



A Conflict Resolution Model Identifying Cause and Effect Relations by Using Fuzzy Expert System

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Abstract

Conflicts in public construction works usually comprise many complex and interrelated factors that mostly stem from contracting parties' contradictions including ambiguity and vagueness. Resolution process through a court system is a costly, time-consuming activity and could delay the completion of a construction project. Therefore, planned public services might be postponed and both the project cost and the project quality might be adversely affected. The aim is to develop a conflict resolution model by using fuzzy expert systems, establishing a cause and effect relation according to both sides' opinions.

1. INTRODUCTION

Conflicts in construction works include many complex and interdependent factors; therefore, predicting the outcome of construction litigation is difficult (Arditi and Behzat 1999). Construction conflicts could arise from misinterpretations of contracts, unforeseen and unplanned site conditions, changes in demands, and the like (Arditi et al. 1998; Chau 2007). Moreover, dubious documents, delay in providing structural drawings, material and construction machines, and low profit margin may lead to disagreements between parties (Kassab et al. 2006; Adrian 1993; Jergeas and Hertman 1994). Resolution of construction disputes through a court system is a highly priced, time-consuming process (Pulket and Arditi 2009). This may lead to delay the completion of a construction project, and so the planned public services are postponed. Furthermore, both of the contracting parties must endure the cost of the resolution.

In the literature, several studies on case-based reasoning, artificial neural networks, fuzzy logic and ant miner have been done for construction conflicts, most of which attempted to predict the outcomes of the litigations but did not show cause and effect relations.

Using of the mediation and arbitration systems is common to accelerate dispute resolution process in some European countries and the USA. The mediation is an integral part of most contracts in the Hong Kong (Cheung et al. 2002); however, in Turkey the use of the mediation system is incipient.

Contradictions in terms lead to conflicts, for instance, one side asserts a claim, while the opposite side asserts the contrary. Assertions are usually not certain but fuzzy; therefore, both to aggregate contracting sides' fuzzy opinions and to derive a conclusion from the laws and the court decisions are elusive. Thanks to Fuzzy logic, we can make optimum decisions under uncertainty (Zadeh 1965; Klir et al. 1997).

This model has been developed with the inspiration of the mediation and arbitration system to encourage the contracting sides to be convinced of the result of the model so that a friendly settlement should be reached and disagreements should be resolved in a short time without going to court. Consequently, it is believed that by means of reducing the court expenses and loss of time, the planned project will be completed in time and the project quality will be improved.

2. CONCEPTUAL MODEL OF IDENTIFYING CAUSE AND EFFECT RELATIONS

2.1. Fuzzy expert systems

Events are complex in the real world. Complexity generally arises from uncertainty in the form of ambiguity (Ross 1997). Fuzzy logic defines concepts containing vagueness and uncertainty by assigning membership degrees to them, and helps us to make optimum decisions under uncertainty (Zadeh 1965; Klir et al. 1997).

A fuzzy logic model with its input and output relation includes four steps: Fuzzification, fuzzy inference, a fuzzy rule base, and defuzzification. In the fuzzification process, crisp inputs are transformed into membership degrees for linguistic variables of fuzzy sets. After fuzzification, the fuzzy inference engine transforms the fuzzy input to the fuzzy output on the basis of association with the fuzzy rule base. The defuzzifier produces the final crisp value from the fuzzy output of the inference engine (Osofisan 2007).

In the fuzzy inference process, if the antecedent part of a triggered rule has more than one linguistic variable, the fuzzy operators are applied to integrate the linguistic values. That is the firing strength of the rule (The MathWorks 2011).

2.2. Fuzzy operators

Three elementary operations on fuzzy sets are the intersection, the union, and the complement of fuzzy sets (Lunze 2012).

Let μ_A and μ_B indicate the membership functions of two fuzzy sets A and B, respectively.

Membership function of the intersection of two fuzzy sets is defined as follows:

$$\mu_A \cap \mu_B = \min(\mu_A, \mu_B) \text{ or} \quad \text{Eqs. (1a)}$$

$$\mu_A \cap \mu_B = \mu_A * \mu_B \quad \text{Eqs. (1b)}$$

Membership function of the union of two fuzzy sets is defined as follows:

$$\mu_A \cup \mu_B = \max(\mu_A, \mu_B) \text{ or} \quad \text{Eqs. (1c)}$$

$$\mu_A \cup \mu_B = \mu_A + \mu_B - \mu_A * \mu_B \quad \text{Eqs. (1d)}$$

Membership function of the complement of the fuzzy set A is defined as follows:

$$\mu_{\bar{A}} = 1 - \mu_A \quad \text{Eqs. (1e)}$$

2.3. Fuzzy inference systems

Some fuzzy inference systems are Mamdani, Larsen and Sugeno methodologies. Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. These methodologies are very similar in many respects. Fuzzifying the inputs and applying the fuzzy operators are analogous. The primary difference is the output membership functions (The MathWorks 2011).

Mamdani's fuzzy inference system cuts an output function at the rule strength (Cook 2011), and Larsen's fuzzy inference system scales an output function at the rule strength (Wu 2011); however, the Sugeno

output membership functions are either linear or constant, namely: First-order Sugeno model and Zero-order Sugeno model, respectively (The MathWorks 2011).

Cutting the output membership function in Mamdani's system alters its original membership function, and causes loss of information, while scaling the output membership function in Larsen's system adapts itself to original output function, and causes very little or no loss of information (Ozbayoglu 2011). The Mamdani method has widespread acceptance because of intuitive and easy to calculate. On the other hand, the Larsen method is preferred when no loss of information is required (Kusiak 2011).

2.4. Defuzzification

Defuzzification is the process of getting a crisp value from the fuzzy output of the inference engine that best represents the possibility distribution of an inferred fuzzy control system. Some of the defuzzification methods are centroid of the area, mean of maximum, max-membership principle, weighted average method, bisector of the area, and first or last of maxima. Centroid of the area is the most common and attractive of all the defuzzification methods. There is no systematic procedure for deciding a proper defuzzification technique (Sazonow 2005).

The Mamdani's and Larsen's fuzzy inference approaches provide the flexibility to choose a defuzzification method to calculate the final output of the system, but this alternative can lead to inconsistent results (Schmidt et al. 2006). On the other hand, there is no defuzzification step in the Sugeno's fuzzy inference system. The final output of the system is calculated by the weighted average of all rule outputs (The MathWorks 2011).

3. RESULTS

This study was divided into four phases:

1. First, the court decisions, laws, and regulations issued for the public construction works were examined, then conflicts were classified, and decision criteria were determined in accordance with these laws and court decisions.
2. The rules were established by using the if-then structures and the reference fraction defectives were calculated for the consequent part of each rule.
3. A rule-based fuzzy logic resolution model was developed to estimate contracting parties' fraction defectives and make recommendations (a cause and effect relation).
4. A computer application was developed to accelerate the resolution process and make the complex calculation easier.

3.1. Examination and classification

Conflicts in public construction works in Turkey occur during the tender process (before a contract signing) or the implementation process of a contract (after a contract signing). The tender process and the implementation process are subject to Turkish Public Procurement Law and Turkish Contracts Law, respectively. There are three contract categories in accordance with these laws.

1. Procurement of works; turn key lump-sum contracts.
2. Procurement of goods or services; turn key lump-sum contracts.
3. Unit price contracts; used in both of the procurement of works and the procurement of goods or services.

This study comprises the implementation process of a contract in the procurement of works (1) and unit price contracts (3) categories.

After having examined relevant Turkish laws and courts' decisions, we classified the conflicts into four main classes and divided each main class into sub-classes. One hundred thirty-nine decision criteria

describing general ideas of the conflicts were determined to estimate contracting parties' possible fraction defectives. Table 1 shows some decision criteria, and the client and contractor sides' possible responses for the class of the "losses or damages of works".

Table 1. Some of the forty decision criteria for "losses or damages of works"

#	Decision criteria	Client's and contractor's responses
1	Are the safe loads, the rolling and moving loads, and the dimension of structures used in the structural calculation proper for the designed project?	Yes/No
2	If # 1 is "No", how much is the loss or the damage of works due to #1?	Nothing / Slightly / Little / Partly / Much / Very Much / Exact
3	Are the soil properties and parameters used in the structural calculation proper for the designed project?	Yes/No
4	If # 3 is "No", how much is the loss or the damage of works due to #3?	Nothing / Slightly / Little / Partly / Much / Very Much / Exact
5	Who prepared the construction application projects? (Who is responsible for those?)	Client / Contractor
6	If # 5 is "Client", did the contractor warn the client because of the improper application projects by letter?	Yes/No
7	If # 6 is "Yes", did the client take the responsibility and get the works made?	Yes/No
8	If # 7 is "Yes", how much is the loss or the damage of works because of the improper application projects prepared by the client?	Nothing / Slightly / Little / Partly / Much / Very Much / Exact
9	If # 5 is "Contractor", did the client warn the contractor because of the improper application projects by letter?	Yes/No
10	If #5 is "Contractor", how much is the loss or the damage of works because of the improper application projects prepared by the contractor?	Nothing / Slightly / Little / Partly / Much / Very Much / Exact

3.1.1. Turkish laws and courts' decision concerning Turkish public procurement contracts:

- Public Procurement Contracts Law (YISK)
- Code of Obligations (TBK)
- General Specification for Public Construction Works (YIGS)
- Inspection Regulation for Public Construction Works (BIKY)
- Inspection and Acceptance Regulation for Public Construction Works (YIMKY)
- Supreme Court's Decisions for Public Construction Works (MK)

3.1.2. Classification of the conflicts:

1. Losses or damages of works; a. Implementation errors, b. Design errors or deficiency of application projects. 2. Losses or damages of third person. 3. Cost of works; a. Implementation errors, b. Amount of payment, c. Late payment, d. Unit price of works not in the contract, e. Work increase. 3. Duration of works, and completion and delivery of works; a. Works side delivery to the contractor, b. Preliminary, final or application projects delivery to the contractor c. Delay in the works schedule, d. Works time extension.

3.2. Rules and reference fraction defectives

Rules and reference fraction defectives are needed to estimate the parties' possible fraction defectives. Therefore, firstly flow charts of the rules were drawn to establish the rules in the form of "if-then" structures in accordance with the law articles and the court decisions. Eighty rules on the basis of one hundred eighty-two law articles and court decisions for the four classes were figured out. Then these rules were used to calculate the reference fraction defectives, so the rule flow charts only show the worst-case scenarios. The flow chart for the conflict class of "losses or damages of works" can be seen in Fig. 1.

3.2.1. Calculation of the reference fraction defectives:

The reference defective fractions were calculated as follows and tabled in Table 2.

$$Z_{j(client)} = NOA_{(client)} / [NOA_{(client)} + NOA_{(contractor)}] \quad \text{Eqs. (2a)}$$

$$Z_{j(contractor)} = NOA_{(contractor)} / [NOA_{(client)} + NOA_{(contractor)}] \quad \text{Eqs. (2b)}$$

Where Z_j : Reference fraction defective where j is the rule no.

NOA: The number of the law articles and the court decisions on the faulty side

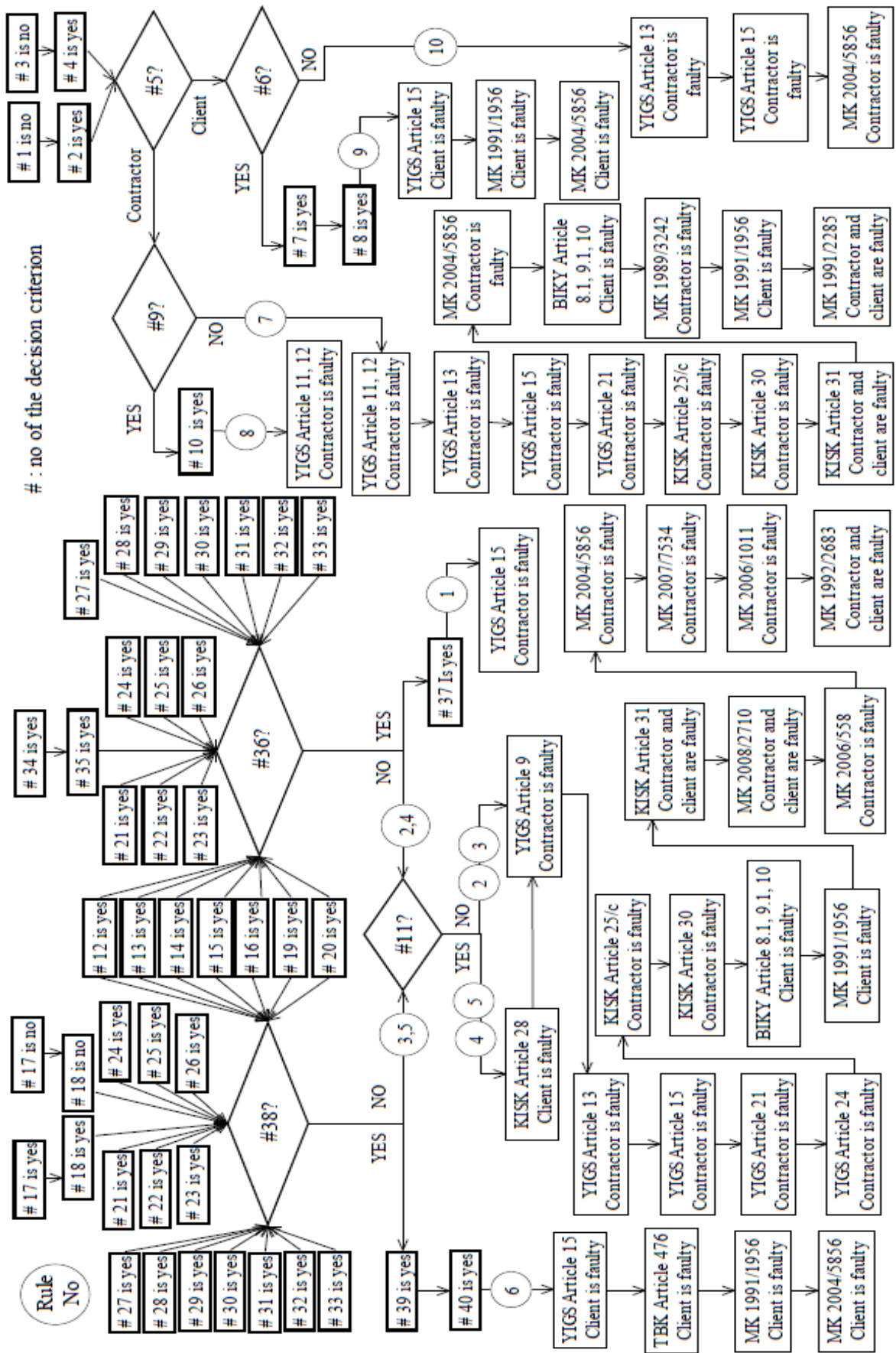


Figure 1. Flow chart of the rules for the conflict class of "losses or damages of works"

Table 2. Reference defective fractions of the rules for the conflict class of “losses or damages of works

Rule no.	The number of the law articles and the court decisions on the faulty side		The reference fraction defectives (%)	
	NOA		Z	
j	Client	Contractor	Client	Contractor
1	0	1	0	100
2	5	14	26	74
3	5	14	26	74
4	6	14	30	70
5	6	14	30	70
6	4	0	100	0
7	4	10	29	71
8	0	1	0	100
9	3	0	100	0
10	0	3	0	100

3.3. Developing the rule-based fuzzy logic resolution model

The resolution model comprises of five steps: To combine contracting sides’ opinions in the input step, to assign membership degrees of the inputs in the fuzzification step, to integrate the fuzzy sets by the “AND” fuzzy operator and to find the firing strength of the rule in the fuzzy inference step, and to estimate the contracting parties’ possible fraction defectives in the final output step. The developing structure of the model can be seen in Fig. 2.

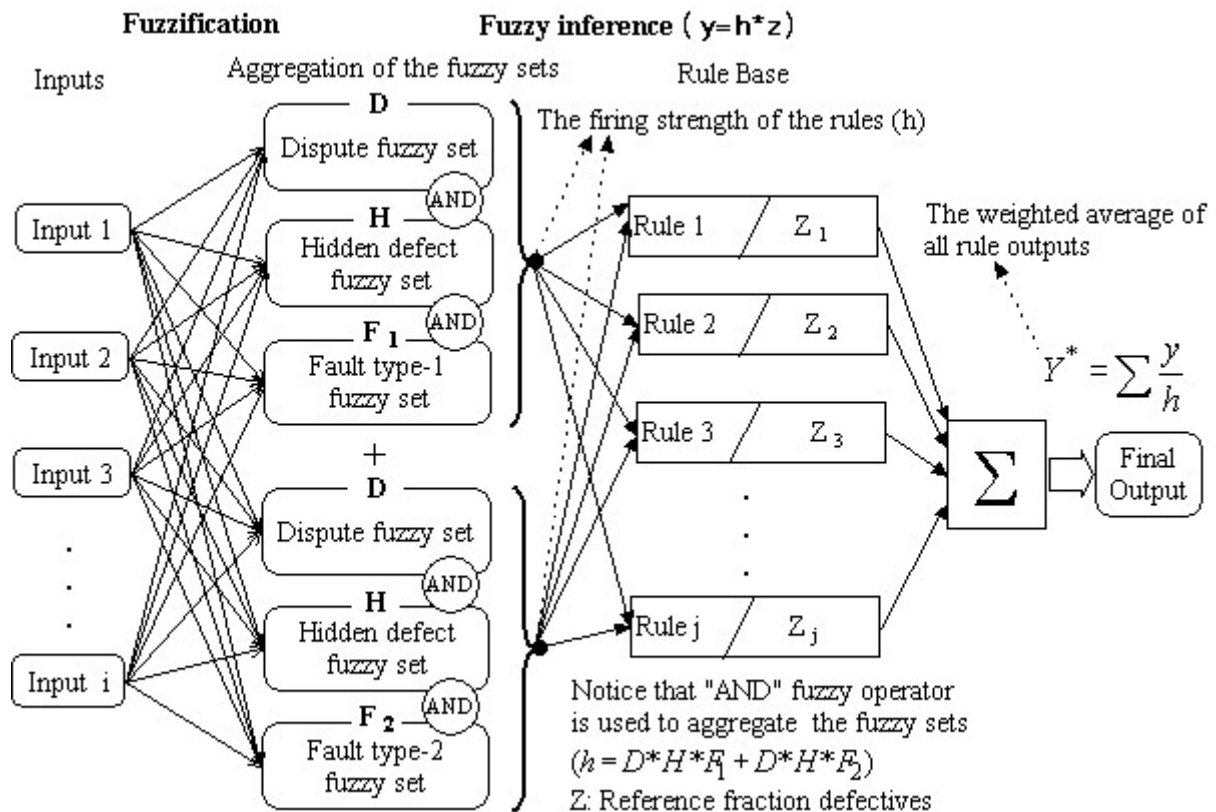


Figure 2. Structure of the rule-based fuzzy logic resolution model

3.3.1. Inputs

The client's and the contractor's responses to the relevant decision criteria are inputs. Different from the ordinary fuzzy logic model, the inputs of the resolution model have linguistic (fuzzy) variables. The decision criteria describe general ideas of the conflicts; hence, the parties can select the decision criteria which are very similar to their opinions. It is not mandatory to respond all the decision criteria, yet some are needed to be replied to trigger the relevant rules.

Since to inquire about a conflict by manual is complicated, a computer prototype has been developed. There are two ways to aggregate opinions from contracting sides. First, contracting sides' responses are selected from the combo boxes on the software inquiry form by a user. Intelligent query is used to do so, meaning that decision criteria will be sorted according to the responses. Such linguistic responses to the decision criteria are "client, contractor, yes, no, nothing, slightly, little, partly, much, very much, and exact". Second, contracting sides note their responses to a word processor and upload it to the software. The relevant and similar decision criteria and their linguistic variables are automatically derived from the uploaded word processor. It also uses fuzzy logic to establish relations between decision criteria and statements in the word but is excluded from this study for now.

3.3.2. Fuzzy Sets and Membership Degrees

Some decision criteria are used to fire the rules, whereas the others are used to evaluate the conflict. We called these triggering decision criteria (TDC) and evaluating decision criteria (EDC), respectively. TDC are crisp. EDC, on the other hand, are fuzzy and members in the fuzzy sets with some fuzzy membership grades. These fuzzy sets are dispute fuzzy set, hidden defect fuzzy set and fault types fuzzy sets.

Dispute fuzzy set (D):

All the EDC belong to the dispute fuzzy set with some membership grades (Fig. 3). These membership grades were determined on the basis of our knowledge. The dispute level in Fig. 3 represents the parties' opinions.

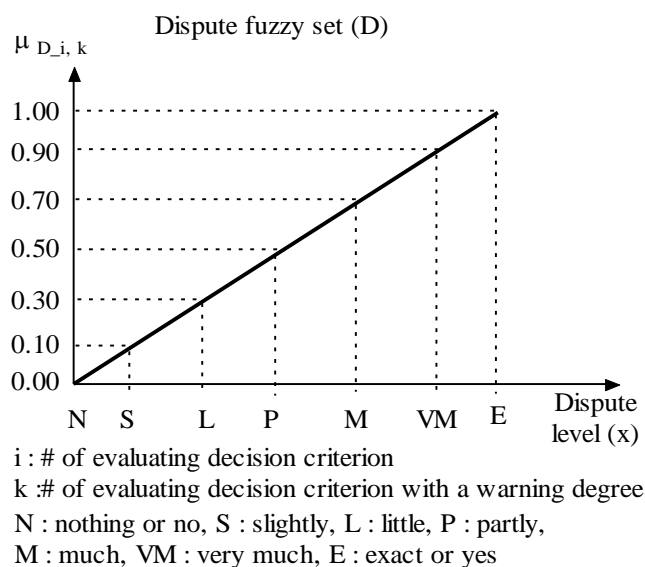


Figure 3. The dispute fuzzy set

D= {0.00/no or nothing, 0.10/slightly, 0.30/little, 50/partly, 0.70/much, 0.90/very much, 1.00/exact or yes }

When one of the conflict sides responses,

$$\mu_{D_{i,k}}(x) = \mu_{D_{i,k}(client)} , \text{ or } \mu_{D_{i,k}}(x) = \mu_{D_{i,k}(contractor)} \tag{3a}$$

When both of the conflict sides response,

$$\mu_{D_{i,k}}(x) = \left[\mu_{D_{i,k}(client)} + \mu_{D_{i,k}(contractor)} \right] / 2 \tag{3b}$$

Where k: No. of the EDC with a warning degree

μ_{D_i} : Membership grade in the dispute fuzzy set where i is the EDC.

μ_{D_k} : Membership grade in the dispute fuzzy set where k is the EDC with a warning degree.

Hidden defect fuzzy set (H):

Only the EDC concerning the implementation of works belong to the hidden defect fuzzy set. There are two kinds of defects; visible and hidden. A visible defect is the lack of works that has to be made in accordance with the requirements of the contract and of the honesty rules. These defects must be easily seen at the inspection; however, a hidden defect is wrongful works that the contractor has made intentionally and fraudulently. These defects might not be seen at the inspection in spite of any attention (Gok 2007).

After a survey had been taken, the membership grades of the decision criteria in the hidden defect fuzzy set concerning the implementation of works were calculated.

Thirty experts working for a public institution as supervisors or inspectors were solicited to grade the decision criteria regarding the implementation of works in the hidden defect fuzzy set from 1 to 10 (scale: 1= the lowest membership degree to the hidden defect; scale: 10=the highest membership degree to the hidden defect). Then these scores were normalized to a range of 0 and 1 (Fig. 4). The membership grades in the hidden defect fuzzy set are as below.

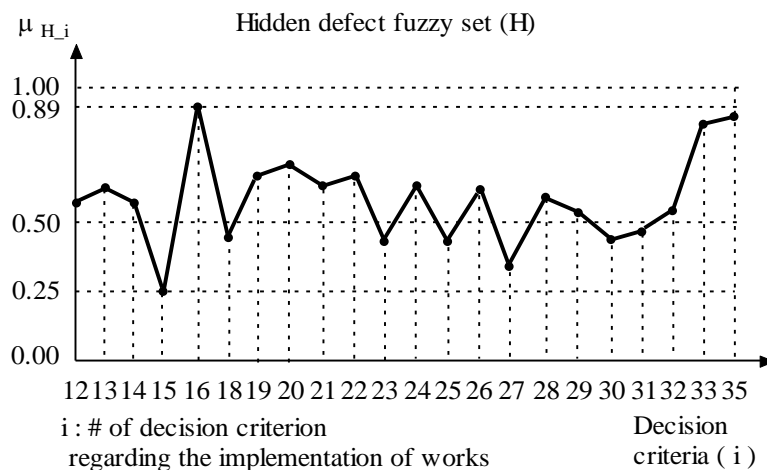


Figure 4. Hidden defect fuzzy set

H={#12, #13, #14, #15, #16, #18, #19, #20, #21, #22, #23, #24, #25, #26, #27, #28, #29, #30, #31, #32, #33, #35}

$H = \{0.54/\#12, 0.58/\#13, 0.56/\#14, 0.25/\#15, 0.89/\#16, 0.45/\#18, 0.69/\#19, 0.73/\#20, 0.63/\#21, 0.69/\#22, 0.43/\#23, 0.66/\#24, 0.43/\#25, 0.62/\#26, 0.38/\#27, 0.59/\#28, 0.52/\#29, 0.44/\#30, 0.48/\#31, 0.53/\#32, 0.84/\#33, 0.87/\#35\}$

Fault type-1 (F1) and type-2 (F2) fuzzy sets:

Fault types appear in the form of imprudence, negligence, conscious-negligence, and wrongful-intention in the law literature (Sayin 2000). There are several articles in TBK that the weights of these fault types are mostly taken into consideration at the phase of judgment.

In this study, two different fault type fuzzy sets were used. These fuzzy sets differ from the case of not warning to the case of warning. We called them Fault Type-1 fuzzy set (F1) and Fault Type-2 fuzzy set (F2), respectively. In other words, when the contractor or the client does not warn the opposed side in case of the improper works, the relevant decision criteria belong to F1 (Fig. 5); when there is warning because of the improper works, the relevant decision criteria belong to F2 (Fig. 6). Certainly, when a decision criterion belongs to F2, it also belongs to F1 with the complement of F2 ($F1 = 1 - F2$) (Eqs. 1e).

Each criterion of the EDC has its own fuzzy value according to its characteristic feature. To simplify the calculation, all the EDC have belonged to the same F1 and F2 and the membership functions have been determined on the basis of our knowledge and experience.

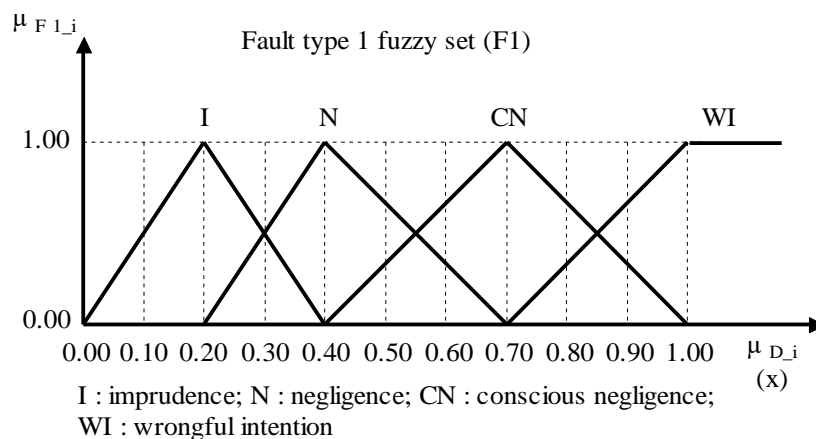


Figure 5. Fault type-1 fuzzy set

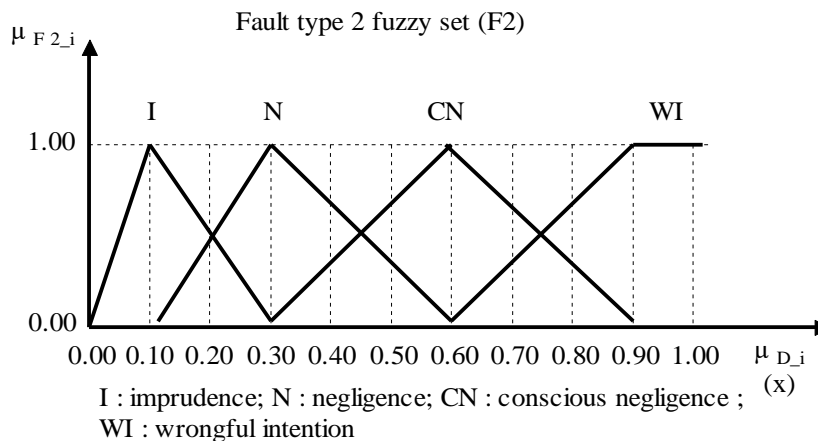


Figure 6. Fault type-2 fuzzy set

Weights (w) of the subsets of the fault types (F1 and F2):

The weights of the subsets of imprudence, negligence, conscious-negligence, and wrongful-intention were determined through a survey taken with the same experts as in the hidden defect fuzzy set. We asked them to grade the fault types from 1 to 10 (scale: 1=the weakest fault weight; scale: 10=the strongest fault weight), and then normalized the scores to a range of 0 and 1. The weights were used to calculate the membership degrees of the relevant decision criteria in F1 and F2 fuzzy sets.

$$w = \{0.193/I, 0.480/N, 0.730/CN, 0.957/WI\}$$

Calculating the Membership Grades in F1 and F2 Fuzzy Sets:

As seen in Eqs.(4a) and (4b), the membership degrees of the EDC in F1 and F2 fuzzy sets were calculated by using the membership functions (Fig. 5 and 6) and the weights of the fault types (w).

$$\mu_{F1_i}(x) = \mu_{I(x)} * w_I + \mu_{N(x)} * w_N + \mu_{CN(x)} * w_{CN} + \mu_{WI(x)} * w_{WI} \quad \text{Eqs. (4a)}$$

$$\mu_{F2_i}(x) = \mu_{I(x)} * w_I + \mu_{N(x)} * w_N + \mu_{CN(x)} * w_{CN} + \mu_{WI(x)} * w_{WI} \quad \text{Eq. (4b)}$$

Where

μ_{F1_i} : Membership grade in the fault type-1 fuzzy set where i is no. of the EDC.

μ_{F2_i} : Membership grade in the fault type-2 fuzzy set where i is no. of the EDC.

$$F1 = \{0.00/0.00, 0.0965/0.10, 0.193/0.20, 0.367/0.30, 0.480/0.40, 0.563/0.50, 0.648/0.60, 0.730/0.70, 0.805/0.80, 0.882/0.90, 0.957/1.00\}$$

$$F2 = \{0.00/0.00, 0.193/0.10, 0.367/0.20, 0.480/0.30, 0.563/0.40, 0.648/0.50, 0.730/0.60, 0.805/0.70, 0.882/0.80, 0.957/0.90, 0.957/1.00\}$$

3.3.3. Fuzzy inference

Sugeno's fuzzy inference system has been preferred because the output of each rule is constant. These constant values (z) have been calculated from the flow charts of the rules. We called these constant values as the reference fraction defectives.

The "AND" fuzzy operator in Eqs. (1b) is used to integrate the fuzzy sets because each fuzzy set has an effect on the output of each rule, and must be included in the calculation.

The fuzzy inference of the four conflict classes is calculated from Eqs. (5a) through Eqs. (5h) as follows:

For class no.1:

For decision criteria regarding the implementation of the works;

$$y_{j,j'} = \sum [\mu_{D_j} * \mu_{H_j} * (1 - \mu_{D_k}) * \mu_{F1_i} * Z_{j'}(\text{contractor}) + \mu_{D_i} * \mu_{H_i} * \mu_{D_k} * \mu_{F2_i} * Z_{j'}(\text{contractor})] \quad \text{Eqs. (5a)}$$

$$h_{j,j'} = \sum [\mu_{D_j} * \mu_{H_j} * (1 - \mu_{D_k}) * \mu_{F1_i} + \mu_{D_i} * \mu_{H_i} * \mu_{D_k} * \mu_{F2_i}] \quad \text{Eqs. (5b)}$$

For decision criteria regarding the construction application projects;

$$y_{j,j'} = \sum [\mu_{D_j} * (1 - \mu_{D_k}) * \mu_{F1_i} * Z_{j'}(\text{contractor}) + \mu_{D_i} * \mu_{D_k} * \mu_{F2_i} * Z_{j'}(\text{contractor})] \quad \text{Eqs. (5c)}$$

$$h_{j,j'} = \sum [\mu_{D_j} * (1 - \mu_{D_k}) * \mu_{F1_i} + \mu_{D_i} * \mu_{D_k} * \mu_{F2_i}] \quad \text{Eqs. (5d)}$$

For class no.2:

$$y_{j,j'} = \sum [\mu_{D_j} * (1 - \mu_{D_k}) * \mu_{F1_i} * Z_{j'}(\text{contractor}) + \mu_{D_i} * \mu_{D_k} * \mu_{F2_i} * Z_{j'}(\text{contractor})] \quad \text{Eqs. (5e)}$$

$$h_{j,j'} = \sum [\mu_{D_j} * (1 - \mu_{D_k}) * \mu_{F1_i} + \mu_{D_i} * \mu_{D_k} * \mu_{F2_i}] \quad \text{Eqs. (5f)}$$

For class no.3 and no.4:

$$y_{j,j'} = \sum [\mu_{D_j} * Z_{j(\text{contractor})} + (1 - \mu_{D_j}) * Z_{j'(\text{contractor})}] \quad \text{Eqs. (5g)}$$

$$h_{j,j'} = \sum [\mu_{D_j} + (1 - \mu_{D_j})] \quad \text{Eqs. (5h)}$$

Where $Z_{j,j'}$: Triggered rules where j, j' are the no. of the rules.
 i: No. of the EDC
 k: No. of the EDC with a warning degree

3.3.4. Final output

The final output of the model (both sides' fraction defectives) is calculated by the weighted average of all rule outputs as follows:

$$Y^*_{(\text{contractor})} = \frac{\sum_{j,j'=1}^I y_{j,j'}}{\sum_{j,j'=1}^I h_{j,j'}} \quad \text{Eqs. (6a)}$$

$$Y^*_{(\text{client})} = 1 - Y^*_{(\text{contractor})} \quad \text{Eqs. (6b)}$$

Where Y^* : Final output of the model; sides' fraction defectives.
 I: Total number of the rules of the conflict class.

3.4. A real-case application

This application was adapted from the Supreme Court Decision: Served May 21, 1992. Docket no. 1992/248, filed 1992/2683. The court found the client and contractor guilty in this case. Both client and contractor responded the decision criteria that are very similar to their opinions as seen in Fig. 7. The inquiry form in Fig. 8 was taken from the software prototype and it shows the cause part of the cause and effect relations.

Conflict class : Losses or Damages of works			
Code : ABC_001			
Name : Istanbul miscellaneous recreational construction project			
#	Decision criteria	Responses	
		Client	Contractor
11	Were the works accepted by the client?	Yes	Yes
12	Did not the implementation of works comply with the requirements of the construction application projects?	Much	Little
16	In the core sample test report, did not the class of concrete used in the construction comply with the requirements of the construction documents?	Yes	Much
30	Did not the bar counts and the bar lengths comply with the requirements of the application projects?	Partly	Slightly
31	Did the iron stirrups used in the construction comply with the requirements of the application projects?	Yes	Partly
36	Did the client warn the contractor because of the implementation not complying with the technical specifications?	No	No
37	If # 36 is "Yes", how much is the loss or the damage of works because of the implementation not complying with the technical specifications?	Nothing	Nothing
38	Did the contractor warn the client because of the fact that the client had made a statement not complying with the requirements of the technical specifications and the contract?	Yes	Yes
39	If # 38 is "Yes", did the client take the responsibility and get the works made?	Yes	Yes
40	If # 39 is "Yes", how much is the loss or the damage of works because the client had made a statement not complying with the technical specifications and the contract?	Nothing	Partly
Client's fraction defective		40%	
Contractor's fraction defective		60%	

Figure 7. Triggered decision criteria and contracting sides' responses

Decision Criteria	Client's responses	Contractor's responses
requirements of the application projects?		
30. Did not the bar counts and the bar lengths comply with the requirements of the application projects?	Partly	Slightly
31. Did the iron stirrups used in the construction comply with the requirements of the application projects?	Yes	Partly
32. Did not the materials used in the construction comply with the requirements of the application projects?		No Slightly Little Partly Much Very Much Yes
33. Was not the technical specification of the materials used in the construction as the same technical specification as the client had taken the samples?		
34. Did the contractor change the application projects without the permission of the client?		
35. If # 34 is "Yes", how much is the loss or the damage of works because of not obtaining permission of the client?		
36. Did the client warn the contractor because of the implementation not complying with the technical specifications?	No	No
37. If # 36 is "Yes", how much is the loss or the	No	No

Figure 8. Inquiry form for the conflict class of “losses or damages of works”

3.4.1. Estimating the contracting parties’ fraction defectives

Three rules (4, 5 and 6) were triggered from the responses (Fig. 1).

$$j, j' = \{4, 5, 6\}$$

$$Z_{4(\text{contractor})} = 0.70$$

$$Z_{5(\text{contractor})} = 0.70$$

$$Z_{6(\text{contractor})} = 0.00$$

$$i = \{12, 16, 30, 31\}$$

$$k = \{37, 40\}$$

$$\text{TDC} = \{11, 36, 38, 39\}$$

$$\text{EDC} = \{12, 16, 30, 31, 37, 40\}$$

3.4.2. The membership degrees of the decision criteria in the fuzzy sets

$$D = \{12, 16, 30, 31, 37, 40\}$$

From Fig. 3 and Eqs. (3b):

$$\mu_{D_{12}} = (0.70 + 0.30) / 2 = 0.50$$

$$\mu_{D_{16}} = (1.00 + 0.70) / 2 = 0.85$$

$$\mu_{D_{30}} = (0.50 + 0.10) / 2 = 0.30$$

$$\mu_{D_{31}} = (1.00 + 0.50) / 2 = 0.75$$

$$\mu_{D_{37}} = (0.00 + 0.00) / 2 = 0.00$$

$$\mu_{D_{40}} = (0.00 + 0.50) / 2 = 0.25$$

$$H = \{12, 16, 30, 31\}$$

From Fig. 4:

$$\mu_{H_{12}} = 0.54$$

$$\mu_{H_{16}} = 0.89$$

$$\mu_{H_{30}} = 0.44$$

$$\mu_{H_{31}} = 0.48$$

$$F1, F2 = \{12, 16, 30, 31\}$$

From Fig. 5 and 6, and Eqs. (4a) and (4b):

$$\mu_{F1_{12}} = 0.563; \mu_{F2_{12}} = 0.648$$

$$\mu_{F1_{16}} = (0.805+0.882)/2=0.844; \mu_{F2_{16}} = (0.882+0.957)/2=0.920$$

$$\mu_{F1_{30}} = 0.367; \mu_{F2_{30}} = 0.480$$

$$\mu_{F1_{31}} = (0.730+0.805)/2=0.768; \mu_{F2_{31}} = (0.805+0.882)/2=0.844$$

3.4.3. Fuzzy inference

From Eqs. (5a) and (5b):

$$y_4 = \mu_{D_{12}} * \mu_{H_{12}} * (1 - \mu_{D_{37}}) * \mu_{F1_{12}} * Z_{4(\text{contractor})} + \\ \mu_{D_{16}} * \mu_{H_{16}} * (1 - \mu_{D_{37}}) * \mu_{F1_{16}} * Z_{4(\text{contractor})} + \\ \mu_{D_{30}} * \mu_{H_{30}} * (1 - \mu_{D_{37}}) * \mu_{F1_{30}} * Z_{4(\text{contractor})} + \\ \mu_{D_{31}} * \mu_{H_{31}} * (1 - \mu_{D_{37}}) * \mu_{F1_{31}} * Z_{4(\text{contractor})}$$

$$y_4 = 0.50*0.54*(1-0.00)*0.563*0.70+0.85*0.89*(1-0.00)*0.844*0.70+ \\ 0.30*0.44*(1-0.00)*0.367*0.70+0.75*0.48*(1-0.00)*0.768*0.70 = 0.781$$

$$h_4 = \mu_{D_{12}} * \mu_{H_{12}} * (1 - \mu_{D_{37}}) * \mu_{F1_{12}} + \mu_{D_{16}} * \mu_{H_{16}} * (1 - \mu_{D_{37}}) * \mu_{F1_{16}} + \\ \mu_{D_{30}} * \mu_{H_{30}} * (1 - \mu_{D_{37}}) * \mu_{F1_{30}} + \mu_{D_{31}} * \mu_{H_{31}} * (1 - \mu_{D_{37}}) * \mu_{F1_{31}}$$

$$h_4 = 0.50*0.54*(1-0.00)*0.563+0.85*0.89*(1-0.00)*0.844+ \\ 0.30*0.44*(1-0.00)*0.367+0.75*0.48*(1-0.00)*0.768 = 1.115$$

$$y_{5,6} = \mu_{D_{12}} * \mu_{H_{12}} * (1 - \mu_{D_{40}}) * \mu_{F1_{12}} * Z_{5(\text{contractor})} + \\ \mu_{D_{12}} * \mu_{H_{12}} * \mu_{D_{40}} * \mu_{F2_{12}} * Z_{6(\text{contractor})} + \\ \mu_{D_{16}} * \mu_{H_{16}} * (1 - \mu_{D_{40}}) * \mu_{F1_{16}} * Z_{5(\text{contractor})} + \\ \mu_{D_{16}} * \mu_{H_{16}} * \mu_{D_{40}} * \mu_{F2_{16}} * Z_{6(\text{contractor})} + \\ \mu_{D_{30}} * \mu_{H_{30}} * (1 - \mu_{D_{40}}) * \mu_{F1_{30}} * Z_{5(\text{contractor})} + \\ \mu_{D_{30}} * \mu_{H_{30}} * \mu_{D_{40}} * \mu_{F2_{30}} * Z_{6(\text{contractor})} + \\ \mu_{D_{31}} * \mu_{H_{31}} * (1 - \mu_{D_{40}}) * \mu_{F1_{31}} * Z_{5(\text{contractor})} + \\ \mu_{D_{31}} * \mu_{H_{31}} * \mu_{D_{40}} * \mu_{F2_{31}} * Z_{6(\text{contractor})}$$

$$y_{5,6} = 0.50*0.54*(1-0.25)*0.563*0.70+0.50*0.54*0.25*0.648*0.00+ \\ 0.85*0.89*(1-0.25)*0.844*0.70+0.85*0.89*0.25*0.920*0.00+ \\ 0.30*0.44*(1-0.25)*0.367*0.70+0.30*0.44*0.25*0.480*0.00+ \\ 0.75*0.48*(1-0.25)*0.768*0.70+0.75*0.48*0.25*0.844*0.00 = 0.586$$

$$h_{5,6} = \mu_{D_{12}} * \mu_{H_{12}} * (1 - \mu_{D_{40}}) * \mu_{F1_{12}} + \mu_{D_{12}} * \mu_{H_{12}} * \mu_{D_{40}} * \mu_{F2_{12}} + \\ \mu_{D_{16}} * \mu_{H_{16}} * (1 - \mu_{D_{40}}) * \mu_{F1_{16}} + \mu_{D_{16}} * \mu_{H_{16}} * \mu_{D_{40}} * \mu_{F2_{16}} + \\ \mu_{D_{30}} * \mu_{H_{30}} * (1 - \mu_{D_{40}}) * \mu_{F1_{30}} + \mu_{D_{30}} * \mu_{H_{30}} * \mu_{D_{40}} * \mu_{F2_{30}} + \\ \mu_{D_{31}} * \mu_{H_{31}} * (1 - \mu_{D_{40}}) * \mu_{F1_{31}} + \mu_{D_{31}} * \mu_{H_{31}} * \mu_{D_{40}} * \mu_{F2_{31}}$$

$$h_{5,6} = 0.50*0.54*(1-0.25)*0.563+0.50*0.54*0.25*0.648+ \\ 0.85*0.89*(1-0.25)*0.844+0.85*0.89*0.25*0.920+ \\ 0.30*0.44*(1-0.25)*0.367+0.30*0.44*0.25*0.480+ \\ 0.75*0.48*(1-0.25)*0.768+0.75*0.48*0.25*0.844 = 1.176$$

3.4.4. Estimating fraction defectives (final output)

From Eqs. (6a) and (6b):

$$Y^*_{(contractor)} = (y_4 + y_{5,6}) / (h_4 + h_{5,6}) = (0.781 + 0.586) / (1.115 + 1.176) = 0.60$$

$$Y^*_{(client)} = 1 - Y^*_{(contractor)} = 1 - 0.60 = 0.40$$

3.4.5. A recommendation report

It is generated from the triggered rules and related to the consequent parts of the if-then structures of the rules (Fig. 1). It shows the effect part of the cause and effect relations. A small part of a recommendation report for the real-case is in Fig. 9.

Rule no	Recommendations	References
1_04, 05	KISK Article 28
1_04, 05	During the implementation of the works, the contractor is discharged only when the client takes the responsibility and gets the works made despite the fact that the contractor warns the client because of the improper application projects, or due to the fact that the client makes a statement not complying with the requirements of the technical specifications and the contract by letter.	YIGS Article 15
1_04, 05	The contractor warning the client because of the improper application project designed by the client is not responsible for losses or damages of the works. Nevertheless, the contractor is responsible for implementing of the works out of the application projects.	Supreme Court Decision. Served April 22, 1991. Docket no. 1990/4761. Filed 1991/1956.
1_04, 05	Supreme Court Decision. 1992/2683
1_06	YIGS Article 15
1_06	If the construction site or materials given by the owner endanger the works, the contractor is responsible unless he or she warns the client beforehand.	Supreme Court Decision. 2004/5856.

Figure 9. A sample recommendation report

4. DISCUSSION

Aside from the studies on the literature, this study was planned to easily handle construction disputes by encouraging contracting parties to reach an agreement without going to court. The aim is to convince contracting sides of the output of the model. This is not a model that judges on behalf of a court, but a model that extracts laws and court decisions relevant to the conflicts from the database of the model and estimates possible fraction defectives instead.

This model especially has been designed according to Turkish laws and court decisions. However, it can be modified with new decision criteria, rules, and reference fraction defectives on the basis of each country's law system. In addition, it is dynamic, but not static; it can be updated with new rules and court decisions, therefore.

The eighty rules and reference fraction defectives, and one hundred thirty-nine decision criteria were determined on the basis of one hundred nineteen law articles and sixty-three court decisions. The model was tested with thirty court decisions and twenty-four of these provided consistent results.

5. CONCLUSION

Resolving construction conflicts is very difficult because of highly complicated and interrelated factors. Disagreements generally impact one or all of the completion time, cost, and quality of a project. Furthermore, both contracting parties endure the cost of the resolution. However, it is impossible to completely avoid construction disputes but possible to resolve these disputes rapidly and costlessly by indicating cause and effect relations so that claimant and the opponent could be convinced of the outcome of the model.

After probing relevant Turkish laws and Turkish Supreme Court decisions, we developed the rule-based fuzzy logic resolution model for conflicts encountered in public construction works in Turkey so as to estimate the contracting parties' possible fraction defectives. One hundred nineteen law articles and sixty-three court decisions were used in the developing process, and the eighty rules and reference fraction defectives, and one hundred thirty-nine decision criteria were determined.

The model tries to estimate possible fraction defectives by generating a cause and effect relation according to both sides' opinions so that both parties will be convinced of the output of the model and stay away from litigation. As a result, we believed that the planned project would be completed in time, the expenses would be reduced, and the project quality would be improved.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors

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