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Vehicle Dispatching Problem with Weighted Additive Fuzzy Multi-Objective Approach: A Case Study from the Cement Silos

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Abstract

This work presents a novel weighted additive fuzzy multi-objective linear programming (FMOLP) model that solves the cement-silo vehicle-dispatch problem in a fuzzy environment. The weighted additive FMOLP model is formulated in such a way as to simultaneously consider minimizing total transportation cost and the total number of times each truck is subject to demand requirements, operational loading and vehicle capacity constraints. This work uses a real cement study case to demonstrate the feasibility of the proposed model. The main contribution of this work to the literature is its fuzzy mathematical programming methodology for solving the cement-silo vehicle-dispatch problems under a fuzzy environment: multi-truck, multi-type, multi-product and multiple ready mixed concrete plants. The analytical results can help dispatching managers to systematically analyze the cost-effectiveness and number of times required for vehicle dispatch planning in practical applications.

Keywords: Vehicle dispatching problem, cement silos, weighted additive fuzzy multi-objective approach, fuzzy mathematical programming, dispatch planning.

1. Introduction

Cement production in Taiwan occurs mainly in the east, whereas cement consumption occurs mostly in the west. Typically, trucks and ships are used to transport the cement. The transportation processes for cement produced in eastern Taiwan begin at Hualien. Here, ships transport cement to silos at the Keelung, Taichung and Kaohsiung ports. Heavy equipment is used to load the trucks, which then transport cement to *ready mixed concrete* (RMC) plants.

Cement silos are in high demand and the number of cement silos at RMC plants is limited. Notably, RMC from these silos is dispatched on trucks. However, the limited number of cement-silo trucks cannot meet the demand of the RMC plants. Therefore, cement-silo trucks and outsourced trucks are used to meet such demands. Modeling the vehicle-dispatch problem for cement-silo trucks is complex. Vehicles are dispatched manually from cement silos, and only rough estimates of vehicle type and number of trips made by these trucks are available to the RMC plants. To meet the demand, cement-silo trucks must make several trips to minimize total transportation cost. Thus, the vehicle-dispatch problem of cement-silo trucks involves determining the optimal vehicle type and number of vehicles dispatched to each RMC plant.

Many studies have examined dispatch and scheduling problems regarding RMC trucks such as Knabbe and Luna [14] who analyzed the automated system at a cement storage and dispatch terminal and included machine-based units and data-processing units. Shih [22] applied three fuzzy linear programming (LP) models to solve the cement transportation-planning problem in Taiwan. These models considered only total transportation cost as their single objective. Feng et al. [9] developed a model based on a genetic algorithm to identify the optimal dispatch schedule which minimizes total wait time for RMC trucks at construction sites, thereby satisfying the delivery requirements for RMC at various sites. Lu et al. [18] developed a simulation model to solve the one-plant multi-site problem for production planning at a Hong Kong RMC plant. Feng and Wu [8] applied fast and messy genetic algorithms and a simulation technique to develop an RMC dispatch model for RMC batch-plant managers. Yan et al. [31] applied a network flow model to determine the optimal RMC-production and truck-dispatching schedules. They designed a mathematical programming solver to solve realistic problems. Lin et al. [17] modeled the job-shop problem as a multi-objective programming problem for RMC trucks in terms of dispatching and scheduling for small- to medium-sized enterprises. Christiansen et al. [6] presented a novel maritime inventory-routing problem with multiple products allocated into different port silos and different compartments on ships. They developed a heuristic approach which included a heuristic solution algorithm and a genetic algorithm. This approach, which was applied to solve real problem instances, obtained satisfactory solutions. Su [24] developed a *fuzzy multi-objective linear programming* (FMOLP) model that solves the cement-silo vehicle-dispatch problem in a fuzzy environment. In summary, few studies have attempted to solve the vehicle-dispatch problem with weighted additive fuzzy multi-objective approach for cement silos.

In real dispatch problems for cement-silo trucks, input data or parameters, such as forecasting demand, resources, costs and the objective function are often imprecise or fuzzy because specific information is incomplete, unavailable or unobtainable. Notably, conventional mathematical programming approaches cannot solve all fuzzy programming problems. The current dispatch problems of cement-silo trucks contain information in a fuzzy environment, in which the objective function and parameters are incompletely defined and cannot be measured precisely. Dispatching cement-silo trucks is usually performed on the basis of batch-based patterns, facilitating rapid response to the needs of RMC plants. The factors considered are demand, loading operations, vehicle capacity and transportation distance. Since RMC plants differ and data for past operations may be unavailable, dispatchers require a fuzzy method to evaluate trucks and meet truck transportation goals.

Fuzzy set theory was initially developed by Zadeh [34] and was subsequently applied by Bellman and Zadeh [3] to solve decision problems with uncertain characteristics. Türkşen [27] reviewed the development of fuzzy system models from fuzzy rule bases, and

Mendel [19] provided personal reflections on some of the important contributions made by Zadeh [32, 33]. Kerre [13] demonstrated the huge capabilities of Zadeh's extension principle in terms of fuzziness and color using classical mathematical concepts to support information in a natural language. De Silva [7] extended this to an analytical basis for controller tuning using fuzzy decision-making provided by Zadeh-MacFarlane-Jamshidi theorems.

Various theories have since been developed and FMOLP methods have been applied to parameters, constraints, and objective-function problems in formulated models with uncertainty. Zimmermann [35] first applied fuzzy set theory to conventional *linear programming* (LP) models. This model considered LP problems with a fuzzy goal and fuzzy constraints. The applicability of *fuzzy multi-objective programming* (FMOP) has been extended by several studies and has been subsequently applied to solve imprecise problems in several fields. For instance, Lee and Li [15] developed a fuzzy multiple objective decision making (MODM) approach focusing on the desirable features of compromise programming and fuzzy set theory. They also designed a two-phase approach for solving both the crisp and the fuzzy MODM problems.

Chang et al. [5] applied an FMOP model to analyze sustainable management strategies of optimal land development in a reservoir watershed. Karsak and Kuzgunkaya [12] developed an FMOP approach which facilitates decision-making when selecting a flexible manufacturing system. White [29] developed two procedures with weighting factor extensions for finding the efficient set of finite multiple objective vector minimization problems. White [30] designed a framework with weighting vectors to solve multiple attribute problems. Borges and Antunes [4] developed an interactive approach base on the search of the weight space which enables one to show graphical information for FMOLP problems. Lin [16] applied a weighted max-min model for *fuzzy goal programming* (FGP) and fuzzy MODM; this model can be combined with other approaches for FGP. Amid et al. [1, 2] proposed a weighted additive fuzzy multi-objective model for the supplier selection problem to deal with vague parameters and the problem of determining the weights of important criteria under conditions of multiple sourcing and capacity constraints on a supply chain. Su et al. [25] developed an FMOP model with a modified S-curve membership function capable of solving integrated multi-component, multi-supplier, and multi-time-period production planning problems by using fuzzy objectives for the mobile phone manufacturing sector.

Ramazani et al. [21] developed a fuzzy incremental traffic assignment algorithm to solve the user equilibrium route choice problem for the prediction of network flows. Soleymani et al. [23] proposed a Pareto-optimal, multi-objective genetic algorithm, a multi-objective adaptive fuzzy controller approach for active vehicle suspension systems under various traffic conditions in a real driving pattern. Jolai et al. [11] formulated a bi-objective simulated annealing approach to solve a no-wait two-stage flexible flow shop scheduling problem with a number of identical machines at each stage. Ghaffari-Nasab et al. [10] developed a hybrid simulated annealing algorithm to solve the location-routing problem with fuzzy demands for vehicles among established facilities. Nabipoor Afruzi et al. [20] formulated an adjusted fuzzy dominance genetic algorithm to solve the multi-mode resource-constrained discrete time-cost tradeoff problem, in which the goals were to minimize total project time and cost.

To solve the multi-objective cement-silo vehicle-dispatch problem within a fuzzy environment, this study applies a new weighted additive FMOLP model. The original FMOLP model simultaneously minimizes total transportation costs and number of trucks with reference to multiple sources, multiple products, multiple vehicles and multiple RMC plants. The remainder of this paper is organized as follows: Section 2 describes the real dispatch-planning problem; Section 3 formulates the weighted additive fuzzy multi-objective cement-silo vehicle-dispatch decision model; Section 4 characterizes a real cement case, which is used to assess the feasibility of the proposed model; Section 5 offers conclusions.

2. Case Description

2.1. Problem description

The problem is a real-life dispatching problem faced by Taiwanese producers that transport cement. Cement is generally produced in eastern Taiwan, but consumed mostly in western Taiwan. Because Taiwan is divided by the Central Mountain Ridge, which is > 1000 m on average, cement is transported by ships and trucks [22]. The cement transportation processes begins at the Ho-Ping Industrial Park for cement produced in eastern Taiwan. The cement is then transported to silos at the Keelung port, Taichung port and Kaohsiung port by cement transport ships. The cement is then bulk-loaded from silos into trucks, which then transport the cement to RMC plants. The producer operates one factory in eastern Taiwan and controls four consumption ports. The producer controls more than 50 silos and 500 RMC plants (see Figure 1).

Dispatching vehicles from cement silos is a daily planning problem and plans are updated daily or when new information is acquired. This problem encompasses the efficient dispatch of cement-silo trucks, as well as determining vehicle type, the number of vehicles to dispatch and the volume of trucks dispatched from different silos. A single cement silo can store two cement products. The capacity of cement silos is within the range of $4500-20000$ tons. Two cement-silos trucks exist, one with a capacity of 24 tons and the other with a capacity of 30 tons. An important planning goal is to maintain inventory levels in cement silos within the defined upper and lower limits. Keeping inventory levels below upper limits at cement silos is necessary to meet the demand from the RMC plants and demand from the RMC plants must be satisfied by cement silos within the same region. Because of uncertainty and limited tank capacity of the RMC plants themselves, these plants depend on trucks to haul cement from silos. However, the number of cement-silo trucks cannot meet the demand; therefore, outsourced trucks must be used.

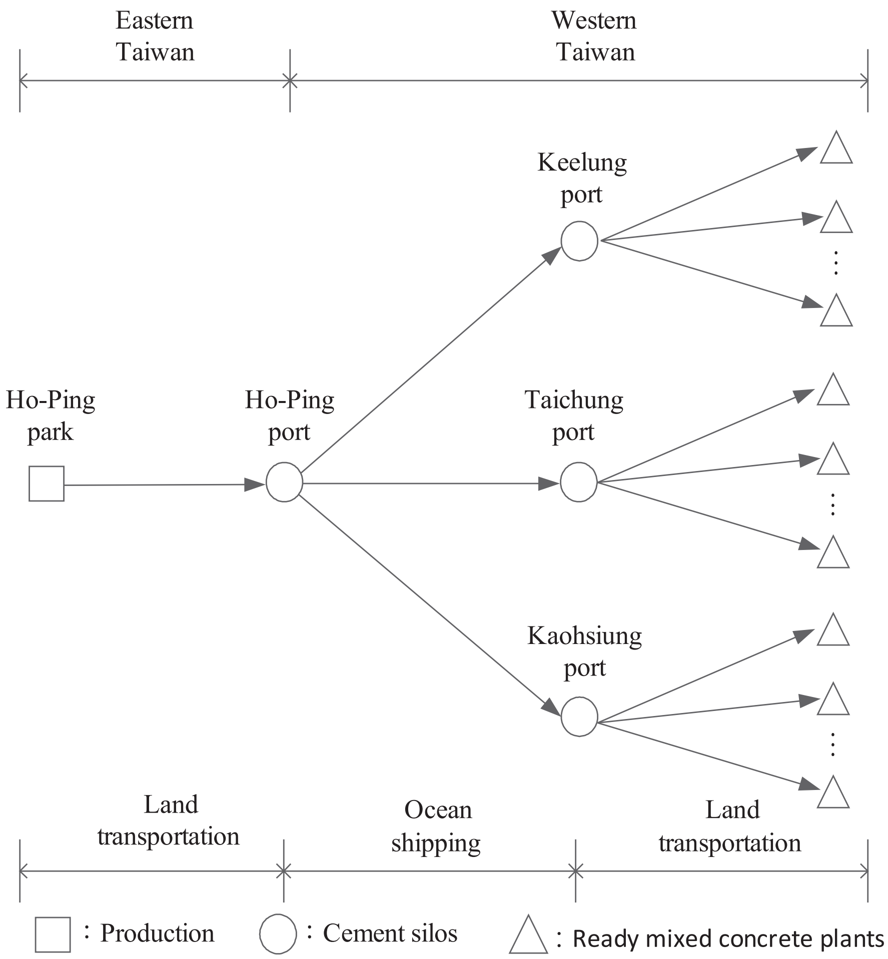

Figure 1: Cement transportation network in Taiwan.

2.2. Current dispatch limitations

Although cement-silo processes have become automated, truck dispatching is still handled manually; for instance, when RMC Plant B requires 100 tons of cement and RMC Plant C requires 200 tons, Company A dispatches trucks manually. Therefore, only rough estimates of vehicle type and the number of vehicles dispatched are available to RMC Plants B and C. In the real-world context of cement-silo truck-dispatch problems, *decision-makers* (DMs) must strike a trade-off among multiple fuzzy goals. For example, the objective function of annual transportation costs may be $1 million, or transportation may be dispatched 150 times. This imprecision requires a set of fuzzy multi-objective models with a set of compromised solutions. Notably, fuzzy multi-objective models can function effectively in uncertain environments. The proposed model minimizes total transportation cost and number of times a truck is dispatched by considering the fixed cost of a truck, transportation cost, truck capacity, operation time of cement silos and maximal transportation distance.

In real dispatch problems for cement-silo, trucks decision-makers encounter a trade-off among multiple fuzzy objectives. These objectives and their related input parameters are usually uncertain due to insufficient information. In other words, the truck-dispatch problem of cement-silo considers two objectives of the monthly total transportation cost and total number of times a vehicle at the same time; in practice, two objective values are the fuzzy values, which need to solve the problem by FMOLP method.

In order to make a comparison of existing cement-silo dispatching results, the solution process needed all parameters adopt the non-fuzzy value, to calculate with existing cement-silo values, such as transportation cost, transportation distance, and loading volume of cement silos per hour, etc. Thus, this work considers the existing cement-silo own truck and outsourcing truck operation related data, uses FMOLP method, to acquire a set of compromise solution, and provide to cement-silo for vehicle dispatching reference.

As such, few studies have focused on the practical issues of the vehicle-dispatch problem for cement silos under a fuzzy environment. Moreover, most studies have attempted to solve the dispatch and scheduling problem for RMC trucks, whereas dispatch problems of cement-silo trucks have not been addressed extensively. However, the proposed RMC truck-dispatch models have not been adequately applied to the vehicle-dispatch problem of cement-silo trucks under a fuzzy environment. Therefore, the following problems require further investigation:

1. As emphasized in previous studies, solving the vehicle-dispatch problem of cement silos under a fuzzy environment is crucial to the transportation planning of cement silos. However, few studies have considered forecasting demand, resources and costs. Additionally, objective functions are often imprecise or fuzzy because some information is incomplete or unobtainable.
2. Flexibility is required to obtain vehicle-dispatch advantages and imprecision is difficult to formulate. Proposed models have focused on dispatching and scheduling problems of RMC trucks or deterministic cases. However, a cement-silo truck-dispatch model with uncertainty is required for actual applications.
3. Relatively few papers have developed effective vehicle-dispatch models for cement silos simultaneously trying to deal with a fuzzy environment and different weights of objective function.
4. Few models have addressed multiple sources, truck types, products and RMC plants with cement silos.

3. The Proposed Model

Assumptions

1. A single cement silo can store two cement products and serve multiple RMC plants.

2. The RMC plants' locations and demand are known and all demand points must be satisfied.
3. Demand of RMC plants is served by multiple vehicles.
4. Multiple types of cement-silo vehicles are considered.
5. A vehicle can only carry one type of cement for discharge at an RMC plant.
6. No violations are allowed for designed vehicle capacity and total vehicle capacity.

Notation

Indices

v : sources of trucks: $v = 0$ if one truck option is selected by a company; otherwise, outsourcing options are selected, $v = 1, 2, \ldots, V$.

k : number of truck types, $k = 1, 2, \ldots, K$.

n : number of each truck type, $n = 1, 2, \ldots, N$.

p : number of cement product types, $p = 1, 2$, where $p = 1$ denotes type I cement, and $p = 2$ denotes type II cement.

u : number of RMC plants, $u = 1, 2, \ldots, U$.

Parameters

d_u : transportation distance from cement silos to RMC plants u (km).

D_{pu} : cement product type demand, p, for RMC plants u (tons).

l_{vknp} : loading volume of the truck dispatched to the vth source, kth truck type and number of trucks n for the pth cement product (tons).

L_{vknp} : loading capacity of the truck dispatched to the vth source, kth truck type and number of trucks n for the pth cement product (tons).

Q_{vkn} : total number of times is dispatched (times/day).

w_i : the weight coefficient that presents the relative importance among the ith fuzzy goals ($0 \leq w_i \leq 1$).

FC_{kn} : fixed cost of truck use for the kth truck type and number of trucks n ($/time).

VC_{vknpu} : transportation cost per km dispatch vth source, kth truck type and number of trucks n for the pth cement product from a cement silo to the RMC plants u ($/km).

$DT^{\max}$: maximal number of times a vehicle is dispatched (times/day).

$OT^{\max}$: maximal operation time of cement silos (hours/day).

SL : loading volume of cement silos per hour (tons/hour).

$TD_{vkn}^{\max}$: maximal transportation distance for the truck dispatched to the vth source, kth truck type and number of trucks n (km/day).

Decision variables

$Y_{vknpu} = 1$ if the vth source, kth truck type and number of trucks n for the pth cement product from cement silos to RMC plants u are selected; otherwise, $Y_{vknpu} = 0$.

3.1. Fuzzy Multi-Objective Linear Programming (FMOLP) model

This study applies the multi-objective function to solve the dispatch problem of cement-silo trucks within a fuzzy environment. In practice, the goals and related input parameters are typically uncertain because information is incomplete. Therefore, this study simultaneously considers two fuzzy objective functions when designing the original FMOLP model.

3.1.1. Objective functions

1. Minimize total transportation costs:

$$\text{Min} \quad Z_1 \cong \sum_{k=1}^{K}\sum_{n=1}^{N} FC_{kn} \cdot Y_{0knpu} + \sum_{v=1}^{V}\sum_{k=1}^{K}\sum_{n=1}^{N}\sum_{p=1}^{2}\sum_{u=1}^{U} VC_{vknpu} \cdot d_u \cdot Y_{vknpu}. \quad (3.1)$$

2. Minimize total the number of times a vehicle is dispatched:

$$\text{Min} \quad Z_2 \cong \sum_{v=1}^{V}\sum_{k=1}^{K}\sum_{n=1}^{N} Y_{vknpu} \qquad \forall\, p, u. \quad (3.2)$$

Symbol "$\cong$" in Eqs. (3.1) and (3.2) is the fuzzified version of "=" and refers to the fuzzification of aspiration levels. For each objective function of the proposed FMOLP model, we assume that a dispatcher has a fuzzy objective. For example, the objective function of annual total transportation costs may be \$2 million, or the number of times is dispatched may be 300. Thus, Eqs. (3.1) and (3.2) are fuzzy with imprecise aspiration levels and incorporate variations of a dispatcher's judgments with regard to solutions for the fuzzy optimization problem. These fuzzy goals require simultaneous optimization by a dispatcher in the framework of a fuzzy aspiration level.

3.1.2. Constraints

1. Constraints on demand for each product and each RMC plant:

$$\sum_{k=1}^{K}\sum_{n=1}^{N}\sum_{p=1}^{2} l_{vknp} \cdot Y_{vknpu} \geq D_{pu} \qquad \forall\, v, u. \quad (3.3)$$

2. Constraints on truck volume for operational loading from cement silos:

$$\sum_{v=1}^{V}\sum_{k=1}^{K}\sum_{n=1}^{N}\sum_{p=1}^{2}\sum_{u=1}^{U} l_{vknp} \cdot Y_{vknpu} \leq OT^{\max} \cdot SL. \quad (3.4)$$

3. Constraints on truck volume for the designed vehicle capacity:

$$l_{vknp} \le L_{vknp} \qquad \forall\ v, k, n, p. \tag{3.5}$$

4. Constraints on transportation distance from cement silos to RMC plants:

$$\sum_{u=1}^{U} d_u \cdot Y_{vknpu} \le TD_{vkn}^{\max} \qquad \forall\ v, k, n, p. \tag{3.6}$$

5. Constraints on the dispatched volume of each product to each RMC plant:

$$\sum_{p=1}^{2}\sum_{u=1}^{U} Y_{vknpu} = Q_{vkn} \qquad \forall\ v, k, n. \tag{3.7}$$

6. Constraints on the total number of trucks dispatched per day:

$$Q_{vkn} \le DT^{\max} \qquad \forall\ v, k, n. \tag{3.8}$$

7. Binary constraints on decision variables:

$$Y_{vknpu} \in \{0, 1\} \qquad \forall\ v, k, n, p, u. \tag{3.9}$$

Equation (3.3) ensures that the total amount of cement transported to each RMC plant exceeds the demand on each cement silo. Equations (3.4) and (3.5) limit truck volume for loading cement at the silos and the volume of trucks for their designed vehicle capacity, respectively; Eq. (3.6) limits transportation distance from cement silos to RMC plants; Eq. (3.7) ensures that the dispatched volume of each product to each RMC plant is appropriate; Eq. (3.8) limits the total number of trips by each truck per day; and Eq. (3.9) models the binary constraints on decision variables.

The original FMOLP model for solving previous problems can be transformed by applying the linear membership function by Zimmermann [35] to represent the fuzzy goals of a DM in the MOLP model and the fuzzy decision-making of multiple-objective proposed by Bellman and Zadeh [3]. The MOLP model was transformed into a fuzzy multi-objective model to solve the ordinary LP problem. In Eq. (3.10), the linear membership function by Zimmermann represents the fuzzy set corresponding to each objective function:

$$f_i(Z_i) = \begin{cases} 1 & \text{if } Z_i \le Z_i^l \\ \dfrac{Z_i^u - Z_i}{Z_i^u - Z_i^l} & \text{if } Z_i^l < Z_i \le Z_i^u \\ 0 & \text{if } Z_i \ge Z_i^u \end{cases} \qquad (i = 1, 2, \ldots, I) \tag{3.10}$$

where Z_i^u and Z_i^l are the upper and lower limits of value domains for the fuzzy objective function for the ith objective function Z_i, respectively. The linear member functions can be specified by requiring the DM to select the objective value interval, $[Z_i^l, Z_i^u]$. From

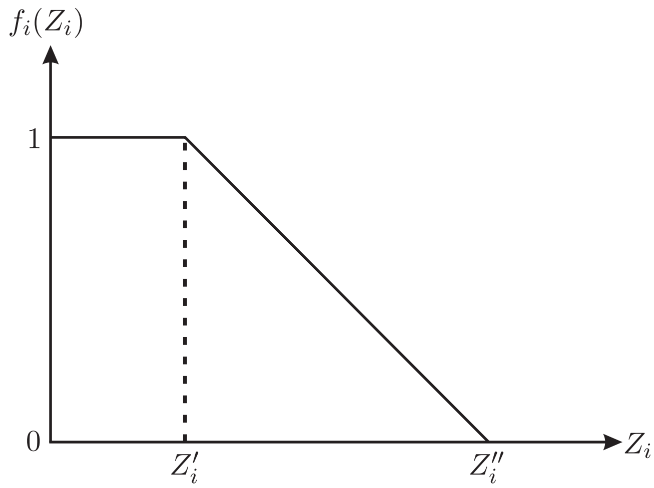

Figure 2: Membership function by Zimmermann.

a practical perspective, the corresponding possible value interval for a fuzzy objective function can be evaluated based on the experience and knowledge of DMs or experts; the equal membership group of the DM is normally in the interval $[0, 1]$. Figure 2 shows the membership functions [35].

The solution procedure of an FMOLP model for the vehicle-dispatch problem of cement silos is as follows:

Step 1: Construct an original FMOLP model for solving the vehicle dispatch problem for cement silos with multiple fuzzy objectives according to Eqs. (3.1)−(3.9).

Step 2: Each fuzzy objective function can be evaluated based on the experience and knowledge of the decision-makers or experts, Z_i, corresponding to the linear membership functions $f_i(Z_i)$.

Step 3: Derive an auxiliary variable, L, and use a minimum operator to integrate the fuzzy set to transform the original FMOLP model into a single objective linear programming model; and introduce L $(0 \leq L \leq 1)$ to measure the degree of satisfaction for decision-making.

Step 4: Solve the single-objective linear programming problem to obtain the initial compromised solution.

Step 5: Complete and modify the interactive model until the measured parameter is satisfied. The FMOLP procedure is as follows:

1. The objective function

$$\text{Max } L \tag{3.11}$$

2. Constraints

$$L \leq \frac{Z_i^u - L_i}{Z_i^u - Z_i^l} \qquad \forall\, i \tag{3.12}$$

Equations (3.3)−(3.9).

3.2. The weighted additive FMOLP model

In the cement-silo vehicle-dispatch problem, fuzzy objectives have different importance to the DM and the suitable fuzzy DM operator should be considered. The weight additive model can handle this problem. This model conceptualizes using a single utility function to present the complete preference of the DM to discover the relative importance of the criteria [28]. In this model, a linear weighted utility function is obtained by multiplying each membership function of the fuzzy objectives by their corresponding weights and then adding the results. If the importance of each objective function differs, a weight is required. The weighted additive models proposed by Tiwari et al. [26] are expressed as:

$$\mu_D(Z_i) = \sum_{i=1}^{I} w_i \cdot f_i(Z_i) \tag{3.13}$$

$$\sum_{i=1}^{I} w_i = 1, \quad 0 \le w_i \le 1 \tag{3.14}$$

where w_i is the weighting coefficient that presents the relative importance among the fuzzy objectives and $\mu_D(Z_i)$ is the membership function for Z_i. The following crisp single objective programming is equivalent to the above model:

$$\text{Max} \ \sum_{i=1}^{I} w_i L_i \tag{3.15}$$

s.t.

$$L_i \le f_i(Z_i), \qquad i = 1, 2, \ldots, I \tag{3.16}$$

$$0 \le L_i \le 1 \qquad \forall \ i \tag{3.17}$$

$$0 \le w_i \le 1 \qquad \forall \ i \tag{3.18}$$

$$\sum_{i=1}^{I} w_i = 1, \quad w_i \ge 0 \tag{3.19}$$

Equations (3.3)−(3.9).

4. Application - cement-silo vehicle-dispatch in Taiwan

This section assesses the accuracy and performance of the proposed model for efficient vehicle-dispatch from cement silos using a real-world test case in Kaohsiung, Taiwan.

4.1. Cement-silo description

Dispatching cement-silo trucks is typically performed on the basis of batch-based patterns to facilitate rapid response to the RMC plant requests. The proposed model

Table 1: Fixed cost of company-owned vehicles.

type of vehicles(tons)	no.	FC_{kn}($)
24	1	1,000
	2	1,000
30	1	1,500
	2	1,500

Table 2: Data for vehicle transportation distances.

source	type of vehicles (tons)	no.	p	$u=1$		$u=2$		$u=3$		$u=4$		$u=5$	
				d_u	VC_{vknpu}	d_u	VC_{vknpu}	d_u	VC_{vknpu}	d_u	VC_{vknpu}	d_u	VC_{vknpu}
0	24	1	1	15	40	18	50	18	50	80	60	120	70
			2	15	40	18	50	18	50	80	60	120	70
		2	1	15	40	18	50	18	50	80	60	120	70
			2	15	40	18	50	18	50	80	60	120	70
0	30	1	1	15	90	18	105	18	105	80	110	120	115
			2	15	90	18	105	18	105	80	110	120	115
		2	1	15	90	18	105	18	105	80	110	120	115
			2	15	90	18	105	18	105	80	110	120	115
1	24	1	1	15	100	18	110	18	110	80	120	120	130
			2	15	100	18	110	18	110	80	120	120	130
		2	1	15	100	18	110	18	110	80	120	120	130
			2	15	100	18	110	18	110	80	120	120	130
1	30	1	1	15	140	18	150	18	150	80	160	120	170
			2	15	140	18	150	18	150	80	160	120	170
		2	1	15	140	18	150	18	150	80	160	120	170
			2	15	140	18	150	18	150	80	160	120	170

is implemented on a real-world test case of cement silos in Taiwan. Here, Company A is major producer of type I and type II cement. These cements satisfy the RMC plant demand from four cement silos in each of the Hualien, Keelung, Taichung and Kaohsiung ports.

This work focuses on the Kaohsiung cement silo. The capacity of the cement silos is 15000 tons, the operation time of the cement silos is 06:00∼18:00 (total, 12 hours), the five RMC plants are located in Tainan and Kaohsiung and eight trucks, including two trucks with capacities of 24 tons and 30 tons, are owned and outsourced. Tables 1−4 list the fixed costs of vehicles, transportation distances, loading data and demand, respectively.

Table 3: Vehicle loading data.

source	type (tons)	no.	p	l_{vknp}	L_{vknp}
0	24	1	1	1-24	24
			2	1-24	24
		2	1	1-24	24
			2	1-24	24
0	30	1	1	1-30	30
			2	1-30	30
		2	1	1-30	30
			2	1-30	30
1	24	1	1	1-24	24
			2	1-24	24
		2	1	1-24	24
			2	1-24	24
1	30	1	1	1-30	30
			2	1-30	30
		2	1	1-30	30
			2	1-30	30

Table 4: Demand in July.

date	p	$u = 1$	$u = 2$	$u = 3$	$u = 4$	$u = 5$
1-10	1	384	312	144	144	612
	2	144	144	72	78	540
11-20	1	378	222	324	144	408
	2	384	138	198	72	282
21-30	1	744	342	504	348	378
	2	546	276	192	258	210
Total	1	1506	876	972	636	1398
	2	1074	558	462	408	1032

4.2. Initial implementation of trucks dispatched for the cement-silos case

4.2.1. Solution for the membership function

The multi-objective vehicle-dispatch problem of cement-silo decision making for the cement case focuses on developing an FMOLP method which optimizes the vehicle-dispatch problem of cement silos within a fuzzy environment. The solution to the fuzzy multi-objective vehicle-dispatch problem should simultaneously minimize total transportation costs and the total number of times trucks are dispatched subject to demand and dispatch volume constraints for each product and each RMC plant, the loading volume of trucks for loading operations from cement silos, the loading volume of trucks

Table 5: Setting membership function values.

Objection functions	Lower bound	Upper bound	Corresponding interval values
Total transportation costs ($)	180,300	194,420	(180,300, 194,420)
Total the number of times is dispatched (times)	30	33	(30, 33)

based on vehicle capacity, the transportation distance from cement silos to RMC plants and total number of trucks dispatched daily.

Total transportation costs in July 26 are the highest. This study is based on July 26 as a fuzzy multi-objective model to assess the applicability of the proposed model. The presence of membership functions for the approach developed by Zimmermann [35] was demonstrated. Calculate the initial solution for Z_i $(i = 1, 2)$ and slightly adjust the upper and lower bounds of the membership function for total costs and times to obtain a corresponding membership function $f_i(Z_i)$ (see Table 5).

Accordingly, the corresponding non-increasing continuous linear membership functions for each of the fuzzy objective functions can be defined via Eq. (3.10), as follows:

$$f_1(Z_1) = \begin{cases} 1 & \text{if } Z_1 \leq 180,300 \\ \dfrac{194,420 - Z_1}{194,420 - 180,300} & \text{if } 180,300 < Z_1 \leq 194,420 \\ 0 & \text{if } Z_1 \geq 194,420 \end{cases} \tag{4.1}$$

$$f_2(Z_2) = \begin{cases} 1 & \text{if } Z_2 \leq 30 \\ \dfrac{33 - Z_2}{33 - 30} & \text{if } 30 < Z_2 \leq 33 \\ 0 & \text{if } Z_2 \geq 33 \end{cases} \tag{4.2}$$

The lower limit (Z_i^l) and upper limit (Z_i^u) in Eqs. (4.1) and (4.2) is acquired through the linear programming software LINGO version 11.0 to solve the crisp single-objective LP model for the vehicle-dispatch problem for the cement-silo case. And the acquired lower and upper limits are $Z_1^l = \$180300$, $Z_1^u = \$194420$, $Z_2^l = 30$ times and $Z_2^u = 33$ times. They shall be the reference of each objective function setting.

4.2.2. Solving the weighted additive FMOLP model

The weighted additive FMOLP model for the vehicle-dispatch problem for the cement-silos case can be transformed into an equivalent ordinary LP form. A weight was assigned to each criterion according to the importance of the relevant goal. The

DM's relational importance or weights of the fuzzy goals are given as $w_1 = 0.9$ and $w_2 = 0.1$; these are relative weights of the transportation cost and the number of times a vehicle is dispatched, respectively. The crisp single objective formulation for the real-world case is as follows:

$$\text{Max } 0.9L_1 + 0.1L_2 \tag{4.3}$$

s.t.

$$L_1 \le \frac{194,420 - Z_1}{14,120} \tag{4.4}$$

$$L_2 \le \frac{33 - Z_2}{3} \tag{4.5}$$

$$0 \le L_i \le 1 \qquad \forall\ i \tag{4.6}$$

$$0 \le w_i \le 1 \qquad \forall\ i \tag{4.7}$$

$$\sum_{i=1}^{I} w_i = 1, \qquad w_i \ge 0 \tag{4.8}$$

Equations (3.3)-(3.9).

The linear programming software program LINGO is used to solve the crisp single-objective LP model for the vehicle-dispatch problem for the cement-silos case. The optimal solution for above formulation is obtained as follows:

Z_1 = \$181,300 and $Z_2 = 31$ times with overall DM satisfaction at the known objective value of 0.9677. To examine the impacts of weights for each objective function and satisfaction degree, this work used 9 test cases are designed. Each test case was a specific combination of (w_1, w_2), where $w_1 \in \{0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1\}$ and $w_2 \in \{0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9\}$. Table 8 describes the solution for the original weight the objective values of \$181,300 for transportation cost goal, 31 (times) for number of times goal, and 0.9667 for satisfaction degree.

Table 6 shows the relevant results, and significant findings are stated below:

1. Due to heavy weight setting, the value of transportation cost and number of times vehicles goals consistently and satisfactory approximated the optimal solution for a single objective.

Table 6: Test of weight ratios.

Cases	(w_1, w_2)	Z_1	L_1	Z_2	L_2	satisfaction degree
1	(0.9,0.1)	181,300	1.0000	31	0.6667	0.9667
2	(0.8,0.2)	181,300	1.0000	31	0.6667	0.9333
3	(0.7,0.3)	181,300	1.0000	31	0.6667	0.9000
4	(0.6,0.4)	184,010	0.8307	30	1.0000	0.8984
5	(0.5,0.5)	184,010	0.8307	30	1.0000	0.9154
6	(0.4,0.6)	184,010	0.8307	30	1.0000	0.9323
7	(0.3,0.7)	184,010	0.8307	30	1.0000	0.9492
8	(0.2,0.8)	184,010	0.8307	30	1.0000	0.9661
9	(0.1,0.9)	184,010	0.8307	30	1.0000	0.9831

2. A goal with high weight ratio indicated high satisfaction. For instance, satisfaction with number of times vehicles reached as high as one in the case 9 of w1=0.1 and w2=0.9. In this case, number of times vehicles is the most important criterion for the dispatcher. The dispatch performance is improved from 31 times to 30 times. Corresponding to the dispatcher preferences ($w_1 = 0.1$ and $w_2 = 0.9$).
3. In the transformation from the weighted additive FMOLP model to single objective model, the membership function was one satisfactory constraint, that is, the membership function setting may have affected the satisfaction degree.
4. Based on the dispatcher's preference, the proposed model has a competence to improve the value of objectives function or performance on the objectives.

4.3. Sensitivity analysis for variable limited values

This work takes the data of actual vehicle-dispatch of cement silo on July 26 as the case, aiming at two values of objective function to design three scenarios for *sensitivity analysis.*

1. Scenario 1: changing the fuzzy intervals of Z_1, the Z_2 are set to their original values in the numerical example. Table 7 presents the data used to implement Scenario 1.
2. Scenario 2: changing the fuzzy intervals of Z_2, the Z_1 are set to their original values in the numerical example. Table 8 presents the data used to implement Scenario 2.
3. Scenario 3: changing the fuzzy intervals of Z_1 and Z_2 at the same time. Table 9 presents the data used to implement Scenario 3.

It is known from above *sensitivity analysis* result that, when the fuzzy intervals of Z_1 and Z_2 are larger, the satisfaction degree gradually decreases from 0.9154 to 0.6154; while the fuzzy intervals are larger, the satisfaction degree decreasing condition would ease up. The result shows that, when the objective value is within the vehicle dispatcher set range, if the satisfaction degree is high, it represents the total transportation costs (Z_1) and total the number of times a vehicle is dispatched (Z_2) increasing would influence the operation performance of cement silo. Thus, the vehicle dispatcher must properly

Table 7: Data for Scenario 1.

Run	1	2	3	4	5	6
Variation rate	0%	+2%	+4%	+6%	+8%	+10%
Z_1	[180,300, 194,420]	[178,497, 196,364]	[176,694, 198,308]	[174,891, 200,253]	[173,088, 202,197]	[171,285, 204,141]
Z_2	[30, 33]					
L	0.9154	0.7653	0.7226	0.6925	0.6667	0.6667

Table 8: Data for Scenario 2.

Run	1	2	3	4	5	6
Variation rate	0%	+2%	+4%	+6%	+8%	+10%
Z_2	[30, 33]	[29, 34]	[28, 35]	[27, 36]	[26, 37]	[25, 38]
Z_1	[180300, 194420]					
L	0.9154	0.8	0.7143	0.6667	0.6364	0.6154

Table 9: Data for Scenario 3.

Run	1	2	3	4	5	6
Variation rate	0%	+2%	+4%	+6%	+8%	+10%
Z_2	[180,300, 194,420]	[178,497, 196,364]	[176,694, 198,308]	[174,891, 200,253]	[173,088, 202,197]	[171,285, 204,141]
Z_1	[30, 33]	[29, 34]	[28, 35]	[27, 36]	[26, 37]	[25, 38]
L	0.9154	0.8	0.7143	0.6667	0.6364	0.6154

control these two objective values, and this work result accord with existing cement silo operation condition.

4.4. Solution for the MODM and the FMOLP

This work takes the data of actual vehicle-dispatch of cement silo on July 26 as the case, and makes comparison aiming at MODM model and FMOLP model; the results are summarized in Table 10. Via Table 10, it is known that the overall satisfaction degree's FMOLP model is better than MODM model. The proposed weighted additive FMOLP model is also better than non-compensatory method and compensatory method, which shows the proposed weighted additive FMOLP model better conforms to the actual demand of vehicle-dispatch of cement silo.

5. Conclusions

Cement silos have become mostly automated; however, truck dispatching is still manual in Taiwan. Dispatchers focus on criteria such as transportation costs, number of dispatches and delivery time. Depending on the dispatching scenario, criteria have varying importance and there is a need to weight them. In real dispatch problems for cement-silo trucks, input data or parameters, such as forecasting demand, resources, costs and the objective function, are often imprecise or fuzzy because some information is incomplete, unavailable or unobtainable. As such, dispatchers encounter a trade-off among multiple fuzzy goals. Fuzzy objectives which have varying levels of importance to

Table 10: Solution of variable methods for the multiple objective decision making.

Method	The MODM model (Goal programming)	The FMOLP model (Non-compensatory method, Zimmermann [35])	The FMOLP model (Compensatory method, Lee and Li [15])	The proposed weighted additive FMOLP model
Objective function	Min $7(d_1^+ + d_1^-)$ $+30,000(d_2^+ + d_2^-)$	Max L	Max $\bar{L} = \frac{(L_1+L_2)}{2}$ $(w_1 = 0.5, w_2 = 0.5)$	Max $w_1 \cdot L_1 + w_2 \cdot L_2$ $(w_1 = 0.9, w_2 = 0.1)$
Value of objective function	588,770	0.8307	0.9154	0.9667
Z_1($)	266,190	184,010	184,010	181,300
Z_2 (times)	33	30	30	31

the dispatcher should be considered. Notably, the weight additive model can handle this problem as this model uses a single utility function to present the complete preference of the dispatcher to reveal the relative importance of criteria.

This paper's major contribution is divided into the methodological perspective and practical perspective. The methodological contribution is that this paper has presented a new the weighted additive FMOLP model to solve the cement-silo vehicle-dispatch problem in a fuzzy environment. The proposed weighted additive FMOLP model simultaneously optimizes total transportation costs and total number of times trucks are dispatched with a fixed truck cost, transportation cost, truck loading capacity, operation time of cement silos and maximal transportation distance. We also make comparison aiming at MODM model and FMOLP model; the proposed weighted additive FMOLP model is better than both MODM model and non-compensatory method and compensatory method. The practical contribution is that it could assist the cement silo dispatchers to plan the vehicle dispatch more efficiently, to greatly reduce the transportation cost. Analytical results obtained for the real-world case indicate that the proposed model offers a practical approach for solving the vehicle-dispatch problem of cement silos within fuzzy environments and effectively meets the practical requirements of dispatchers.

This paper uses a real cement-silo study case to demonstrate that the application of the weighted additive FMOLP model can optimize dispatching alternatives. Even though this is a case study on cement-silo transportation planning, the proposed model can be applied to other industries with similar transportation planning and vehicle dispatching issues, notably, the oil and gas industry. The main contribution of this paper is to make the literature more robust with regard to fuzzy mathematical programming methodology for solving the cement-silo vehicle-dispatch problem in a fuzzy environment.

Future studies the proposed weighted additive FMOLP model may be applied to evaluate dispatching decisions at cement silos that involve different levels of demand uncertainty and other cost components.

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