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FUZZY QFD-BASED PRIORITIZATION OF WORK ACTIVITIES OF CONSTRUCTION FOR SAFETY

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Abstract. *Despite many efforts to prevent accidents at the construction site, there are still a lot of casualties caused by safety accidents. Work activity of construction may make a positive or a negative impact on each other for safety, or it is not interactive in some cases. It is desirable to give priority order to the activities to maximize the effects of construction requirements at the construction phase. This study uses fuzzy quality function deployment utilizing the technique to visually derive the relationships between the activities and the requirements of the customer, company executive, manager, etc. We formulate the mathematical model for mixed integer programming to solve the problem of the priority order of the activities and present an illustrative example. By applying this study to multiple projects, we compare the impact values to see how effective it is through the requirements.*
Keywords: Safety management, Priority, Fuzzy quality function deployment, Construction work activity

1. **Introduction.** Construction industries have been taking a series of measures to prevent industrial accidents. Despite their efforts in safety management, there are still more accidents occurring than in other sectors. Safety management includes facility management and work management. The work activity management for effective safety management should also be systematically carried out. There may be changes in the schedule of work activities for safety management, budget commitment to safety management, entire work schedule, etc. Construction requirements are related to budget, project duration, personnel management, the facility for safety, contract management, and workplace environmental management, etc. In the work activity management, it takes account of the realization of project planning, design and process methods, the workability of implementation, the feasibility of a safety management plan, the safety management organization, the ability to perform work, communication and meeting, etc. In the workplace environmental management, we review the traffic safety facilities and traffic plan, control plan for drainage and land subsidence, anti-damage plans for residents from noise, dust, and vibration of the construction site. The construction process includes three phases, i.e., the business planning phase, the preconstruction phase, construction phase. In the business planning phase, it is generally to make plans on a budget, the construction period, and the validation of the process. In the preconstruction phase, we review construction process methods, process plans, safety plans, and vendor selection plans. In the construction phase, construction management, quality control, safety management, and construction compliance management activities are performed. The construction requirements are derived from customers, project managers, safety personnel, and company executive. The

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purpose of this study is to present a method of prioritization on construction activities using fuzzy-based Quality Function Deployment (QFD), which consequently increases the satisfaction of requirements.

Fuzzy QFD deals with the impreciseness of customer requirements. We review the existing studies in Section 2 and discuss the house of quality for safety management in Section 3 and the application possibility theory for QFD. Linear programming maximizes (or minimizes) a linear objective function subject to one or more constraints. Mixed-integer programming adds additional conditions that at least one of the variables can only take on integer values. Using fuzzy logic-based QFD, we formulate a mathematical model for mixed integer programming to prioritize construction activities with an illustrative example in Section 5. By applying this study to multiple projects, we compare the impact values to see how effective it is through the requirements in Section 6. Section 7 discusses the overall findings of this study and concludes.

2. **Related Study.** QFD is a structured approach to defining customer needs or requirements and translating them into specific plans to produce products to meet those needs. Akao [1] developed QFD which is a method to help transform the voice of the customer into engineering characteristics of a product. Quality function deployment was used to prioritize conflicting needs and provide a tool for making more accurate decisions [2]. Lee and Kusiak [3] studied on prioritizing the application of various design guidelines or design rules to consider productivity and convenience in the manufacturing process to meet multiple quality characteristics in the product design. The framework of the QFD technique was used to design a safety management system to prevent accidents through a sequential linkage process ranging from required safety, safety characteristics, direct causes, the underlying causes, and safety management activities [4]. The applicability of QFD was examined to determine the best marketing strategy and to make a comparison between the performances of different competitors [5]. QFD was used to find the most critical needs for the customers of the construction companies [6]. QFD was widely used in all industries, including product development, service, education, society, culture, health, safety, etc. [7-10].

A method of analyzing the correlation of work activities, risk events, and results using QFD techniques was presented to reduce the number of accidents in the construction industry, where risk analysis and safety management are complicated compared to other sectors [11]. The approach based on the QFD and fuzzy logic was adopted to improve construction project development [12]. Although there have been efforts for construction safety management, it has been used as limited to the development of only simple requirements and engineering characteristics. Research on the prioritization of work activities for construction safety management has not been sufficiently performed.

3. **House of Quality for Safety Management.** In this study, we transform the voice of the construction project manager or project contractor into work activity for the construction of a building, bridge, highway, etc. It identifies and classifies customer desires, identifies the importance of those desires, identifies work activities which may be relevant to those desires, correlates the two, allows for verification of those correlations, and then assigns objectives and priorities for the construction requirements. Customer's or construction work manager's needs, desires, and a strategy of the company are reflected in the construction requirements.

Prioritization of construction work activities allows the manager to focus on activities that have an impact on the requirements. A work activity has diverse relationships with the requirements; an activity may improve one requirement but may degrade other requirements.

3.1. **Linguistic variables.** The strength of the relationships between a construction requirement and work activity and the strength of the interaction between the work activities can be expressed in a linguistic or a crisp variable. Table 1 shows linguistic variables represented as symbols of positive, negative, etc. and commonly used conversion values for the symbols in the house of quality. When a work activity is not related to a construction requirement, i.e., one cannot apply the work activities for the requirement, the impact of the work activities on the management requirement is not considered. Hence, the symbol (-) in Figure 1 is used only on the roof of the house of quality.

TABLE 1. Definition of linguistic variables and coefficient

Symbol	Linguistic variable	The interval of the coefficient value
●	Positive	$[2.0, 6.0]$
○	Weak positive	$[0.0, 4.0]$
-	Not interactive	$[-2.0, 2.0]$
▼	Weak negative	$[-4.0, 0.0]$
⊗	Negative	$[-6.0, -4.0]$

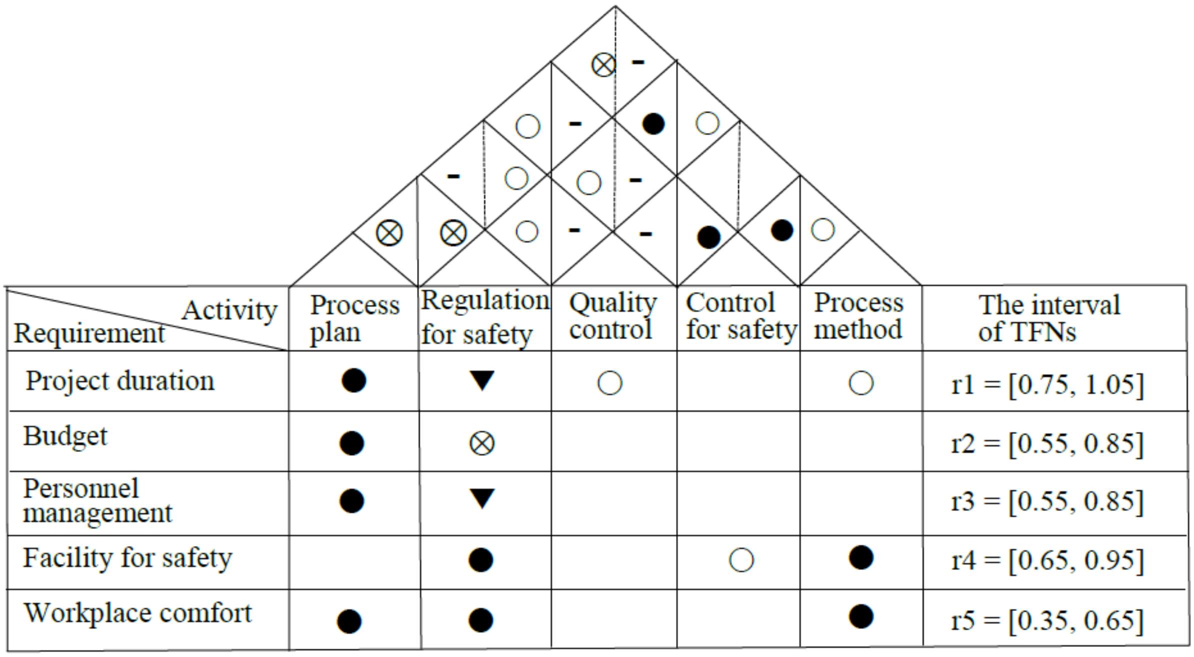

FIGURE 1. Modified HOQ for work activity priority order

3.2. **Structure of HOQ.** To develop the roof of the House of Quality (HOQ), one needs to define the interactions between any pair of work activities. This paper modifies the house of quality to establish the qualitative relationships between a variety of construction requirements and the corresponding work activities. The construction requirements replace customer attributes and the work activities replace engineering characteristics. When one work activity is applied before another work activity, the work activity applied first may make it better or worse to apply the other work activity. The diamond-shaped cell is bisected by a line on the roof of the house of quality to represent the interaction outcomes of a pair of work activity as shown in Figure 1. The entry on the left-hand side of a diamond-shaped cell indicates an affected outcome of work activity j from work activity i when work activity i is applied prior to work activity j. The entry on the right-hand side of the diamond-shaped cell indicates an affected outcome of work activity i from work activity j when work activity j is applied before work activity i.

The center of HOQ in Figure 1 indicates how activities affect the construction requirements, and the left side of the HOQ indicates the requirements. The right side of the HOQ indicates the relative importance of construction requirements. The interval of Triangular Fuzzy Number (TFN) of requirement rating value can be obtained as Figure 1 using the analytic hierarchy process [13]. Construction requirement derived is in a mutually independent relationship. The relationship between requirements and activities and interaction between activities vary, which depend on construction condition and situations.

4. **Application of Possibility Theory for QFD.** One can analyze the interactions between a pair of work activities and the impact of the work activities on the management requirements based on linguistic variables. This study uses possibility theory [14] for the 'voice of the customer', which is intrinsic in natural language. The interval of the symmetrical TFN indicates that the strength of the relationships between the management requirement and the work activity and the strength of the interaction between the work activities. Fuzzy numbers, which can be considered as a possibility distribution [15], are used to describe the coefficients of a linguistic variable. When work activity i is applied first and then work activity j, the combined interval of a symmetrical TFN of the impact on the construction requirements can be represented: $A_{ij} = [\alpha_{ij}, \beta_{ij}]$. A typical membership function for a symmetrical TFN can be expressed as next:

$$\mu_{A_{ij}}(a_{ij}) = 1 - \frac{2\left(\left|a_{ij} - \frac{\beta_{ij}-\alpha_{ij}}{2}\right|\right)}{\beta_{ij} - \alpha_{ij}}, \quad a_{ij} \in A_{ij} \tag{1}$$

By extension, the principle proposed by Zadeh [16], the addition and subtraction operations on TFNs definitely give a TFN. A multiplication operation on TFNs does not necessarily give a TFN. However, the results of the operation can be reasonably approximated [17]. The arithmetic interval operations of two symmetrical TFNs can be expressed:

$$\begin{aligned} &[\alpha_{ij}, \beta_{ij}] \cdot [\alpha_{pq}, \beta_{pq}] \\ &= [\min(\alpha_{ij}\alpha_{pq}, \alpha_{ij}\beta_{pq}, \beta_{ij}\alpha_{pq}, \beta_{ij}\beta_{pq}), \max(\alpha_{ij}\alpha_{pq}, \alpha_{ij}\beta_{pq}, \beta_{ij}\alpha_{pq}, \beta_{ij}\beta_{pq})] \end{aligned} \tag{2}$$

$$[\alpha_{ij}, \beta_{ij}] + [\alpha_{pq}, \beta_{pq}] = [\alpha_{ij} + \alpha_{pq}, \beta_{ij} + \beta_{pq}] \tag{3}$$

$$[\alpha_{ij}, \beta_{ij}] - [\alpha_{pq}, \beta_{pq}] = [\alpha_{ij} - \beta_{pq}, \beta_{ij} - \alpha_{pq}] \tag{4}$$

where $[\alpha_{ij}, \beta_{ij}]$ and $[\alpha_{pq}, \beta_{pq}]$ are the intervals of the two symmetrical TFNs.

In this study notion is defined as next:

m: the number of construction requirements

n: the number of work activities

B_i: a set of construction requirements corresponding to work activity i

C_{ij}: the interval of the symmetrical TFN of work activity i affecting work activity j when one considers work activity i before work activity j

D_{ih}: the interval of the symmetrical TFN of the work activity i impacting on construction requirement h

R_h: the interval of the symmetrical TFN of the construction requirement rating h

$x_{ij} = 1$: if work activity i is applied before work activity j

0: otherwise

$y_{ik} = 1$: if work activity i is ranked kth order

0: otherwise

The list of the construction requirements will contain a wide variety of needs of customers and project managers, some of which will be considered to be more critical than others. The mean ratings of the construction requirements can be obtained through the interviewing of experts on construction. In the house of quality, a larger technical importance rating generally denotes a stronger desire to have the related characteristic incorporated into a new management plan or strategy. Stronger attention should be given to a more critical construction requirement. The allowable range for each construction requirement rating is $[0,1]$. The interval of the symmetrical TFN of the construction requirement rating is then derived from the mean ratings and the predetermined uncertainty value. In this study, the uncertainty value is fixed at ± 0.15 for the symmetrical TFN of the construction requirement rating. For example, let r'_h be the mean ratings of the construction requirement h. The rating range of construction requirement h, R_h is obtained as $[r'_h - 0.15, r'_h + 0.15]$.

5. **Fuzzy Based Integer Programming Approach.** Based on the possibility theory in the previous section, the work activity priority problem for average TFNs, $(\alpha_{ij} + \beta_{ij})/2$ can be formulated as the following mixed-integer programming model.

$$\text{Max} \sum_{i=1}^{n} \sum_{j=1}^{n} x_{ij}(\alpha_{ij} + \beta_{ij})/2 \text{ for } \forall i, j \ (i \neq j) \tag{5}$$

$$\text{Subject to: } x_{ij} + x_{ji} = 1 \tag{6}$$

$$\sum_{j=1(j\neq i)}^{n} x_{ik} \geq s y_{ik} \quad \text{for } \forall i, \text{ for } \forall k; \ s = n-1, n-2, \ldots, 1 \tag{7}$$

$$\sum_{k=1}^{n} y_{ik} = 1 \quad \text{for } \forall i \tag{8}$$

$$\sum_{i=1}^{n} y_{ik} = 1 \quad \text{for } \forall k \tag{9}$$

$$x_{ij} = 0, 1 \quad \text{for } \forall i, j \ (i \neq j) \tag{10}$$

$$y_{ik} = 0, 1 \quad \text{for } \forall i, k \tag{11}$$

The objective function (5) maximizes the impact value in the interval of a symmetrical TFN on the construction requirements. Constraint (6) ensures a priority order for each pair of work activities. Constraints (7), (8), (9), and (10) are added to eliminate the subtour(s) from going back to a node which has been visited, e.g., zero-one variables x_{ij}, x_{jk}, and x_{ki} for work activities i, j, and k are selected. Constraint (7) imposes consistency. Constraint (8) requires that each work activity holds exactly one order rank number. Constraint (9) imposes that an order rank number is assigned to exactly one work activity. In constraint (10), x_{ij} takes either the value zero or one to ensure that one activity should have a higher priority than the other in each pair of activity. Constraint (11) imposes integrality. The formulations (5)-(11) involves $2n^2 - n$ variables and $3n^2 + 2n$ constraints. Activity priority problems for the major TFNs can be formulated by replacing the objective function $\text{Max} \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_{ij} x_{ij}$.

6. **Problem-Solving and Result.** Figure 1 shows the interval of the TFNs of construction requirement rating value and the variables. We apply to the interval of the TFN to the principle [3] and obtain total impact value on the requirement by applying activity i before activity j (A_{ij}), i.e., $A_{ij} = \sum_{h \in Bi} R_h D_{ih} + C_{ij} \sum_{h \in Bj} R_h D_{jh}$. If $A_{ij} < A_{ji}$, we apply activity j before activity i in performing work activity to maximize the impact of the activity on the construction requirements. To generate mixed integer programming for the example of Figure 1 with the coefficient interval of linguistic variable in Table 1, the interval of TFN for A_{12} can be calculated as next: $A_{12} = \sum_{h \in B1} R_h D_{1h} + C_{12} \sum_{h \in B2} R_h D_{jh} = [-40, 84.6]$ from $\sum_{h \in B1} R_h D_{1h} = [4.4, 20.4]$, $C_{12} \sum_{h \in B2} R_h D_{jh} = [-6, -4][-10.7, 7.4]$. Therefore,

$\alpha_{12} = -40$, $\beta_{12} = 84.6$, and $(\alpha_{12} + \beta_{12})/2 = 22.30$. Similarly, the rest of α_{ij}, $(\alpha_{ij} + \beta_{ij})/2$, and β_{ij} are obtained. By applying the formulations (5)-(11) to the data of an example in Figure 1, mixed integer programming codes are generated. For the problems generated, we obtain the solutions for the ranking order of activities for three TFNs in Table 2 by using LINDO software [14]. The selected variables for major TFNs, y_{11}, y_{22}, y_{34}, y_{43}, and y_{55}, mean that work activity 1 is ranked 1st, work activity 2 is ranked 2nd, work activity 3 is ranked 4th, work activity 4 is ranked 3rd, and work activity 5 is ranked 5th. The ranking order of activities for major TFNs is activities 1, 2, 4, 3, and 5, which is the same as one of the average TFNs. In this case, it is desirable to adopt the order that corresponds to a majority of the three results. The ranking order of activities in the final solution means that the process plan for safety among the activities should be considered with the highest priority, regulation for safety with the next highest priority, and so on.

TABLE 2. The ranking order of activities

	y_{ij} selected $(y_{ij} = 1)$	Objective function value
Major TFNs	y_{11}, y_{22}, y_{34}, y_{43}, y_{55}	718.30
Minor TFNs	y_{12}, y_{23}, y_{31}, y_{44}, y_{55}	−146.70
Average TFNs	y_{11}, y_{22}, y_{34}, y_{43}, y_{55}	280.95

We take data from six construction projects to demonstrate the validity of this study. For six projects, we obtained priority orders for the minor, average, and major TFNs, respectively, and adopted a priority order of average TFNs. In Figure 2, the total impact value of work activities on the construction requirements by this study is compared with the total impact value by the random order rank. It shows that applying a proper priority order of activities in the construction phase increases the impact on the overall requirements. Projects 1, 2, and 3 have a significant overall impact on the budget, human resources, project duration, etc., about safety. On the other hand, projects 5 and 6 are a relatively small impact on the requirements.

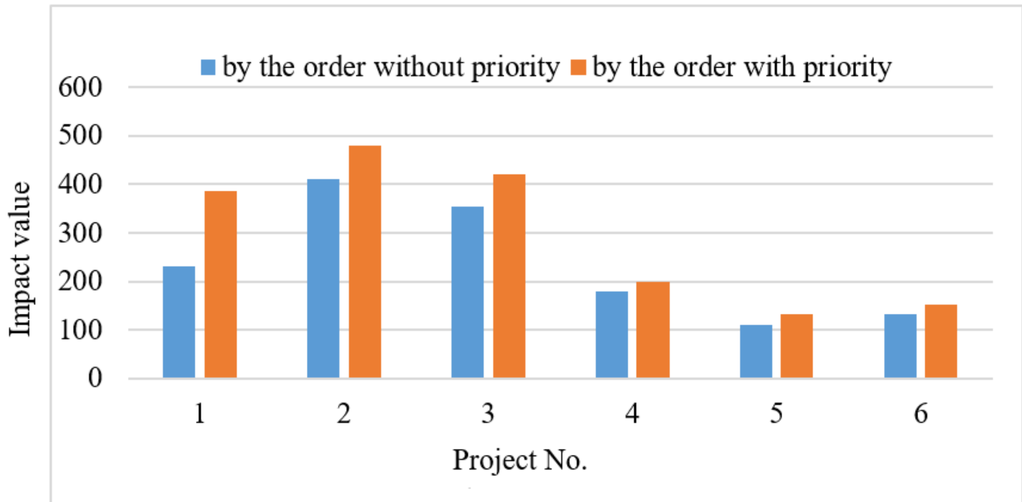

FIGURE 2. Comparison of impact values

7. **Conclusions.** This study presented a method of prioritization on construction activities using fuzzy-based QFD. It has been demonstrated that determining a proper order of activities based on priorities increases the impact value on construction requirements. In the example of a construction project, a process plan for safety contributes to the

operation and management of personnel, creating a good atmosphere in the workplace, securing budgets, and setting project duration. The process plan for safety to comply with limited budgets and deadlines may also be limited in embracing safety regulations. In such cases, there is a risk that the construction will be carried out in violation of the rules. If one makes a process plan for safety before the setting of the process method, the process plan negatively affects the construction process method. On the other hand, by setting the process method carried out before the process plan, the process method does not change the process plan. It seems that the process method should be performed before the activity of the process plan. However, the activity of the process plans a more significant impact on the overall requirements than the activity of the process method. Hence, the planning activity should be carried out as a priority over the setting of process methods.

It is difficult to define the interaction between the work activities and the relationship between the construction requirements and a work activity since the conditions of the construction project and the conditions of the construction site are not the same. The interaction and the relationship in HOQ should be defined depending on the project as the customer's voice may be different, and the priority order of activities for safety should be determined accordingly.

It is time-consuming to generate a mixed integer programming code to use LINDO software. In the future, we will develop a system that can prioritize more effectively so that users can easily use it in real time.

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REFERENCES

[1] S. Mizuno and Y. Akao, *QFD: The Customer Driven Approach to Quality Planning and Deployment*, Asian Productivity Organization, Minato, Tokyo, 1994.
[2] J. C. Mallon and D. E. Mulligan, Quality function deployment – A system for meeting customers' needs, *J. of Construction Engineering and Management*, vol.119, pp.516-531, 1993.
[3] G. H. Lee and A. Kusiak, The house of quality for design rule priority, *International J. of Advanced Manufacturing Technology*, vol.17, pp.288-296, 2001.
[4] K. B. Lee, *A Study of Safety Function Deployment*, Master Thesis, Myongji University, 2003.
[5] M. I. Dikmen, T. Birgonul and S. Kiziltas, Strategic use of quality function deployment (QFD) in the construction industry, *Building and Environment*, vol.40, no.2, pp.245-255, 2005.
[6] S. Bazaati and D. Beheshtizadeh, Using quality function deployment (QFD) in the construction company, *J. of Applied Environmental and Biological Sciences*, vol.7, no.6, pp.7-16, 2017.
[7] K. Sivasamy, C. Arumugam, S. R. Devadasan, R. Murugesh and V. M. M. Thilak, Advanced models of quality function deployment: A literature review, *Quality & Quantity*, vol.50, pp.1399-1414, 2016.
[8] A. Kullberg, C. Nordqvist, K. Lindqvist and T. Timpka, Examining quality function deployment in safety promotion in Sweden, *Health Promotion International*, vol.29, no.3, pp.414-426, 2014.
[9] T. Agrawal and J. Sharma, Quality function deployment in higher education: A literature review, *International J. of Service Science, Management, Engineering, and Technology*, vol.5, no.1, pp.1-13, 2014.
[10] G. S. Gandara, R. Muri and H. H. Purba, Increase service selling of formaldehyde products by implementing quality function deployment (QFD), *J. of Applied Research on Industrial Engineering*, vol.6, no.3, pp.219-231, 2019.
[11] M. Fargnoli, M. Lombardi, N. Haber and F. Guadagno, Hazard function deployment: A QFD-based tool for the assessment of working tasks – A practical study in the construction industry, *International J. of Occupational Safety and Ergonomics*, pp.1-22, 2018.
[12] Y. H. Feng, Use of fuzzy QFD in construction project developing, in *Advanced Material Research*, Q. Yang, L. H. Zhu, J. Ji. He, Z. F. Yan and R. Ren (eds.), Trans Tech Publications, Ltd., 2012.
[13] T. L. Saaty, Decision making with the analytic hierarchy process, *International J. of Services Sciences*, vol.1, no.1, pp.83-98, 2008.
[14] J. C. Bezdek, *Pattern Recognition with a Fuzzy Objective Function Algorithm,* Plenum Press, New York, 1981.
[15] H. J. Zimmermann, *Fuzzy Sets Theory and Its Applications*, Kluwer Academic Publishers, 2011.

[16] L. A. Zadeh, Fuzzy sets, *Information and Control*, vol.8, pp.338-353, 1980.
[17] A. Kaufmann and M. M. Gupta, *Introduction to Fuzzy Arithmetic*, North-Holland, Amsterdam, 1985.
[18] L. E. Schrage, *Linear, Integer, and Quadratic Programming with LINDO*, Scientific Press, 1986.