373,375	184,445

Table 5 The result of example problem

Global optimal solution found			
Total cost ($):	2,248,082	Operation cost ($):	493,925
Fixed cost ($):	72,500	Revenue ($):	180,125
Transport cost ($):	1,469,164	Penalty cost ($):	392,617
Selected TDWCSC:	TDWCSC 2		
Selected TDWPRC:	TDWPRC 1, TDWPRC 2		
Selected Landfill site:	Landfill 1, Landfill 2		
Cpu time(s):	0.21		

According to the results from Table 6 and Table 7, the differences between the g optimum figures of the LINGO software and the proposed algorithm using PSO ar are sufficiently small. When the results of the PWSCM problem without a lin locations are reviewed as is shown in Table 6 and Fig. 9(a), the maximum g 2.36%, as the difference from the global optimum, is admissible in persuadin acceptability of the proposed algorithms' performance. While LINGO software not find the solution within a reasonable computing time (12 hrs.), as the probler increases, PSO and DE showed their potential in solving the larger problems (case without difficulties. The performance of the LINGO software overcame the PSO an while in many cases it took more time than the proposed algorithm that used PS(DE. In the very large- size problem (case 16-20), the proposed algorithm using PS(DE found a preferred solution to what the LINGO software was able to find average gap of the very large-sized problem from PSO was -4.80, while the DE was -

In the results of the PWSCM problem with the limit of locations, as is shown in Ta and Fig. 9(b), the maximum error of both algorithms obtained from the global opt was 2.22% and 2.77%, respectively. In this case, the LINGO software was able to

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sized problem using the LINGO software generated worse solutions than the pro algorithm, in which case 16 could outperform the others at 0.43% by PSO and 0.28 DE. From case 17 to case 20, the LINGO software could not find a solution t problem, while the proposed algorithm using PSO and DE was able to gener solution easily in a relatively short period of time. According to the two case group found that the solution of the PWSCM problem with a limit of facility location is q bit harder to reach than the PWSCM problem without a limit of facility location. T because there would be a longer computation time needed when the problem is s using LINGO software.

To compare the degree of performance of PSO and DE, the results of the *RI* are s in Fig. 10. Fig. 10(a) presents the computational results without the limit of loc while Fig. 10(b) shows the computational results with the limit of location. Notabl more positive *RI* is the superior performance of PSO to the DE. As is shown in 10(a), the DE was able to find the best solution and better average solution than the in some cases. However, the PSO also displays the outstanding performance of th when compared with all of the cases. In terms of the problem with the limit of loc that is shown in Fig. 10(b), the proposed algorithm using PSO produced outsta results when compared to the DE. There were just two cases of the *RI* for whic average displayed a lower level of performance than DE (Cases 6 and 11). A sumn of each problem group produces a positive value, which means that the PSO perfo far better when compared to the DE.

The proposed algorithm also has produced an error in the optimal solution (fe solution), but that error is admissible and can still confirm the acceptability o proposed algorithm's performance. With regard to the employment of metaheur both PSO and DE were considered efficient algorithms to solve the problem i study, wherein which each algorithm serves a different purpose. Though the DE ut a shorter runtime than the PSO and outperformed the PSO in some cases, the generally yielded outstanding results when compared to the DE because the o results of the PSO could generate the final solution better than the DE, especially instances of "with limit location" that are shown in Fig. 10(b). However, both PS DE could be applied to this problem efficiently.

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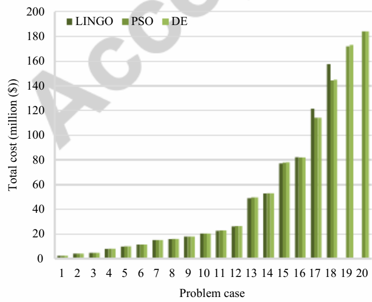

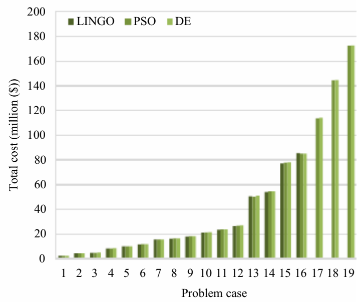

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ntal results of total costs in supply chain network on a set of generated problems for PWSCM problem without a limit of facility

Time(s)	PSO			Time(s)		Gap	DE			Time(s)		Gap		RI PSO V.S. DE	
	Best	Avg.	$\%\frac{SD}{\bar{x}}$	Max	Avg.		Best	Avg.	$\%\frac{SD}{\bar{x}}$	Max	Avg.			Best	Avg.
0.12	2,248,082	2,248,082	0.00	9.23	8.70	0.00	2,248,082	2,248,082	0.00	6.91	6.63	0.00		0.000	0.000
0.19	4,147,719	4,197,464	0.69	16.58	15.85	0.00	4,154,247	4,201,890	0.48	10.45	9.54	0.16		0.157	0.105
0.26	4,717,774	4,770,161	0.61	19.17	15.73	0.37	4,743,637	4,778,167	0.49	10.91	10.03	0.92		0.548	0.168
4.91	7,966,519	7,971,479	0.12	21.66	20.19	1.24	7,966,519	7,976,440	0.15	12.10	10.60	1.24		0.000	0.062
46.31	9,991,247	10,002,143	0.16	32.87	30.48	2.36	9,991,247	9,991,539	0.00	19.19	17.41	2.36		0.000	-0.106
					Avg.	0.79					Avg.	0.94	Sum	0.706	0.230
26.70	11,389,372	11,396,028	0.17	68.81	49.23	1.41	11,389,372	11,389,372	0.00	27.51	26.14	1.41		0.000	-0.058
59.24	15,131,298	15,156,036	0.10	142.37	109.38	0.20	15,131,298	15,137,134	0.02	52.95	46.65	0.20		0.000	-0.125
11.97	15,919,309	15,941,996	0.12	196.40	156.33	0.99	15,919,309	15,946,133	0.12	86.56	72.43	0.99		0.000	0.026
329.57	17,932,287	17,954,250	0.11	283.89	197.57	0.53	17,932,287	17,947,596	0.07	105.48	95.98	0.53		0.000	-0.037
4,800.40	20,455,602	20,487,863	0.16	419.70	389.98	0.68	20,451,317	20,467,015	0.07	250.21	167.53	0.66		-0.021	-0.102
					Avg.	0.76					Avg.	0.76	Sum	-0.021	-0.296
568.39	22,722,402	22,734,780	0.04	319.84	278.16	0.42	22,724,201	22,748,009	0.09	187.56	138.72	0.43		0.008	0.058
*	26,289,751	26,367,311	0.20	605.91	550.57	0.75	26,277,343	26,330,763	0.11	236.78	195.35	0.71		-0.047	-0.139
*	49,569,429	49,675,117	0.13	518.06	491.83	1.34	49,616,613	49,699,993	0.10	293.57	260.35	1.44		0.095	0.050
*	52,955,126	53,054,256	0.14	2267.63	1551.38	0.65	52,914,825	53,058,966	0.18	1156.65	834.72	0.57		-0.076	0.009
*	77,850,798	78,097,400	0.15	4161.66	2318.99	1.08	78,067,804	78,131,755	0.06	1257.37	1150.33	1.36		0.279	0.044
					Avg.	0.85					Avg.	0.90	Sum	0.259	0.023
*	81,948,577	82,102,085	0.09	6429.49	4698.04	-0.14	81,982,681	82,113,771	0.10	3828.86	2863.43	-0.10		0.042	0.014
*	114,119,072	114,184,771	0.04	5632.94	5397.10	-5.93	114,120,154	114,187,495	0.04	3186.78	2979.96	-5.93		0.001	0.002
*	144,331,371	144,559,635	0.18	5988.12	4386.87	-8.33	144,772,211	144,983,525	0.09	2784.12	1627.94	-8.05		0.305	0.293
*	171,946,226	172,317,432	0.10	5497.75	5011.51	N/A	173,021,584	173,127,012	0.04	3321.10	2108.60	N/A		0.625	0.470
*	184,017,153	184,110,265	0.03	23112.97	22843.68	N/A	184,039,379	184,224,530	0.09	17669.26	15648.61	N/A		0.012	0.062
					Avg.	-4.80					Avg.	-4.69	Sum	0.985	0.842

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ental results of total costs in supply chain network on a set of generated problems for PWSCM problem with a limit of facility

Time(s)	PSO			Time(s)		Gap	DE			Time(s)		Gap		RI PSO V.S. DE	
	Best	Avg.	$\%\frac{SD}{\bar{x}}$	Max	Avg.		Best	Avg.	$\%\frac{SD}{\bar{x}}$	Max	Avg.			Best	Avg.
0.11	2,287,871	2,287,871	0.00	8.36	7.02	0.00	2,287,871	2,287,871	0.00	5.27	5.08	0.00		0.000	0.000
0.22	4,248,466	4,261,580	0.15	13.43	10.12	0.00	4,248,466	4,262,005	0.14	7.75	6.39	0.00		0.000	0.010
0.33	4,781,516	4,869,678	1.18	14.96	11.43	0.06	4,906,223	4,914,580	0.06	6.99	6.77	2.67		2.608	0.922
10.81	8,320,360	8,411,137	1.36	21.23	18.87	0.71	8,381,368	8,466,295	0.84	10.98	9.77	1.44		0.733	0.656
170.93	10,005,681	10,116,301	0.82	19.62	19.21	1.53	10,127,872	10,504,335	1.94	10.98	9.19	2.77		1.221	3.836
					Avg.	0.46					Avg.	1.38	Sum	4.563	5.424
99.24	11,718,222	11,798,881	0.77	40.45	36.64	2.22	11,718,222	11,721,883	0.05	21.42	16.82	2.22		0.000	-0.653
43,200.00	15,467,545	15,528,214	0.29	62.04	58.04	0.00	15,484,260	15,541,952	0.24	38.14	34.54	0.11		0.108	0.088
413.49	16,360,544	16,519,496	0.84	39.79	31.50	0.68	16,378,618	16,627,432	0.77	20.26	19.07	0.79		0.110	0.653
910.23	18,085,518	18,278,828	0.48	53.95	49.05	1.01	18,231,508	18,571,328	1.47	23.71	17.70	1.82		0.807	1.600
7,440.47	21,314,826	21,500,924	0.50	84.88	69.80	1.90	21,385,088	21,547,541	0.96	45.07	33.80	2.24		0.330	0.217
					Avg.	1.16					Avg.	1.44	Sum	1.355	1.906
*	23,668,575	23,797,760	0.45	120.29	118.75	0.98	23,699,489	23,785,861	0.40	75.93	67.64	1.11		0.131	-0.050
*	26,728,440	27,022,953	0.90	80.40	65.06	1.25	26,890,925	27,376,307	1.03	39.79	26.38	1.87		0.608	1.308
*	50,115,669	50,656,224	0.51	109.71	89.03	-0.66	50,985,276	51,854,275	1.18	38.97	24.38	1.06		1.735	2.365
*	54,365,664	54,666,788	0.30	758.13	719.99	0.60	54,502,530	54,885,033	0.44	423.19	342.99	0.86		0.252	0.399
*	77,817,591	78,120,094	0.15	1622.43	1449.33	1.02	78,060,828	78,428,764	0.17	596.84	527.80	1.34		0.313	0.395
					Avg.	0.64					Avg.	1.25	Sum	3.038	4.417
*	85,015,474	85,215,109	0.19	858.74	722.76	-0.43	85,135,823	86,117,567	1.23	691.52	626.78	-0.28		0.142	1.059
*	113,711,350	113,977,700	0.14	2631.92	2543.34	N/A	114,064,853	114,389,559	0.20	1595.46	1215.63	N/A		0.311	0.361
*	144,412,521	144,582,565	0.09	2848.63	2651.79	N/A	144,601,319	145,158,103	0.16	2354.22	1883.26	N/A		0.131	0.398
*	172,408,347	172,692,499	0.11	4119.55	3655.57	N/A	172,622,228	173,407,216	0.18	5024.26	2622.45	N/A		0.124	0.414
*	183,205,084	183,769,445	0.11	10167.94	9138.07	N/A	183,915,996	184,679,456	0.15	7965.27	5776.45	N/A		0.388	0.495
					Avg.	-0.43					Avg.	-0.28	Sum	1.095	2.728

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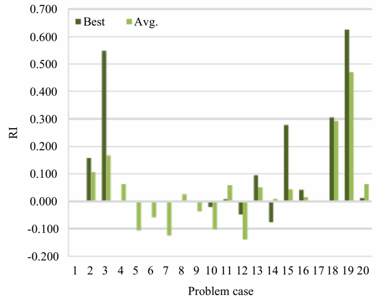

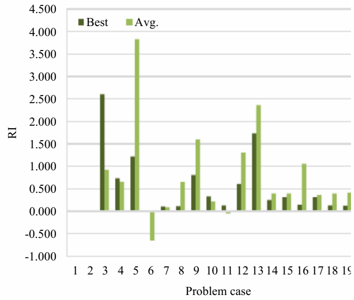

(a) (b)

Fig. 10. The *RI* of each solution between PSO and DE;
(a) without the limit of location, (b) with the limit of location.

5.3 Numerical tests for PWSCM improvement

In this section, we aim to represent the benefits of PWSCM improvement integrated decisions for the on-site and off-site separation of recyclable mat Although the superior performance of the mixed model has been confirmed in studies and has been achieved in many real cases [13], we also desire to prese advantages of this model from an economic perspective and an environn perspective with respect to our proposed model. In this numerical test, Case 9 is u show the performance of the proposed model. The proposed model is comparec the on-site and off-site separation models in the handling of recyclable materials respect to our system. The proposed model is reformulated for on-site separatio off-site separation. To formulate the on-site separation model, the proposed mo Section 3 is reformulated by adding equation 35. While the off-site separation mc formulated by adding equation 36. The numerical tests are solved without the li location. The solution results of the three models are tabulated in Table 8 and are s in Fig. 11.

$$\sum_{k} \xi b_{ik} = 0 \qquad \forall i \qquad ($$

$$\sum_{j} \xi a_{ij} = 0 \qquad \forall i \qquad ($$

From the solution results in Table 8, we can see that the mixed separation r employed for handling recyclable materials could overcome the results of the o and the off-site separation models in terms of both an economic perspective a environmental perspective. The mixed separation model could reduce the total cc 4.04% from the total cost of the off-site separation model and 0.08% from the tota of the on-site separation model. Based on the worst values of each cost, the r separation model with respect to our proposed model was able to increase the le

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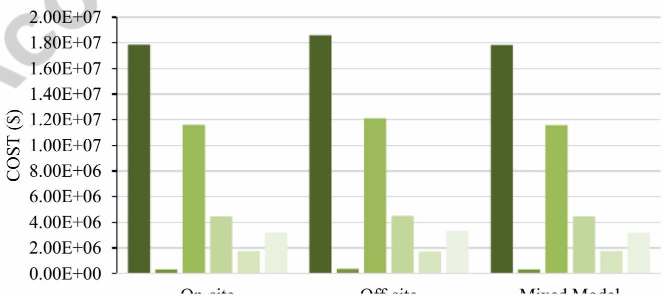
0.16%, and 0.11%, respectively. Whereas, the on-site separation model could over the mixed separation model in terms of fixed costs, operational costs, and re yields at 1.50%, 0.04%, and 0.03%, respectively. Although some costs in the o separation model were preferred over the mixed separation model, the mixed sepa model was still considered to be superior to the on-site separation model in terms overall costs. From an environmental perspective, based on penalty costs, the r separation model could overcome the on-site and off-site separation at 0.11% 3.49%, respectively. In other words, the mixed separation model could reduc negative effects on the environment and humans. Fig. 11 reveals that the r separation model could not overcome all costs in both the on-site and off-site sepa models simultaneously, but the mixed separation model could balance the costs o models. Ultimately, the mixed separation model was able to minimize the total costs was able to overcome both the on-site and off-site separation models.

As is stated in the above analysis, we have determined that our proposed mo capable of down system performance deficiencies in a post-disaster waste supply management context. This provided the empirical insight into how change is imp with regard to post-disaster waste supply chain management systems. With PW improvement, this is a choice that can be a benefit for the government in design planning the sustainable PWSCM strategy in the future.

Table 8 The results of on-site, off-site, and mixed model separation for recy material in terms of cost (cost unit: $).

	On-site	Off-site	Mixed Model	% of cha
Total cost (Z)	17,853,049	18,589,503	17,838,077	4.04%
Fixed cost (FC)	333,500	368,500	338,500	8.14%
Transport cost (TC)	11,599,307	12,113,922	11,580,392	4.40%
Operation cost (OC)	4,466,163	4,514,490	4,468,004	1.03%
Revenue (R)	1,759,015	1,733,091	1,758,498	1.47%
Penalty cost (PC)	3,213,094	3,325,682	3,209,679	3.49%

Note: The percentage of change is based on the worst value of the three models; the more negative of Z, FC, TC, OC, and PC is the superior performance of the worst value; the more positive value the superior performance of worst value.



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This research studied the problem of post-disaster waste supply chain managemen respect to a minimization of total costs in the supply chain. The facility locatio allocation problems were applied in this study. To achieve the sustainable post di waste management system, this research aims to employ an economic perspectiv an environmental perspective simultaneously. The objective function was to min the financial totals of the fixed costs and the variable costs as well as the penalty that are associated with the negative environmental and human effects of post-di waste and to maximize the potential revenue incurred from the sellable waste network structure of the proposed mixed-integer linear programming model composed of the debris collection and separation sites, the processing and rec sites, the disposal sites and the market sites with decision-making for locatin suitable temporary debris collection sites, processing sites and landfills and was u facilitate the debris flow decision-making process. Furthermore, this model deter the separation of recyclable materials where debris is separated on-site or off-sit also determined the RSR technologies in this study as well. Since the problem i hard, this paper proposes employing two metaheuristic approaches with the enc and decoding schemes to solve this problem. The performance values of the pro algorithm by PSO and DE were evaluated using the set of generated cases and compared with the results obtained from the exact solution method using L software solver. The experimental results showed that the proposed algorithm pro an error in the optimal solution (feasible solution), but that error is consi admissible in terms of the acceptability of the proposed algorithm's performance. the PSO and DE could be used as an efficient alternative approach for solving the disaster debris supply chain management problem. However, the PSO dis outstanding performance of the DE since it was able to find an effective quality so even if the runtime was longer than the DE. Finally, we have also propose numerical tests in order to determine the performance of the proposed model.

A key advantage of this research was to analyze the entire supply chain with reg the post-disaster debris problem and to balance the advantages and disadvantages on-site and off-site separation processes of recyclable materials. The proposed could be employed to serve emergency management purposes in the preparation and the recovery stage. Also, our proposed algorithms can be applied in the practice in decision-making in the operation for the purposes of facility locatio distribution in the PWSCM problem. This can evaluate in a variety of scenarios variety of possible data in order to reach an acceptable solution by using the computation time to reach a desired solution for the model. Due to the fac substantial disasters will likely occur in the future as either natural disasters or made disasters, it is believed that the proposed algorithm can be employed to a this challenge. Nevertheless, this research still has some limitations. The pro model in this study was based on a constant parameter and deterministic model, may not represent the uncertainty of different parameters and scenarios. Thu mathematical model needs to be modified for real-world situations. This can be ha

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the appropriate strategy. To apply the real-world problem, the decision makers s prepare potential data carefully, with regard to the volume of the disaster debris. techniques should be used to forecast or predict relevant data. To apply to the s case or special area such as highly populated cities, rural cities, coastal mountainous areas and so on, the proposed model should be revised and conditions should be added in order to solve the problem efficiently. Howeve procedures depend on the decision of the policymakers and the specific situation find themselves in.

Further studies are recommended that should include other constraints in order to addressing the problem more practical such as with regard to road closures or congestion, different modes of transportation, operation times or time schedule uncertainty of disasters, resources, and in other such examples. Finally, the resear have continued to investigate ways to improve the algorithm performance with a range of post-disaster debris management problems.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the data in brie file).

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Highlights

- Post-Disaster Waste Supply Chain Management (PWSCM)
- A mixed-integer linear programming optimization model is proposed.
- The integrated decisions on on-site and off-site separation for recyclabl materials.
- A solution algorithm for the larger problem via two metaheuristics (PSC DE)

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