An integrated fuzzy QFD and fuzzy goal programming approach for global facility location-allocation problem

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AN INTEGRATED FUZZY QUALITY FUNCTION DEPLOYMENT AND FUZZY GOAL PROGRAMMING APPROACH FOR GLOBAL FACILITY LOCATION-ALLOCATION PROBLEM

Companies pursuing extension of their activities and new companies in establishment phase are using various concepts and techniques to consider location decision, because location greatly affects both fixed and variable costs and on the overall profit of the company. This paper suggests a new use of quality function deployment (QFD) for facility location selection problem instead of applying it to traditional product quality promotion. Fuzzy sets concept is also incorporated to deal with imprecise nature of the linguistic judgments of decision makers. First, fuzzy quality function deployment as a stand alone approach is presented to address international facility location selection decision. To consider resource limitations and operational constraints, fuzzy goal programming is combined with fuzzy quality function deployment to present a developed approach to deal with global facility location-allocation decision. A demonstration of the applicability of proposed methodologies in a real world problem is presented.

Keywords: Global facility location-allocation problem, Fuzzy quality function deployment, Fuzzy goal programming, Linguistic variables, Fuzzy numbers.

1. Introduction

Facility location-allocation problem is becoming much more complex with the globalization of business activities. In today's global economy, consumers all over the world want to buy best products at the lowest prices, regardless of where they are produced. This recent trend has resulted in rapid increase of global markets which are causing new competitive pressures on companies to engage in global production and service operations.[1] For a new institute in system design phase selection of best location is inevitable decision. These decisions include selecting suitable location to build new facilities, hiring and buying current facilities. In short, location strategy is selecting a place for new facilities that minimize production and distribution costs or cost of service to potential customers.

Facility location-allocation decision involves organizations seeking to locate, relocate or expand their operations. The facility location-allocation decision process encompasses the identification, analysis, evaluation and selection among alternatives. Plants, warehouses, retail outlets, terminals and storage yards are typical facilities to be located. Site selection starts normally with the recognition of a need for additional capacity.[2] Structuring global manufacturing and distribution networks is a complicated decision making process. The typical input to such a process is a set of markets to serve, a set of products that the company will produce and sell, demand projections for different markets and information about future macroeconomic conditions, transportation and production costs.[3] Recent changes in world politics and economy have made facilities location decisions even more significant and difficult. When a company cannot serve a foreign market by exporting to it because of high transportation costs, tariffs and other restrictions, a viable alternative is to open manufacturing facilities in that country.[1]

Quality function deployment (QFD) originated in 1972 in Japan, as a methodology to be adopted to improve products quality in Japanese firms, such as Mitsubishi, Toyota and their suppliers.[4] QFD is planning and problem solving tool that is gaining growing acceptance for translating customers' requirements into technical attributes of a product. QFD is an effective tool for planning attributes of new products based on customer demands and involves all members of producer or supplier organization.[5] A matrix called the house of quality (HOQ) is used to display relationships between the customers' requirements (WHATs) and the quality characteristics (HOWs). Then through QFD process, HOQ is deployed to ensure the quality characteristics satisfy customers' requirements. Recent QFD applications for various topics and fields are as follows: supplier management,[6-9] logistics management,[10,11] facility location,[12,13] automotive,[14-17] construction,[18-20] Shipping investment process,[21] education,[22-29] electronics,[30-33] food industry,[34-38] healthcare,[39-42] marketing,[43-47] service,[48-55] software,[56-61] product life cycle,[62] e-CRM framework assessment[63] and product planning[64]. This paper suggests a new application for QFD to global facility location-allocation problem, instead of applying it to product quality promotion.

Since the selection of facility location among alternative locations normally involves more than one criterion it can be modeled as multiple criteria decision making (MCDM) problem[65-68] including both quantitative and qualitative criteria. In many situations, the values of qualitative criteria are often imprecisely defined by decision makers with subjective judgments. Always in location-allocation decisions, different locations are compared to each other with respect to different criteria (qualitative and quantitative), such as nearness to the market, availability of raw materials, availability of needed workforce, etc. In fact decision makers subjectively assess these locations by linguistic terms in conjunction with different criteria and then rank them. Decision makers assess different locations with vague linguistic terms such as "better than", "very high" and "very important" and like these. Due to difficulty of forecasting future events, required information is not completely available. Clearly, these assessments have fuzzy nature.

Fuzziness is a type of imprecision that has no well-defined boundaries for its description. It is particularly frequent in the area where human judgment, evaluation and decisions are important, such as decision making, reasoning, learning and so on.[69] The conventional approaches to facility location problem tend to be less effective in dealing with the imprecise or vague nature of linguistic assessments. Fuzzy sets theory is very applicable to dealing with such ill-defined situations and to better reflection of decision makers' vague assessments. Zadeh[70] proposed the fuzzy sets theory providing a highly effective means of handling with imprecise data. To deal with the uncertainty or imprecision in QFD, numerous researchers have attempted to apply fuzzy sets theory to QFD and have developed various fuzzy QFD (F-QFD) approaches. In this paper F- QFD approach is used to help to determine best location in international settings from the viewpoints of decision makers. The paper applies two methodologies for international facility location-allocation decision. First the F-QFD is presented as stand alone methodology and then a combination of F-QFD and fuzzy goal programming (FGP) is presented as extension to consider additional criteria such as resource availability and operational constraints in decision making process. To demonstrate the practicality of proposed methodology, a real world global facility location-allocation problem is studied.

The remainder of the paper is organized as follows. In section 2 a brief literature review about research background is presented. In section 3 fuzzy numbers ranking method is introduced. In section 4.1 F-QFD methodology for international facility location selection decision is described. In section 4.2 combination of F-QFD and FGP as developed approach will be presented. Section 5 demonstrates applicability of the model. Finally in section 6 conclusions will be drawn.

2. Literature Review

There are many studies in the subject of facility location-allocation problem. In view of the rather large number of literatures on the subject, just closely related studies are considered. These literatures are: Bass et al.[71]; Haug[72]; Hodder and Jucker[73]; Hodder and Dincer[74]; Badri et al.[75]; Badri[76]; Canel and Khumawala[1]; Hoffman and Schniederjans[77]; Canel and Khumawala[78]; Badri[79]; Canel and Das[80]; MacCarthy and Atthirawong[81]; Kouvelis et al.[3]; Lorentz[82]; Chen[83]; Chou et al.[84]; Kahraman et al.[85]; Ertuğrul and Karakaşoğlu[86]; Yong[87]; Chou et al.[88]; Guneri et al.[89]; Kuo et al.[90]; Wang et al.[91]; Ertay et al.[92]; Shariff et al.[93]; Syam and Cote[94]; Syam and Cote[95]; Bischoff and Dachert[96]; Ishfaq and Sox[97]; Liu and Xu[98]. Considering the subject of the paper, we only review researches that have been carried out on global facility location-allocation.

Bass et al.[71] implemented a survey by the authors of 118 plants in Latin America, Europe, and Asia recently constructed (or purchased) by U.S. firms to identify what factors guide management's decision to invest abroad directly, what factors influence where they decide to invest, who decides and how, what factors influence the effectiveness of their decisions and what are their biggest unforeseen problems. Haug[72] presented a multi period, mixed integer programming model for multinational facility location-allocation that maximizes after-tax profit to the parent corporation by selecting the optimal overseas manufacturing location(s). Hodder and Jucker[73] formulated the problem of locating plant internationally under price and exchange uncertainty for a mean-variance decision maker. This formulation results in a mixed-integer quadratic programming problem and solution procedure also is presented. Hodder and Dincer[74] presented a model for analyzing international plant location-allocation and financing decisions under uncertainty. The result is a model which is computationally feasible for problems of reasonable size while still including the effects of uncertainty, financial subsidies and hedging strategies on international location-allocation decisions. Badri et al.[75] proposed decision support models for the location of firms in industrial sites. This study was designed as an explanatory investigation of the industrial location decision behavior of executives. In order to obtain the research objectives, three models were developed using multiple linear discriminant analysis. Badri[76] developed a goal programming model to make location-allocation decisions in an international setting in the presence of multiple conflicting factors. With regard to international factors, he incorporated an equation that reflected the ranking of alternative locations as a goal. Canel and Khumawala[1] presented a mixed-integer programming approach for the international facilities location-allocation problem. Their 0-1 mixed integer programming formulations were developed for the capacitated and incapacitated multi- period international facility location problem. Hoffman and Schniederjans[77] developed a two stage model that combines the concepts of strategic management, management science technique of goal programming and microcomputer technology to provide managers with a more effective and efficient method for evaluating global facility sites and making selection decisions. Canel and Khumawala[78] proposed an algorithm for multi- period international facilities location-allocation problem. They provided an efficient branch and bound procedure for solving the incapacitated multi- period international facilities location-allocation problem. Badri[79] proposed the use of Analytic Hierarchy Process (AHP) and goal programming (GP) methodology as aids in making global location-allocation decisions. Canel and Das[80] presented a mathematical model for global facility location-allocation that integrates marketing and manufacturing decisions in a global context. They also presented a four-stage evolutionary model that can guide managers in making global facility location-allocation decisions. MacCarthy and Atthirawong[81] by implementing a Delphi study identified a comprehensive set of factors that may influence international location decisions. Kouvelis et al.[3] studied the design of global facility networks and presented a mixed integer programming model that captures essential design trade-offs for such networks and explicitly incorporates government subsidies, trade tariffs and taxation issues. Lorentz[82] utilized AHP method in the creation of a location/investment target model, with input from a panel of decision makers in the Finnish food industry and a real life application from the Russian agribusiness industry was presented.

3. Ranking Fuzzy Numbers

Different methods for ranking fuzzy numbers have been presented in literatures. We use the Liou and Wang[99] approach for ranking fuzzy numbers in present study. In Liou and Wang[99] method, given $\alpha \in [0,1]$ total integral value of a trapezoidal fuzzy number $\widetilde{A} = (\alpha, \beta, \gamma, \delta)$ is:

$$I_T^{\alpha}(\widetilde{A}) = \alpha I_R(\widetilde{A}) + (1-\alpha) I_L(\widetilde{A}) = \alpha \int_0^1 g_{\widetilde{A}}^{R}(y)dy + (1-\alpha)\int_0^1 g_{\widetilde{A}}^{L}(y)dy = \tag{1}$$

$$\alpha \int_0^1 [\delta + (\gamma - \delta) y] dy + (1-\alpha)\int_0^1 [\alpha + (\beta - \alpha) y] dy = \frac{1}{2}[\alpha(\gamma + \delta) + (1-\alpha)(\alpha + \beta)]$$

Where $I_T^{\alpha}(\widetilde{A})$ is total integral value $\widetilde{A}$, $g_{\widetilde{A}}^{R}(y)$ is the inverse function of right membership function $R(x)$ of $\widetilde{A}$, $g_{\widetilde{A}}^{L}(y)$ is the inverse function of left membership function $L(x)$ of $\widetilde{A}$, $I_R(\widetilde{A})$ is the right integral value of $\widetilde{A}$, $I_L(\widetilde{A})$ is the left integral value of $\widetilde{A}$ and α is the index of optimism that represents the degree of optimism of a decision maker. A larger α indicates a higher degree of optimism. More specifically, when $\alpha = 0$, the total integral value $I_T^0(\widetilde{A})$ which represents a pessimistic decision maker's viewpoint is equal to the left integral value of $\widetilde{A}$, i.e. $I_L(\widetilde{A})$. Conversely, for an optimistic decision maker, i.e. $\alpha = 1$, the total integral value $I_T^1(\widetilde{A})$ is equal to $I_R(\widetilde{A})$. For a moderate decision maker, with $\alpha = 0.5$, the total integral value becomes:

$$I_T^{0.5}(\widetilde{A}) = \frac{1}{2}[I_R(\widetilde{A}) + I_L(\widetilde{A})] \tag{2}$$

If the decision maker is optimistic, α is equal to 1 and in Eq. (1) the total integral value is:

$$I_T^1(\widetilde{A}) = \frac{1}{2}[\gamma + \delta] \tag{3}$$

4. Integrated F-QFD and FGP Process for Global Facility Location-Allocation

This paper proposes an integrated algorithm to deal with the global facility location–allocation problem. The proposed approach consists of two phases: (1) Ordering the alternative facility locations by using F-QFD methodology, and (2) Combining the result of phase 1 with FGP approach to handle the international location-allocation problem.

4.1. F-QFD process for global facility location selection problem

The basic structure of a HOQ for developing global facility location model has been depicted in Fig. 1. Note that just location ordering is done by F-QFD and location-allocation process is implemented by F-QFD-FGP approach that will be detailed in section 4.2.

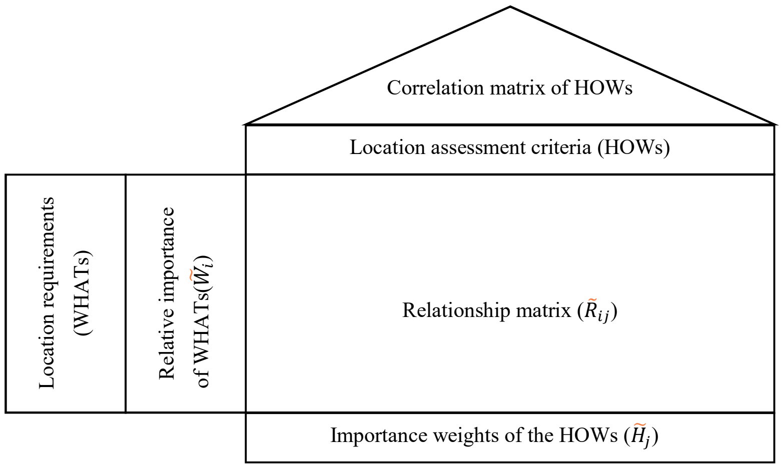

Fig.1: Basic structure of a HOQ for developing global facility location selection model

As indicated in Fig.1 the principal components of proposed HOQ are as follows:

(1) A structured list of major location requirements, which are the customers' requirements (WHATs) in traditional HOQ for product design project.
(2) Main location assessment criteria which are technical attributes (HOWs) in the traditional HOQ for product design.
(3) A central relationship matrix to link the relationships between main location requirements and main location assessment criteria. This matrix presents the degree to which each location assessment criteria satisfies each location requirement.
(4) A column vector displays the relative importance weights of each facility location requirement.
(5) A row vector represents the importance weights of location assessment criteria and identifies the degree to which each location assessment criteria satisfies the overall location requirements.

The correlation degrees between HOWs are not interested in proposed approach in this study. The proposed F-QFD approach for ordering the facility location alternatives is described in a stepwise manner:

Step1: Identifying major facility location requirements (WHATs)
These are the features that a location must have in order to satisfy special requirements. These requirements are derived from existing literatures and also experts' opinions as two main resources for establishing the left column of HOQ. Three experts in economics, political sciences and geographical sciences were invited to state their judgments by linguistic terms. The concept of fuzzy linguistic variable is very useful to dealing with situations which are too complex or too ill defined to be reasonably described in conventional quantitative expressions. A fuzzy linguistic variable is a variable whose

values are words or phrase in natural or artificial language. A fuzzy linguistic variable is often characterized by fuzzy number.[100]

Step 2: Determining the critical location assessment criteria (HOWs)

In this step by interviewing with experts and surveying relevant literatures the important criteria that should be considered for establishing the upper row of HOQ are determined.

Step 3: Determining the relative importance of WHATs

Experts were requested to state their judgments about the weight (relative importance) of *WHATs* by linguistic terms.

Let e be the number of experts and their individual preference on ith WHAT is denoted by $\widetilde{W}_i^k$, k= 1, 2,…, e and i=1,2,…, m. Using the average operator , the final weight of ith WHAT is calculated as:

$$\widetilde{W}_i = \frac{1}{e}\sum_{k=1}^{e}\widetilde{W}_i^{\,k} \qquad (i = 1, 2,\ldots,m) \qquad (4)$$

The synthesized weight $\widetilde{W}_i$ is also a trapezoidal fuzzy number representing a trade–off among the preferences of decision makers.

Step 4: Determining the correlation scores between WHATs and HOWs

Experts express their opinion on correlation between WHATs and HOWs using linguistic variables. By aggregating the assessments of all experts, the final relationship measure between ith WHAT and jth HOW is obtained as:

$$\widetilde{R}_{ij} = \frac{1}{e}\sum_{k=1}^{e}\widetilde{R}_{ij}^{k} \qquad i = 1, 2,\ldots, m\ ,\ j=1,2,\ldots,n \qquad (5)$$

Where $\widetilde{R}_{ij}^{k}$ denotes the relationship measure between ith WHAT and jth HOW through the kth expert's judgment. The synthesized relationship measure $\widetilde{R}_{ij}$ is a trade-off of the group knowledge on the problem and is a fuzzy number too.

Step 5: Calculating the importance weights of HOWs and building HOQ

We can now complete the HOQ, by calculating the importance weights of the HOWs. Like previous step the importance weights of HOWs are defined as fuzzy numbers by deriving the experts' judgments. Fuzzy weighted average is adopted to calculate the final importance weights of HOWs. The fuzzy importance of HOWs, denoted by $\widetilde{H}_j$, is calculated as:

$$\widetilde{H}_j = \frac{\sum_{i=1}^{m}\widetilde{W}_i\widetilde{R}_{ij}}{\sum_{i=1}^{m}\widetilde{W}_i} \qquad (j=1,2,\ldots,n) \qquad (6)$$

Since $\widetilde{W}_i$ and $\widetilde{R}_{ij}$ are fuzzy numbers, the fuzzy weighted average $\widetilde{H}_j$ is also a fuzzy number.

Step 6: Assessing each potential location in conjunction with different HOWs

After establishing HOQ, experts express their opinions about different locations in relation to each HOWs with linguistic variables.

Step 7: Calculating suitability measure (SM) for each potential location and final ranking of locations

In final step, SM is calculated for each location alternative. This measure reflects the overall level of satisfaction that each location provides in relation to different HOWs. The SM for rth location alternative $\tilde{S}_r$ is obtained by the following equation:

$$\tilde{S}_r = \frac{1}{\sum_{j=1}^{n} \tilde{H}_j} \sum_{j=1}^{n} \left(\frac{1}{e} \sum_{k=1}^{e} \tilde{L}_{krj}\right) \tilde{H}_j = \frac{1}{e \sum_{j=1}^{n} \tilde{H}_j} \sum_{j=1}^{n} \sum_{k=1}^{e} \tilde{L}_{krj} \tilde{H}_j \qquad r = 1,2,\dots,s \tag{7}$$

Where $\tilde{L}_{krj}$ is the assessment of kth expert for rth location regarding jth HOW, s is the number of locations, e is the number of experts (decision makers). The SM also is trapezoidal fuzzy number and in essence is fuzzy weighted average.

Step 8: ranking the suitability measures of locations.

The calculated SMs for each location are fuzzy numbers and so fuzzy numbers ranking method as detailed in section 3 is used to prioritize different locations. The result of F-QFD will be the order of alternative locations. These results will be integrated with FGP in the next phase.

4.2. The combined F-QFD and FGP (F-QFD-FGP) approach for global facility location-allocation problem

The F-QFD only approach does not consider resource limitations and operational constraints to support selected facility locations. If the F-QFD approach suggests greater importance to certain locations, there should be enough resources available to support the selection of those locations. The higher SM in phase 1 for a location does not necessarily ensure the establishment of that location due to resource shortages and other operational constraints that may not suggest its selection.

Therefore in this section a combined F-QFD and FGP approach abbreviated as F-QFD-FGP is proposed for taking into account resource restrictions and relevant constraints.

When formulating a multi-objective linear programming problem, various factors of the real world system should be reflected in the description of the objective functions and the constraints. Naturally, these objective functions and constraints involve many parameters of which possible values are assigned by the experts. But in most real situations, the possible values of these parameters are often imprecisely or ambiguously known to the experts. Therefore it may be more appropriate for these parameters to be represented by fuzzy numbers.[101] We have two fuzzy goals and ten resource and production and operations related constraints that some of them have fuzzy nature.

The model involves two types of decision variables. The first set of decision variables denotes the location alternatives Y_r, which is a zero-one variable (equals 1, if location *r* is open, and zero, if it is closed). The second set denotes the allocation (or transportation) from locations to distribution centers (X_{rd} is quantity of units transported from location *r* to distribution center *d*). Description of the variables and parameters used in the model has been presented in Appendix A.
The fuzzy objective functions are as follows:

- Maximizing the chance of selection for locations with greater SM in F- QFD

$$Max\ \tilde{Z}_1 = \sum_{r=1}^{s} \tilde{S}_r Y_r \tag{8}$$

This goal establishes a strong relationship between output of F-QFD and FGP so that ensures potential location alternatives that has larger SM have greater chance to be open and this is reasonable.

- Minimizing total costs

$$Min\ \tilde{Z}_2 = \sum_{r=1}^{s} \tilde{F}_r Y_r + \sum_{r=1}^{s} \tilde{V}_r Y_r + \sum_{r=1}^{s}\sum_{d=1}^{f} \tilde{C}_{rd} X_{rd} \tag{9}$$

The system constraints reflect resource restrictions and related functional limitations are given by the following set of equations:

- Fixed costs budget

$$\sum_{r=1}^{s} \tilde{F}_r Y_r \le \tilde{F} \tag{10}$$

- Variable costs budget (include materials, labor and overhead costs)

$$\sum_{r=1}^{s} \tilde{V}_r Y_r \le \tilde{V} \tag{11}$$

- Product demand by different distribution centers

$$\sum_{r=1}^{s} X_{rd} \ge \tilde{D}_d \qquad for \quad d = 1,\dots,f \tag{12}$$

- Maximum production limit for different locations

$$\sum_{d=1}^{f} X_{rd} \le \tilde{P}_r \qquad for \quad r = 1,2,\dots,s \tag{13}$$

- Quality of life

$$\sum_{r=1}^{s} \tilde{Q}_r Y_r \ge \tilde{Q} \tag{14}$$

- Transportation costs budget

$$\sum_{r=1}^{s}\sum_{d=1}^{f}\widetilde{C}_{rd}X_{rd} \leq \widetilde{C} \tag{15}$$

- Country restriction for air quality

$$\sum_{d=1}^{f}X_{rd} \leq T_r \qquad for \quad r=1,2,\ldots,s \tag{16}$$

- Government awarded loans

$$\sum_{r=1}^{s}\widetilde{G}_r Y_r \geq \widetilde{G} \tag{17}$$

- Desired expansion rate

$$\sum_{r=1}^{s}Y_r \geq L \tag{18}$$

There is a need for system constraints to ensure that transportation will proceed only if the location is open. The following inequality meats this requirement:

$$\sum_{d=1}^{f}X_{rd} - MY_r \leq 0 \quad and \quad X_{rd} \geq 0 \qquad for\, r=1,2,\ldots,s\,) \tag{19}$$

Where, M is an arbitrary large number.

As stated before, first objective function is to ensure locations with higher SM have more chance to be selected. The second objective is cost minimization type and at present model it includes three cost items: fixed costs budget, variable costs budgets (materials, labor and overhead costs) and transportation costs budget (all costs at present model are categorized as these three items).

Constraints (10) and (11) present upper limits of fixed and variable costs. Constraint (12) guarantees meeting product demand by different distribution centers and constraint (13) prevent production of different locations exceed their limits.

The term quality of life (QOL) refers to the general well-being of individuals and societies. The term is used in a wide range of contexts, including the fields of international development, healthcare, and politics.[102] In 2005, The Economist Intelligence Unit (EIU) applied a survey to determine different countries quality of life score using nine factors as follows: (1) healthiness, (2) family life, (3) community life, (4) material well being, (5) political stability and security, (6) climate and geography, (7) job security, (8) political freedom and (9) gender equality.[103] The obtained scores were out of 10 but we multiplied them by 10 to round numbers and make the computations easier. The data of quality of life index was for 6 years ago and so based on the experts' advice we made some modifications in the data. Constraint (14) ensures that total quality of life for selected locations will be higher than total targeted level for quality of life. Constraint (15) is about maximum transportation costs budget.

Air quality restrictions are standards and legislations developed by different countries to keep the air clean and healthy (as presented by constraint (16)). Air quality index (AQI) is a number used by government agencies to communicate to the public how polluted the air is currently or how polluted it is forecast to become. Many countries monitor groundlevel ozone, particulates, sulfur dioxide, carbon monoxide and nitrogen dioxide and calculate air quality indices for these pollutants.[104]

Constraint (17) guarantees that total government awarded loans for selected locations will be higher than targeted value. As presented by constraint (18), the desired expansion rate is the minimum number of locations that must be opened.

The general steps of F-QFD-FGP approach are summarized in Fig. 2.

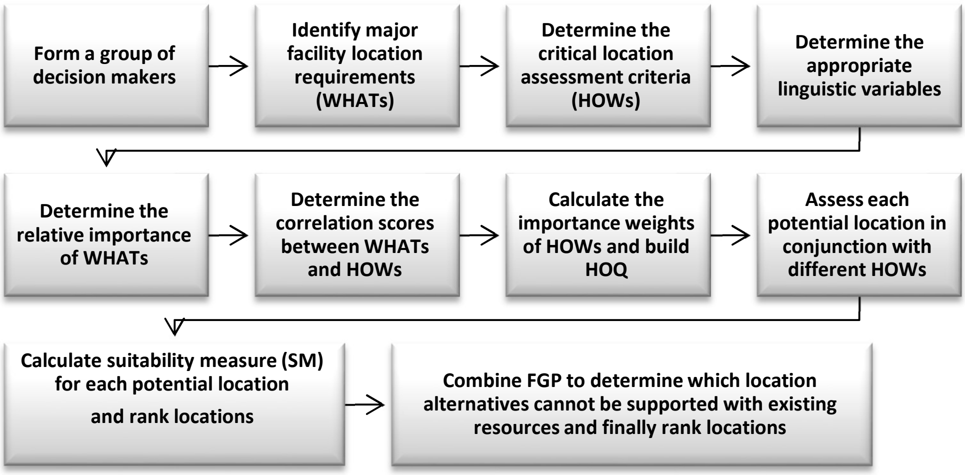

Fig. 2: The general steps of proposed F-QFD-FGP approach

5. Model Implementation

The global facility location-allocation problem which considered by Badri[79] is restudied in this work because both studies consider the same problem (global facility location-allocation problem). The obtained results finally will be compared and discussed. The problem is as follows:

A petrochemical company is evaluating six potential plant location sites in six Middle Eastern countries, namely Kingdom of Saudi Arabia (KSA), the United Arab Emirates (UAE), Bahrain (BAH), Kuwait (KUW), Qatar (QAT) and Oman (OMN). The production plants are to serve six distribution centers in Dubai (in the United Arab Emirates), Tehran (in Iran), Jeddah (in Kingdom of Saudi Arabia), Manama (in Bahrain), New Delhi (in India) and Amsterdam (in Netherlands). Given the resource limitations and preferences, decision makers need to determine which location site to open and how much in quantity to transport from each location to each distribution center.

The input data which indicate the parameters of the problem are shown in Table 1.

Table 1: The required resources and operations data (in annual basis)

		Location Alternatives					
Data	Level	UAE	KSA	BAH	KUW	QAT	OMN
Fixed Costs	α	1500	2050	2800	1400	1550	1450
	β	1700	2350	3100	1600	1750	1650
	γ	1800	2450	3200	1700	1850	1750
	δ	2000	2750	350	1900	2050	1950
Variable Cost	α	400	500	550	450	450	400
	β	500	600	650	550	550	500
	γ	600	700	750	650	650	600
	δ	700	800	850	750	750	700
UAE Unit Transportation Cost	α	40	250	400	220	210	120
	β	50	350	450	270	260	150
	γ	55	400	500	320	310	180
	δ	65	450	550	370	360	210
IRN Unit Transportation Cost	α	150	325	250	150	200	130
	β	180	375	300	250	250	160
	γ	210	425	350	300	300	190
	δ	240	475	400	350	350	220
KSA Unit Transportation Cost	α	250	80	150	190	220	250
	β	300	100	180	220	270	300
	γ	350	120	210	250	320	350
	δ	400	140	240	280	370	400
BAH Unit Transportation Cost	α	210	170	210	230	150	235
	β	260	220	260	280	170	285
	γ	310	270	310	330	190	335
	δ	360	320	360	380	210	385
IND Unit Transportation Cost	α	205	295	260	265	265	165
	β	255	345	310	315	315	195
	γ	305	395	360	365	365	225
	δ	355	445	410	415	415	255
NET Unit Transportation Cost	α	500	600	530	570	510	460
	β	570	680	600	640	580	525
	γ	640	760	670	710	650	590
	δ	710	820	740	780	720	655
Quality Of Life	α	80	60	70	70	75	50
	β	100	80	90	90	95	70
	γ	120	100	110	110	115	90
	δ	140	120	130	130	135	110
Governmental Loans(10^6\$)	α	80	60	70	65	70	50
	β	100	80	90	85	90	70
	γ	120	100	110	105	110	90
	δ	140	120	130	125	130	110
Maximum Production	α	1600	1400	1300	700	1900	900
	β	1800	1600	1500	800	2100	1000
	γ	1900	1800	1700	900	2200	1100
	δ	2100	2000	1900	1000	2400	1200

Table 1: Continued

Data	Targeted Level			
	α	β	γ	δ
Transportation cost	8000000	9750000	10250000	12000000
Demand for UAE	1050	1200	1300	1450
Demand for IRN	1200	1400	1500	1700
Demand for KSA	1100	1300	1400	1600
Demand for BAH	560	660	710	810
Demand for IND	1050	1200	1300	1450
Demand for NET	350	400	450	500
Quality of life	250	350	400	500
Governmental loans (US dollars)	280	330	380	430

Table 1: Continued

Fixed cost (US dollars)	71690000
Variable Cost (US dollars)	2800
UAE restrictions for air quality	2000
KSA restrictions for air quality	1800
BAH restrictions for air quality	1700
KUW restrictions for air quality	1100
QAT restrictions for air quality	2200
OMN restrictions for air quality	1000
Desired expansion rate	4

Table 2 presents fundamental facility location requirements (WHATs) by details. These features were derived from facility location literatures (MacCarthy and Atthirawong[81]; Badri et al.[75]; Heizer and B. Render[105]; Badri[79]; Bass et al.[71]; Canel and Khumawala[1]; Kouvelis et al.[3]; Lorentz[82]; Hodder and Dincer[74]; Hoffman and Schniederjans[77]; Chuang[13]; Canel and Khumawala[78] and Canel and Das[80]) and experts' judgments.

Table 2: Major facility location requirements (WHATs)

WHATs	Details	Abbreviation
Proximity to customers to being responsiveness to market trends	Proximity to demand; size of the market that can be served; cost of serving markets; shipping costs to market areas; responsiveness and delivery time to markets; population trends and variations in demand	PC
Labor availability, costs and attitudes toward unions	Availability of required professional and nonprofessional workforce; wage rates; unions' regulations, quality of workforce; workforce productivity; unemployment rate	LA
Availability of raw materials and related costs	Closeness to material and components, location of suppliers, availability of storage facilities and freight costs of raw materials and components	AM
Costs and availability of utilities	Quality and reliability of utilities (e.g. water supply; waste treatment; power supply; availability of fuels, etc.); utilities costs; telecommunication systems	CA
Government incentives	Government provided industrial infrastructures, roads, insurance, tax exemptions, tax holidays and interest-free loans	GI
Land and constructions costs	Costs related to purchasing land for facilities construction; constructions costs of buildings; Availability of space for future expansion	LC
Nearness to air, rail, highway and water way systems	Closeness to transportation facilities	NA
Attractiveness of region	Culture; climate; taxes; living conditions, relative humidity; air pollution; community attitudes toward business and industry; schools; churches; hospitals; recreational opportunities (for staff and children); educational systems, crime rate and standard of living	AR

A set of principal HOWs (Major facility location assessment criteria) were derived from relevant literatures (MacCarthy and Atthirawong[81]; Badri et al.[75]; Heizer and B. Render[105]; Badri[79]; Bass et al.[71]; Canel and Khumawala[1]; Kouvelis et al.[3]; Lorentz[82]; Hodder and Dincer[74]; Hoffman and Schniederjans[77]; Chuang[13]; Canel and Khumawala[78] and Canel and Das[80]) and experts' comments. These criteria with their descriptions are presented in Table 3.

Table 3: Major facility location assessment criteria (HOWs)

HOWs	Details	Abbreviation
Quality and location of suppliers	Having relationships with reliable suppliers; proximity to suppliers; alternative suppliers and speed and responsiveness of suppliers	QL
Location of markets and easy access	Easy accessibility to market; location of markets for easy and on time market serving; nearness to markets to being responsiveness to demand patterns	LM
Human resource market conditions	Labor availability; labor costs; attitudes toward works and labor turnover, economical growths and declines effects on human resources market	HR
Economics related factors	Exchange rate; tax structure and tax incentives, financial incentives, custom duties; standard of living; balance of payments status; availability and size of government aids; unemployment and compensation premiums; business climate; interest rates	EF
Global competition and survival related factors	Availability of materials; availability of labor; market opportunities; availability of foreign capital; proximity to other international markets; proximity to competitors	GC
Political issues	Record of government stability; government structure, consistency of government policy; attitude of government to inward investment	PI
Social and cultural issues	Different norms and customs; culture; language; customer characteristics; availability of universities or colleges; availability of religious facilities; attitudes of community towards business	SC

Experts stated their judgments about the weight (relative importance) of WHATs by linguistic terms. Seven different level of importance have been used in this study. Table 4 presents these linguistic values and corresponding trapezoidal fuzzy numbers. The linguistic terms are translated into trapezoidal fuzzy numbers by defining appropriate fitness functions. Membership functions for linguistic variables that characterized by fuzzy numbers are depicted in Fig. 3. Finally the experts' assessments about the relative importance of location requirements have been displayed in Table 5.

Table 4: Linguistic values for relative importance of WHATs

Weights	Corresponding fuzzy number				Abbreviation
	α	β	γ	δ	
Very Low	0	0	8	14	VL
Low	8	14	22	28	L
Rather Low	22	28	40	46	RL
Medium	40	46	54	60	M
Rather High	54	60	72	78	RH
High	72	78	86	92	H
Very High	86	92	100	100	VH

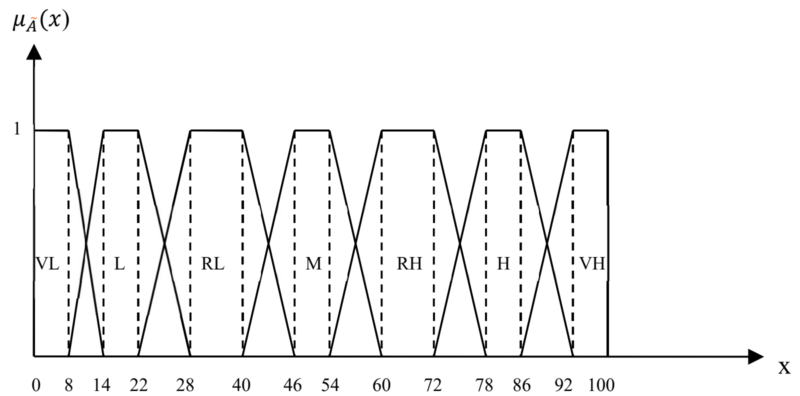

Fig. 3: Membership functions of linguistic terms about relative importance of WHATS

Table 5: Experts' linguistic judgments about relative importance of WHATs

WHATs	Exp. 1	Exp.2	Exp.3
PC	VH	VH	VH
LA	H	H	VH
AM	H	VH	VH
CA	H	VH	H
GI	H	H	H
LC	RH	H	M
NA	H	VH	RH
AR	H	RH	H

The obtained weights by applying equation (4) to aggregate the experts' opinions are presented in Table 6.

Table 6: Obtained weights by aggregating the experts' opinions

WHATs	Obtained weights			
	α	β	γ	δ
PC	86	92	100	100
LA	76.6	82.7	90.7	94.7
AM	81.3	87.3	95.3	97.3
CA	76.7	82.7	90.7	94.7
GI	72	78	86	92
LC	55.3	61.3	70.7	76.7
NA	70.7	76.7	86	90
AR	66	72	81.3	87.3

Experts express their opinion about correlation between WHATs and HOWs using one of seven linguistic variables that have been presented in Table 7. Membership functions of fuzzy correlation scores between WHATs and HOWs are indicated in Fig.4. Table 8 shows the experts subjective judgments about correlation scores between WHATs and HOWs which are described by linguistic terms.

Table 7: Linguistic values for correlation scores between WHATs and HOWs

Correlation scores	Corresponding fuzzy number				Abbreviation
	α	β	γ	δ	
Very Weak	0	0	0.8	1.4	VW
Weak	0.8	1.4	2.2	2.8	W
Rather Weak	2.2	2.8	4.0	4.6	RW
Medium	4.0	4.6	5.4	6.0	M
Rather Strong	5.4	6.0	7.2	7.8	RS
Strong	7.2	7.8	8.6	9.2	H
Very Strong	8.6	9.2	10	10	VS

Table 8: Experts' subjective judgments about correlation scores between WHATs and HOWs

HOWs	EXP	WHATs							
		PC	LA	AM	CA	GI	LC	NA	AR
QL	1	VW	W	VS	W	M	VW	VS	M
	2	W	W	VS	M	M	VW	VS	RS
	3	W	W	VS	W	RS	VW	VS	M
LM	1	VS	VW	W	M	S	VW	VS	W
	2	VS	W	W	W	RS	VW	VS	M
	3	VS	M	W	M	RS	VW	VS	M
HR	1	W	VS	W	W	S	VW	M	RS
	2	W	VS	M	W	RS	W	RS	M
	3	VW	VS	W	W	RS	W	RS	M
EF	1	RS	S	S	S	VS	S	M	S
	2	M	RS	S	S	VS	VS	M	S
	3	S	S	S	VS	VS	S	M	S
GC	1	S	S	VS	S	S	S	VS	M
	2	VS	S	VS	S	VS	S	S	M
	3	VS	VS	S	S	VS	S	VS	M
PI	1	S	S	VS	M	S	M	S	S
	2	S	S	VS	RS	S	RS	RS	VS
	3	RS	RS	S	M	RS	M	M	VS
SC	1	M	M	M	S	M	M	M	VS
	2	RS	RS	M	RS	M	M	W	VS
	3	RS	M	W	M	M	M	M	VS

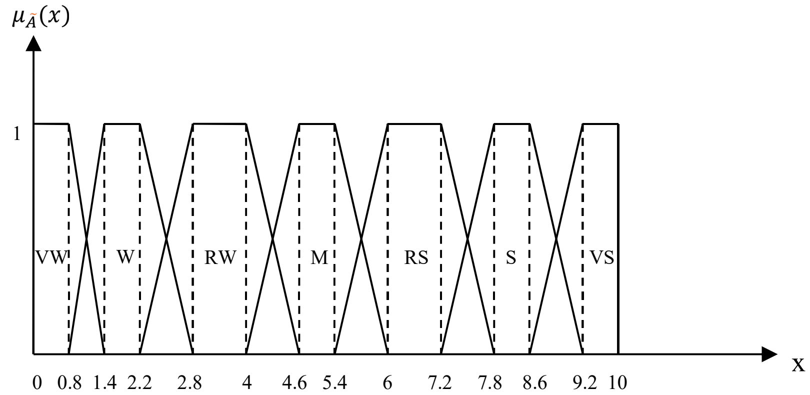

Fig. 4: Membership functions of linguistic terms on correlation scores between WHATs and HOWs

Now the HOQ can be completed by calculating the weights of the HOWs using equation (5) to aggregate experts' opinion on correlation scores between WHATs and HOWs and equation (6) to calculate the importance weights of HOWs. The outcome is given in completed fuzzy HOQ in Fig. 5.

					QL				LM				HR				EF				GC				PI				SC			
	α	β	γ	δ	α	β	γ	δ	α	β	γ	δ	α	β	γ	δ	α	β	γ	δ	α	β	γ	δ	α	β	γ	δ	α	β	γ	δ
PC	86	92	100	100	0.53	0.93	1.73	2.33	8.6	9.2	10	10	0.53	0.93	1.73	2.33	5.53	6.13	7.07	7.67	8.13	8.73	9.53	9.73	6.6	7.2	8.13	8.73	4.93	5.53	6.6	7.2
LA	76.7	82.7	90.7	94.7	0.8	1.4	2.2	2.8	1	1.4	2.33	2.93	8.6	9.2	10	10	6.6	7.2	8.13	8.73	7.67	8.27	9.07	9.47	6.6	7.2	8.13	8.73	4.47	5.07	6	6.6
AM	81.3	87.3	95.3	97.3	8.6	9.2	10	10	8.8	1.4	2.2	2.8	1.87	2.47	3.27	3.87	7.2	7.8	8.6	9.2	8.13	8.73	9.53	9.73	8.13	8.73	9.53	9.73	3.4	4	4.93	5.53
CA	76.7	82.7	90.7	94.7	1.87	2.47	3.27	3.87	2.93	3.53	4.33	4.93	0.8	1.4	2.2	2.8	7.67	8.27	9.07	9.47	7.2	7.8	8.6	9.2	4.47	5.07	6	6.6	5.53	6.13	7.07	7.67
GI	72	78	86	92	4.47	5.07	6	6.6	6	6.6	7.67	8.27	6	6.6	7.67	8.27	8.6	9.2	10	10	8.13	8.73	9.53	9.73	6.6	7.2	8.13	8.73	4	4.6	5.4	6
LC	55.3	61.3	70.7	76.7	0	0	0.8	1.4	0	0	0.8	1.4	0.53	0.93	1.73	2.33	7.67	8.27	9.07	9.47	7.2	7.8	8.6	9.2	4.47	5.07	6	6.6	4	4.6	5.4	6
NA	70.7	76.7	86	90	8.6	9.2	10	10	8.6	9.2	10	10	4.93	5.53	6.6	7.2	4	4.6	5.4	6	8.13	8.73	9.53	9.73	5.53	6.13	7.07	7.67	2.93	3.53	4.33	4.93
AR	66	72	81.3	87.3	4.47	5.07	6	6.6	2.93	3.53	4.33	4.93	4.47	5.07	6	6.6	7.2	7.8	8.6	9.2	4	4.6	5.4	6	7.67	8.27	9.07	9.47	8.6	9.2	10	10

$\widetilde{H}_1$				$\widetilde{H}_2$				$\widetilde{H}_3$				$\widetilde{H}_4$				$\widetilde{H}_5$				$\widetilde{H}_6$				$\widetilde{H}_7$			
α	β	γ	δ	α	β	γ	δ	α	β	γ	δ	α	β	γ	δ	α	β	γ	δ	α	β	γ	δ	α	β	γ	δ
2.49	4.33	5.6	6.89	3.19	4.07	5.91	7.21	2.76	3.61	5.42	6.82	4.82	6.65	9.09	10.9	5.9	7.21	9.72	11.44	5.05	6.25	8.65	10.43	3.72	4.79	6.87	8.45

Fig. 5: The completed fuzzy HOQ

Table 9 shows the outcome of assessing each potential location in respect to different HOWs. The SM for each potential location is calculated applying equation (7) and the results are presented in Table 10. As Table 11 indicates the ranking order of locations based on their SM values is:

UAE > QAT > BAH > KUW > KSA > OMN

Table 9: The outcome of assessing each potential location in conjunction with different HOWS

HOWs	EXP	Location alternatives					
		UAE	KSA	BHA	KUW	QAT	OMN
QL	1	VS	S	V	S	VS	RS
	2	VS	S	V	S	VS	S
	3	VS	VS	S	V	VS	RS
LM	1	S	S	S	RS	S	RS
	2	S	RS	S	S	RS	RS
	3	VS	S	S	S	RS	RS
HR	1	VS	S	S	S	S	V
	2	S	S	S	RS	RS	V
	3	S	S	S	RS	S	S
EF	1	VS	S	S	S	S	M
	2	VS	RS	S	S	S	M
	3	VS	RS	RS	RS	S	RS
GC	1	VS	S	S	S	VS	S
	2	VS	RS	V	S	S	S
	3	VS	S	S	V	S	RS
PI	1	VS	RS	S	S	S	RS
	2	VS	S	S	S	VS	RS
	3	S	VS	S	V	S	M
SC	1	VS	RS	S	S	S	RS
	2	VS	M	S	S	RS	M
	3	VS	RS	RS	S	S	M

Table 10: The SM for each potential location

Locations	SM			
	α	β	γ	δ
UAE	3.27	6.39	13.42	21.80
KSA	2.93	5.14	11.21	19.16
BHA	3.24	5.63	12.01	20.36
KUW	3.26	5.66	11.95	20.30
QAT	3.25	5.67	12.08	20.36
OMN	2.52	4.47	10	17.25

Table 11: Resulted ranking orders for locations

Location	Ranking Value	Ranking Order
UAE	17.61	1
KSA	15.18	5
BAH	16.18	3
KUW	16.12	4
QAT	16.22	2
OMN	13.62	6

By implementing phase one all of the data for establishing the F-QFD-FGP model are prepared. After integrating the FGP model which was clarified through Equation (10) to equation (19), Wu et al.[101] and Saad[106] approaches are used to deal with the resulted fuzzy multi objective problem. We applied Wu et al.[101] and Saad[106] approaches to transform the problem from its fuzzy mathematical goal programming form to a deterministic linear programming problem that finally was solved by LINDO software package. The results of model solution are displayed in Table 12. Table 12 shows the comparison between our proposed F-QFD-FGP model solution results and the results obtained by the AHP-GP model presented in Ref. [79]. As it is clear in Table 12, because of resource limitations and other relevant functional constraints the F-QFD-FGP solutions suggest KUW and OMN to be closed. In other words, the output of F-QFD approach acts as input for F-QFD-FGP approach. Higher importance degrees for a given location obtained by F-QFD methodology do not ensure that those locations certainly should be open because resource shortages and other operational constraints may impose pressures against their selection. Considering the obtained results we can conclude this priority for our potential location alternatives: UAE > QAT > BAH > KSA. Our model solutions for allocation (transportation) from different locations to distribution centers and comparison between our proposed approach allocation results and which was obtained by the model suggested by Badri[79] has been presented in Table 13.

Table 12: Comparison between proposed model selection decisions and the selection decisions of the model presented by Badri[79]

Location alternative	The F-QFD only selection decision	The AHP selection decision[79]	The combined F-QFD-FGP selection decisions	The combined AHP-GP selection decisions[79]
UAE	First choice	First choice	Yes ($Y_1 = 1$)	Yes ($Y_1 = 1$)
KSA	Fifth choice	Third choice	Yes ($Y_2 = 1$)	Yes ($Y_2 = 1$)
BAH	Third choice	Sixth choice	Yes ($Y_3 = 1$)	No ($Y_3 = 0$)
KUW	Fourth choice	Second choice	No ($Y_4 = 0$)	No ($Y_4 = 0$)
QAT	Second choice	Fifth choice	Yes ($Y_5 = 1$)	Yes ($Y_5 = 1$)
OMN	Sixth choice	Fourth choice	No ($Y_6 = 0$)	Yes ($Y_6 = 1$)

Table 13: Comparison between proposed model allocation results and allocation results of the model presented by Badri[79]

Combined F- QFD - FGP model solutions							
		to					
		UAE	IRN	KSA	BAH	IND	NET
From	UAE	875	394	-	-	313	306
	KSA	-	380	753	327	288	-
	BAH	-	205	248	324	823	-
	QAT	452	512	336	645	-	203
Badri's AHP-GP model solutions							
		to					
		UAE	IRN	KSA	BAH	IND	NET
From	UAE	1075	-	-	660	625	-
	KSA	-	-	1200	-	-	-
	BAH	-	1300	-	-	-	-
	QAT	-	-	-	-	550	300

The main advantages and differences of the F-QFD-FGP methodology proposed in this study in comparison with AHP-GP methodology suggested by Badri[79] are the followings:

1- Compared to AHP-GP methodology for global facility location-allocation decision model applied in [79], in our proposed F-QFD-FGP approach the HOQ structure takes into account many more factors to address international facility location-allocation problem. This capability enhances its precision and practicality and can be claimed as one of main preferences of QFD comparing with AHP. In addition, because inconsistency in pair-wise comparison matrices of AHP has impacts on the results of priority vector[107,108], it affects the accuracy and precision of the results.

2- In AHP-GP methodology proposed by Badri[79], there is not a strong relationship between the outputs of AHP approach and inputs of GP model. An equation is added to AHP-GP model to incorporate AHP weightings as one of its goals but that AHP-GP model only minimizes the negative deviations from the sum of AHP weightings(that must be one) and does not consider resulted AHP weights as main affecting factors to location selection decisions. In our proposed F-QFD-FGP approach the first objective function maximizes the chance of selection for location alternatives that have greater SM obtained by F-QFD. Therefore an effective relationship is established between F-QFD approach outputs and the combined F-QFD-FGP model inputs.

3- As Bellman and Zadeh[69] described the nature of decision making, most of the decisions are made in a fuzzy environment where the objective functions, constraints and decision variables are not completely defined and can not be precisely measured. Considering the increasing importance of managers subjective and qualitative predictions of future events and their intuitive findings and judgments and also regarding fuzzy sets theory as a strong instrument in quantifying linguistic and qualitative variables, these predictions, findings and judgments can be included as quantitative factors and constraints in real world decision making models. So the proposed methodology incorporates the fuzzy sets theory to promote actuality and practicality of decisions made.

4- It is more rational to consider the resource shortages and operational limitations as constraints (as is in this study) not goals (the approach adopted by Badri[79]). Therefore our proposed F-QFD-FGP model has two goals and considers other resource limitations and functional restrictions as constraints.

6. Conclusions

International facility location-allocation is a multi objective decision making problem that considers both qualitative and quantitative factors. Selecting a facility location is becoming much more complex and unpredictable with the globalization of the business activities and uncertainty and volatility of global business environment. QFD is a method for structured product planning and development that enables a development team to specify clearly the customer wants and needs, and then evaluates each proposed product systematically in terms of its impact on meeting those needs. Although the QFD technique has gained growing acceptance for new product design and development project, employing QFD to international location-allocation decision is a new application for it. This paper offered two approaches to the global facility location-allocation problem: the F-QFD approach and F- QFD-FGP approach. First F-QFD approach was implemented that considers many qualitative and quantitative factors to assess different potential location alternatives. The output of F-QFD is different suitability weights that in second stage are combined to FGP model to present a developed model that regards resource limitations and operational constraints in choosing different locations. The proposed approach presents a systematic way to address global facility location-allocation decision problem and is easily applicable to real world and practical situations.

There are some possible future directions. As main part of GDP (Gross Domestic Production) in developed countries and even in developing countries are from service sector, future extension of this model for facility location decision of service industries will be interesting area of research. In addition, like many other studies in the area of facility location one of objective functions in our study is of cost minimization type. However, the objective functions type can be maximizing return on investment for different locations or maximizing revenue or profit for different potential location alternatives. Furthermore, more empirical research is required to develop better understanding of factors affecting facility location decision of companies in manufacturing and service sectors. Finally, because different MCDM methods rank alternatives using different approaches and may yield different results when applied to the same problem, one feasible way is to apply combinations of MCDM methods to the same problem. A ranking agreed by multiple MCDM methods is more trustful than one generated by a single MCDM method.[67] So, how to reconcile these different results of MCDM methods for global facility location-allocation problem can be a fruitful field for future research.

Appendix A: Variables and parameters used in the F- QFD-FGP model

$\widetilde{S}_r$	The SM for *r*th location alternative
Y_r	Zero-one variable (1 if location *r* is open, 0 otherwise)
X_{rd}	Allocation of units from location *r* to distribution center *d*
$\widetilde{F}_r$	Fixed cost associated with selecting location *r*
$\widetilde{F}$	Fixed cost budget
$\widetilde{V}_r$	Variable cost associated with choosing location *r*
$\widetilde{V}$	Variable cost budget
$\widetilde{D}_d$	Total product demand by distribution center *d*
$\widetilde{P}_r$	Maximum production limit for location *r*
$\widetilde{Q}_r$	Quality of life in location *r*
$\widetilde{Q}$	Total targeted level for quality of life
$\widetilde{C}_{rd}$	Unit transportation cost from location *r* to distribution center *d*
$\widetilde{C}$	Transportation cost budget
T_r	Country restriction for air quality in location *r*
$\widetilde{G}_r$	Government awarded loans in location *r*
$\widetilde{G}$	Total targeted level for government awarded loans
L	Targeted level for desired expansion rate

References

1. C. Canel, and B.M. Khumawala, A mixed-integer programming approach for the international facilities location problem, *Int. J. Oper. Prod. Manage.* 16(1996) 49-68.
2. J. Yang, and H. Lee, An AHP decision model for facility location selection, *Facilities* 15(1997) 241-254.
3. P. Kouvelis, M.J. Rosenblatt, and C.L. Munson, A mathematical programming model for global plant location problems: Analysis and insights, *IIE Trans*. 36(2004) 127-144.
4. JR. Hauser, and D. Clausing, The house of quality, *Harvard Bus. Rev.* 66(1988) 63-73.
5. Y. Chen, RYK. Fung, and J. Tang, Rating technical attributes in fuzzy QFD by integrating fuzzy weighted average method and fuzzy expected value operator, *Eur. J. Oper. Res* 174(2006) 1553-1566.
6. N. Rich (1995), The use of QFD for relationship assessment and supplier development: adversary, associate or partner? Forth International Conference of IPSERA, The University of Birmingham, Birmingham.
7. M. Bevilacqua, F.E. Ciarapica and G. Giacchetta, A fuzzy-QFD approach to supplier selection, *J. Purch. Supply. Manag***.** 12(2006) 14-27.
8. S.A. Hassanzadeh, and J. Razmi, An integrated fuzzy model for supplier management: A case study of ISP selection and evaluation, *Expert. Syst. Appl.* 36(2009) 8639-8648.
9. A. Bhattacharya, J. Geraghty and P. Young, Supplier selection paradigm: An integrated hierarchical QFD methodology under multiple-criteria environment, *Appl. Soft. Comput*. 10(2010) 1013-1027.
10. E. Bottani, and A. Rizzi, Strategic management of logistics service: A fuzzy QFD approach, *Int. J. Prod. Econ.* 103(2006) 585-599.
11. W. Ho, D.J. Bennett, K.L. Mak, K.B. Chuah, C.K.M. Lee and M. Hall, Strategic logistics outsourcing: An integrated QFD and AHP approach, *IEEE Int. Confer. Ind. Eng. Eng. Manag.*(Hong-Kong, 2009).
12. F.Y. Partovi, An analytic model for locating facilities strategically, *Omega* 34(2006) 41-55.
13. P.T. Chuang, A QFD approach for distribution's location model, *Int. J. Qual. Reliab. Manag.* 19(2002) 1037-1054.
14. D. De Vera, T. Glenon, A.A. Kenny, M.A.H. Khan, and M. Mayer, An automotive case study, *Qual. Progr.* 21(1988) 35-38.
15. Y. Tsuda, Concurrent engineering case studies applying QFD models, *Concurrent. Eng.* 5(1997) 337-346.
16. H. Yuksel, Design of automobile engines for remanufacture with quality function deployment, *Ind. J. Sustain. Eng*. 3(2010) 170-180.
17. T. Ertay, G. Büyüközkan, C. Kahraman and D. Ruan, Quality function deployment implementation based on analytic network process with linguistic data: An application in automotive industry, *J. Intell. Fuzzy Syst.* 16(2005) 221-232.
18. T. Ertay, D.E. Akyol and C. Araz, An integrated fuzzy approach for determining engineering characteristics in concrete industry, *Appl. Artif. Intel.* 25(2011) 305-327.
19. H. Abdul-Rahman, C.L. Kwan, and P.C. Woods, Quality function deployment in construction design: Application in low-cost housing design, *Int. J. Qual. Reliab. Manag.* 16(1999) 591-605.
20. I. Dikmen, M.T. Birgonul, and S. Kizilats, Strategic use of quality function deployment (QFD) in the construction industry, *Build. Environ.* 40(2005) 245-255.
21. M. Celik, S. Cebi, C. Kahraman, and I. Deha Er, An integrated fuzzy QFD model proposal on routing of shipping investment decisions in crude oil tanker market, *Expert. Syst. Appl.* 36(2009) 6227-6235.
22. I. D. Bier and R Cornersky, Using QFD to construct higher education curriculum, *Qual. Progr.* 34(2011) 64-68.
23. C. L. Chen and S. F. Bullington, Development of a strategic research plan for an academic department through the use of quality function deployment, *Comput. Ind. Eng*. 25(1993) 49-52.
24. D. S. Ermer, Using QFD becomes an educational experience for students and faculty, *Qual. Progr*. 28(1995) 131-136.
25. M. Franceschini and F. Terzago, An application of quality function deployment to industrial training courses, *Int. J. Qual. Reliab. Manag.* 15(1998) 753-768.

26. H.B. Hwarng, and C. Teo, Translating customers' voices into operations requirements- A QFD application in higher education, *Int. J. Qual. Reliab. Manag.* 18(2001) 195-225.
27. K. Lam, and X. Zhao, An application of quality function deployment to improve the quality of teaching, *Int. J. Qual. Reliab. Manag.*15(1998) 389-413.
28. G. Pitman, J. Motwani, A. Kumar and C. H. Cheng, QFD application in an educational setting: A pilot field study, *Int. J. Qual. Reliab. Manag.* 12(1995) 63-72.
29. C. Shieu-Ming, Evaluating the service quality of undergraduate nursing education in Taiwan- Using quality function deployment. *Nurse Educ. Today* 24(2004) 310-318.
30. P. Burrows, In search of perfect product. Electron. Bus. 17(1991) 70-74.
31. G. Herzwurm, and D.Schockert, The leading edge in QFD software and electronic business, *Int. J. Qual. Reliab. Manag.* 20(2003) 36-55.
32. M. Liner, E N. Loredo, H. S. Gitlow and N. G. Einspruch, Quality function deployment applied to electronic design, *Qual. Eng*. 9(1997) 237-248.
33. C. M. Tan and T. K. Neo, QFD implementation in a discreet semiconductor industry. *Proc. Ann. reliab. Maint. symp.* (Anaheim: LA, 2002), pp. 484-489.
34. A. C. Bech, M. Hansen and L. Wienberg, Application of house of quality in translation of customer needs into sensory attributes measurable by descriptive sensory analysis, *Food Qual. Preference.* 8(1997) 329-348.
35. M. Benner, A.R. Linnemann, W.M.F. Jongen and P. Folstar, Quality function deployment (QFD)-can it be used to develop food product? *Food. Qual. Preference.* 14(2003) 327-339.
36. W. Charteris, Quality function deployment- A quality engineering technology for food industry, *J. Soc. Dairy Technol.* 46(1993) 12-21.
37. A.I.A. Costa, M. Dekker and W.M.F. Jongen, Quality function deployment in the food industry: A review. *Trends. Food. Sci. Technol.* 11(2000) 306-314.
38. J. Viaene, and R. Januszewska, Quality function deployment in the chocolate industry, *Food Qual. Preference.* 10(1999) 337-385.
39. W.F. Foester, Customer driven healthcare: QFD for process improvement and cost reduction, *Qual. Progr.* 34(2001) 123-124.
40. M. Jeong, and H. Oh, Quality function deployment: An extended framework for service quality and customer satisfaction in the hospitality industry. *Int. J. Hosp. Manag.* 17(1998) 375-390.
41. B.M. Moores, Radiation safety management in healthcare - the application of Quality Function Deployment, *Radiography* 12(2006) 291-304.
42. R. Radharamanan, and L. P. Godoy, Quality function deployment as applied to healthcare system, *Comput. Ind. Eng.* 31(1996) 343-356.
43. S. Aungst, R.R. Barton and D.T. Wilson, Integrating marketing models with quality function deployment, *Adv. Bus. Market. Purch.* 12(2003) 119-140.
44. M. H. Lu, C. N. Madu, C. H. Kuei and D. Wikonur, Integrating QFD, AHP and benchmarking in strategic marketing, *J. Bus. Ind. Market.* 9(1994) 41-50.
45. M. H. Lu and C. H. Kuei, Strategic marketing planning: A quality function deployment approach, *Int. J. Qual. Reliab. Manag.* 12(1995) 85-96.
46. I. Mohr-Hackson, Quality function deployment: A valuable marketing tool, *J. Market. Theory Pract.* 4(1996) 60-67.
47. G.L. Vairaktarakis, Optimization tools for design and marketing of new/improved products using the house of quality, *J. Oper. Manag.* 17(1999) 645-663.
48. T. Arai, and Y. Shimomura, Service CAD System - Evaluation and Quantification, *CIRP Ann. Manuf. Technol.* 54(2005) 463-466.
49. D K. Denton, The service imperative, Pers. J. 69(1990) 66-74.
50. L. Dube, M. D. Johnson and L. M. Renaghan, Adapting of the QFD approach to extend service transactions, *Prod. Oper. Manag*. 8(1999) 301-317.

51. D. S. Ermer, and M. K. Kniper, Delighting the customer: quality function deployment for quality service design, *Total Qual. Manag.* 9(1998) 86-91.
52. A. Ghobadian, and A. J. Terry, How Alitalia improves service quality through quality function deployment, *Manag. Serv. Qual*. 5(1995) 25-30.
53. B. Graessel, and P. Zeidler, Using quality function deployment to improve customer service, *Qual. Progr*. 26 (1993) 59-63.
54. K. F. Pun, K. S. Chin H. Lau, A QFD/hoshin approach for service quality deployment: A case study, *Manag. Serv. Qual.* 10(2000) 156-170.
55. W.J. Selen, and J. Schepers, Design of quality service systems in the public sector: Use of quality function deployment in police services, *Total Qual. Manag.* 12(2001) 677-687.
56. W. D. Barnett, and M. K. Raja, Application of the QFD to the software development process, *Int. J. Qual. Reliab. Manag.* 12(1995) 24-42.
57. I. Erikkson, and F. McFadden, Quality function deployment: A tool to improve software quality, *Inform. Software Technol.* 35(1993) 491-498.
58. M. I. Elboushi, and I. S. Sherif, Object-oriented software design utilizing quality function deployment, *J. Sys. Software* 38(1997) 133-143.
59. S. Haag, M. K. Raja and L. L. Schkade, Quality function deployment usage in software development, *Commun. ACM* 39(1996) 41-49.
60. J. Karlsson, Managing software requirements using quality function deployment, *Software Qual. J.* 6(1997) 311-325.
61. W. C. Pai, A Quality-Enhancing Software Function Deployment Model, *Inform. Syst. Manage.* 19(2002) 20-24.
62. Y. C. Lee, L. C. Sheu and Y. G. Tsou, Quality function deployment implementation based on fuzzy Kano model: An application in PLM system, *Comput. Ind. Eng.* 55 (2008.) 48-63.
63. F. Zandi, and M. Tavana, A fuzzy group quality function deployment model for e-CRM framework assessment in agile manufacturing, *Comput. Ind. Eng.* 61 (2011) 1-19.
64. A. H. I. Lee, H.Y. Kang, C. Y. Yang and C. Y. Lin, An evaluation framework for product planning using FANP, QFD and multi-choice goal programming, *Int. J. Prod. Res*. 48(2010) 3977-3997.
65. G. Kou, Y. Lu, Y. Peng and Y. Shi, Evaluation of classification algorithms using MCDM and rank correlation, *Int. J. Inf. Technol. Decis. Mak.* 11(2012) 197-225.
66. Y. Peng, Y. Zhang, G. Kou and Y. Shi, A multi criteria decision making approach for estimating the number of clusters in a data set, *PLoS ONE* 7(2012) 1-9.
67. Y. Peng, G. Kou, G. Wang and Y. Shi, FAMCDM: A fusion approach of MCDM methods to rank multi class classification algorithms, *Omega* 39(2011) 677-689.
68. Y. Peng, G. Kou, G. Wang and W. Wu, Ensemble of software defect predictors: an AHP based evaluation method, *Int. J. Inf. Technol. Decis. Mak.* 10(2011) 187-206.
69. R.E. Bellman, and L.A. Zadeh, Decision-Making in a Fuzzy Environment, *Manage. Sci*. 17(1970) 141-164.
70. L.A. Zadeh, Fuzzy sets, *Inform. Contr.* 8(1965) 338-353.
71. B.M. Bass, D.W. Mcgregor and J.L. Walters, Selecting foreign plant sites: Economics, social and political considerations, *Acad. Manage. J.* 20(1977) 535-551.
72. P. Haug, A multi-period, mixed-integer-programming model for multinational facility location, *J. Manage*.11(1985) 83-96.
73. J.E. Hodder, and J.V. Jucker, International plant location under price and exchange rate uncertainty, *Eng. Cost. Prod. Econ.* 9(1985) 225-229.
74. J.E. Hodder, and M.C. Dincer, A multifactor model for international plant location and financing under uncertainty, *Comput. Oper. Res.* 13(1986) 601-609.
75. M.A. Badri, D.L. Davis, and D. Davis, Decision support models for the location of firms in industrial sites, *Int. J. Oper. Prod. Manage*. 15(1995) 50-62.

76. M. A. Badri, A multi criteria approach to global facility location-allocation problem, *Int. J. Inform. Manag. Sci.* 7(1996) 1-20.
77. J.J. Hoffman, and M.J. Schniederjans, A two-stage model for structuring global facility site selection decisions: the case of brewing industry, *Int. J. Oper. Prod. Manage.* 14(1996) 23-34.
78. C. Canel, and B.M. Khumawala, Multi-period international facilities location: an algorithm and application, *Int. J. Prod. Res.* 35(1997) 1891-1910.
79. M. A. Badri, Combining the analytic hierarchy process and goal programming for global facility location-allocation problem, *Int. J. Prod. Econ.* 62 (1999) 237-248.
80. C. Canel, and S.R. Das, Modeling global facility location decisions: integrating marketing and manufacturing decisions, *Ind. Manage. Data Syst.* 102(2002) 110-118.
81. B.L. MacCarthy, and W. Atthirawong, Factors affecting location decisions in international operations - a Delphi study, *Int. J. Oper. Prod Manage***.** 23(2003) 794-818.
82. H. Lorentz, Production locations for the internationalizing food industry: case study from Russia, *Brit. Food. J.* 110(2008) 310-334.
83. C. T. Chen, A fuzzy approach to select the location of the distribution center, *Fuzzy Set. System*. 118(2001) 65-73.
84. S. Y. Chou, Y. H. Chang and C. Y. Shen, A fuzzy simple additive weighting system under group decision-making for facility location selection with objective/subjective attributes, *Eur. J. Oper. Res*. 189(2008) 132-145.
85. C. Kahraman, D. Ruan and I. Doğan, Fuzzy group decision-making for facility location selection. *Inform. Sci.* 157(2003) 135-153.
86. I. Ertuğrul, and N. Karakaşoğlu, Comparison of fuzzy AHP and fuzzy TOPSIS methods for facility location selection, *Int. J. Adv. Manuf. Technol*. 39(2008) 783-795.
87. D. Yong, Plant location selection based on fuzzy TOPSIS, *Int. J. Adv. Manuf. Technol.* 28(2006) 839-844.
88. T. Y. Chou, C. L. Hsu and M. C. Chen, A fuzzy multi-criteria decision model for international tourist hotels location selection*, Int. J. Hosp. Manag.* 27(2008) 293-301.
89. A. F. Guneri, M. Cengiz, S. Seker, A fuzzy ANP approach to shipyard location selection, *Expert Syst. Appl.* 36(2009) 7992-7999.
90. R. J. Kuo, S. C. Chi and S. S. Kao, A decision support system for locating convenience store through fuzzy AHP, *Comput. Ind. Eng.* 37(1999) 323-336.
91. S. Wang, J. Watada and W. Pedrycz, Recourse-based facility-location problems in hybrid uncertain environment, *IEEE Tans. Syst. Man Cybern.* B. 40(2010) 1176-1187.
92. T. Ertay, D. Ruan and U. R. Tuzkaya, Integrating data envelopment analysis and analytic hierarchy for the facility layout design in manufacturing systems, *Inform. Sci.* 176(2006) 237-262.
93. S.S.R. Shariff, N.H. Moin and M. Omar, Location allocation modeling for healthcare facility planning in Malaysia, *Comput. Ind. Eng.* 62(2012) 1000-1010.
94. S.S. Syam, and M.J. Cote, A location-allocation model for service providers with application to not for profit health care organizations, *Omega* 38(2010) 157-166.
95. S.S. Syam, and M.J. Cote, A comprehensive location-allocation method for specialized healthcare services, *Oper. Res. Health Care*, DOI: j.orhc.2012.09.001.
96. M. Bischoff, and K. Dachert, Allocation search methods for a generalized class of location-allocation problems, *Eur. J. Oper. Res.* 192(2009) 793-807.
97. R. Ishfaq, and C.R. Sox, Hub location-allocation in intermodal logistic networks. *Eur. J. Oper. Res.* 210 (2011) 213-230.
98. Q. Liu, and J. Xu, A study on facility location-allocation problem in mixed environment of randomness and fuzziness, *J. Intell. Manuf.* 22 (2011) 389-398.
99. T. S. Liou, and M. T. Wang, Ranking fuzzy numbers with integral value, *Fuzzy Set. System*. 50(1992) 247-255.

100. G.J. Klir and B. Yuan, *Fuzzy sets and fuzzy logic, theory and applications*, (Prentice Hall of India, New Delhi, 2005).
101. F. Wu, J. Lu and G. Zhang, A new approximate algorithm for solving multiple objective linear programming problems with fuzzy parameters, *Appl. Math. Comput.* 174(2006) 524-544.
102. Quality of life, http://en.wikipedia.org/wiki/Quality_of_life.
103. Quality-of-life Index, http://en.wikipedia.org/wiki/Quality-of-life_Index.
104. Air quality index, http://en.wikipedia.org/wiki/Air_quality_index.
105. J. Heizer and B. Render, Production and operations management, strategic and tactical decisions (Prentice –Hall, New Jersey, 2004).
106. O.M. Saad, An iterative goal programming approach for solving fuzzy multi objective integer linear programming problems, *Appl. Math. Comput.* 170(2005) 216-225.
107. D. Ergu, G. Kou, Y. Peng and Y. Shi, A simple method to improve the consistency ratio of the pairwise comparison matrix in ANP, *Eur. J. Oper. Res.* 213(2011) 246-259.
108. D. Ergu, G. Kou, Y. Shi and Y. Shi, Analytic network process in risk assessment and decision analysis, *Comput. Oper. Res.*(Article in Press) doi*:* 10.1016/j.cor.2011.03.005.