Management Science Letters 1 (2011) 127–138

Contents lists available at GrowingScience

Management Science Letters

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A system dynamic model for measuring the construction quality of buildings' structures

Mehrdad Shokouh-Abdi[a*], Morteza Zahedi[a] and Ahmad Makui[b]

[a]*School of Civil Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran*
[a]*School of Industrial Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran*

A R T I C L E I N F O

Article history:
Received October 10 2010
Received in revised form
25 December 2010
Accepted 30 December 2010
Available online
3 January 2011

Keywords:
Dependence and feedback
Decision making trial and evaluation laboratory (DEMATEL)
System dynamic
Construction building

A B S T R A C T

One of the most important issues on quality of building structure is its resistance against earthquake. Earthquake, as one of natural disasters, has been one of the main reasons of fatal incidents in developing countries. Any attempt to increase the quality of building structure could reduce any possible damages an earthquake could cause on society. This paper presents a system dynamic model to study the importance and behavior of the factors which affect the construction quality of buildings' structures. The proposed model of this paper is analyzed for a case study and the results are discussed. The paper also uses DEMATEL technique to compare the results of the proposed method. The paper concludes that among the whole factors which affect the construction quality of buildings' structures, the "performance of related organizations and institutions" is of the most important ones.

1. Introduction

Structural quality is considered as one of the most important requirements in constructions. There are many evidences, which indicate that the quality of construction in many metropolitan cities is not at the desirable level. There are different reasons to blame the low quality of construction such as weaknesses in design and execution, use of non-standard materials, incorrect welding and joints, non-compliance with concrete implementation standards, etc. There are various methods to improve the quality of construction such as the implementation of total quality management (Arditi & Gunaydin, 1997). An increase in quality of construction requires spending more expenditure. Abdelsalam and Gad (2009) studied the cost of quality on residential construction projects using prevention–appraisal–failure technique to evaluate the cost of quality and to determine its optimum value for the residential construction projects in Dubai. The cost and time spent on a construction project normally involves the implementation of mathematical techniques where optimal solution cannot be achieved very easily. For instance, Zhang and Xing (2010) presented a fuzzy multi-objective model to find a trade-off between time and the cost of construction project. The resulted problem formulation was then solved using particle swarm optimization technique.

* Corresponding author. Tel:
E-mail addresses: m_shokouh_abdi@parsgc.com (M. Shoouh Abdi)

doi: 10.5267/j.msl.2011.01.001

One of the main reasons for blaming low quality construction is the lack of a good communication among the team members when a project is built. Leung (2008) proposed a real-time integrated communication system to monitor the progress and quality of construction works. In fact, site monitoring not only minimizes the construction defects and human flaws but also it can support project team members making strategic decisions in some important events.

Tehran, as a capital city of Iran, accommodates over 13 million people during the day and roughly about eight million people during the night. The city is highly populated and it suffers from different issues such as traffic jam, air pollution, low quality of construction, etc. Recently, there have been different studies performed by different governmental organizations about the consequence of an earthquake on this city. According to one the unpublished studies, an earthquake could result in the destruction of 500 thousand buildings, or 55% of total buildings and the death of 400 thousand people only in one of the regions called Ray located in sought part of Tehran. Another study examined 1284 buildings in Tehran municipality and reported that 18% suffered from design weakness, 42% from execution weakness and 40% from both. The other study determined more than 39 effective factors for privately constructed buildings of up to five stories. Although it is important to identify and classify the factors affecting the quality of structures, according to experts, making overall managerial decisions to promote construction quality is a tedious task based on a simple list of factors or assumptions. This paper presents system dynamic to analyze different factors influencing the quality of the construction. The proposed model of this paper uses different stages to determine the important factors influencing the quality of construction. In the first stage, we use a multiple criteria decision making (MCDM) method to determine the most important factors influencing the quality of construction. The MCDM method uses Delphi method to determine the influencing factors and then uses decision making trial and evaluation laboratory (DEMATEL) technique (Fontela & Gabus ,1976) to rank the factors. The survey gathers 14 experts' feedbacks from different fields of governmental, academic, consultancy and construction fields of activities. In the second phase, we use system dynamic methodology to build a conceptual model based on the factors determined in the first phase.

This paper is organized as follows. We first present the conceptual system dynamic model in section 2. Section 3 presents the implementation of the proposed system dynamic and the sensitivity analysis of the proposed model is given in section 4. Finally, conclusion of the paper is given in the last part to summarize the contribution of the paper.

2. The proposed method

In this section, we present two phases of the proposed model of this paper. As explained earlier, we first need to determine the important factors affecting the quality of construction. The following summarizes the result of our survey on factors affecting the quality of construction,

A. Quality of materials (3 factors)
B. Performance of related people (according to law) (5 factors)
C. Performance of related organizations and institutions (according to law) (9 factors)
D. Quantity and Quality of regulations and technical documents (15 factors)
E. Quality at educational and cultural levels (factor 5)
F. Application of industrial construction (2 factors)

2.1 Impact network affecting groups

The impact network of affecting groups is depicted in Fig. 1. As we can observe from the figure, the parameters A, B,..., F not only influence the target parameter quality (Q) but also there are some influences among all these factors as well. Parameters A1, B1,..., F1 replace the original variables and have no independent identity and they are defined to facilitate the definition of the equations.

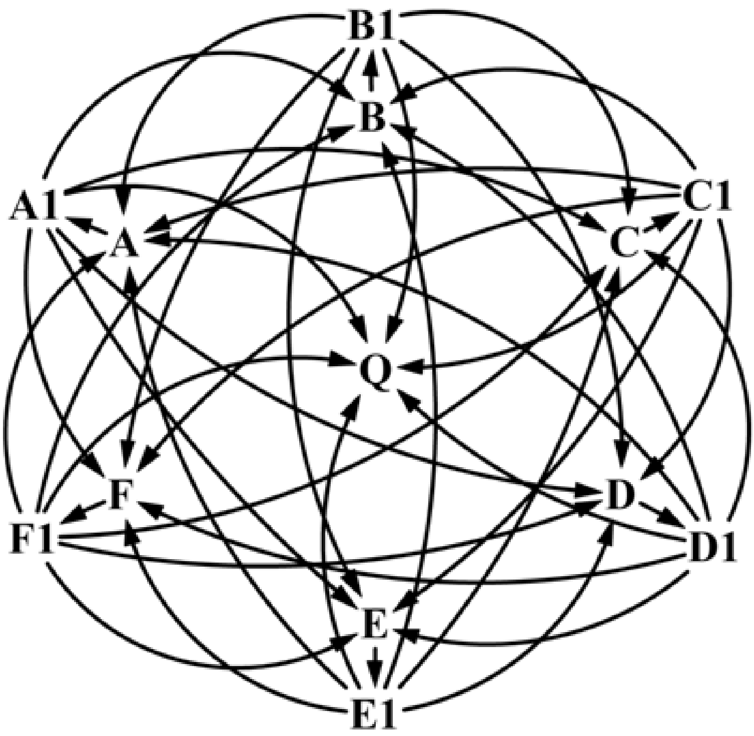

Fig. 1. The impact network of affecting groups on quality

2.2 Mathematical model

In order to gather the necessary information we first define three categories of good, moderate and bad for the factors affecting the quality of construction. In our survey, once we consider all possible scenarios, there are 729 possible cases for a single target parameters. Questioning experts to this extent for seven target parameters, for six groups plus quality parameter, obviously is not practical. Thus, a form was designed to reduce the number of cases while preserving the logical consistency of the subject to direct acceptable equations and manage the observers in a logical, systematic and gradual manner. The following cases were included in the questionnaire:

- All variables are "good", "moderate" or "bad": 3 cases
- One variable is "bad" and the others are "good": 6 cases
- One variable is "good" and the others are "bad": 6 cases
- Gradual change from "all good" to "all bad": 7 cases
- Gradual change as above with a different trend: 7 cases
- Gradual change from "all bad" to "all good": 7 cases
- Gradual change as above with a different trend: 7 cases

Although the number of the cases equals 43, eliminating duplicated cases to provide a logical arrangement for responses reduced the number of cases to 27. The experts evaluated the above cases in seven questionnaires, assigning parameters as "good", "moderate to high", "moderate", "moderate to low" and "bad". Quantitative values corresponding to the above options proceed from 0 to 1 at intervals of 0.25. Table 1 shows the median of the results of the survey.

Table 1

A sample of one table collecting experts' feedbacks

General	Special	E	C	D	F	A	Z*	B Performance of related persons (according to law) 1	2	3	4	5	median	mean
1	1	good	good	good	good	good	good	1	1	1	1	1	1	1
2	2	moderate	moderate	moderate	moderate	moderate	moderate	0.75	0.5	0.5	0.5	0.5	0.5	0.55
3	3	bad	bad	bad	bad	bad	bad	0.25	0	0	0	0	0	0.05
4	4	bad	good	good	good	good	good	0.5	0.5	0.75	0	0.75	0.5	0.5
5	5	good	bad	good	good	good	good	1	0.75	0.5	0.5	0.25	0.5	0.6
6	6	good	good	bad	good	good	good	0.75	0.75	0.5	0.5	0.5	0.5	0.6
7	7	good	good	good	bad	good	good	1	0.75	0.5	0.25	0.75	0.75	0.65
8	8	good	good	good	good	bad	good	1	0.75	0.5	0	0.75	0.75	0.6
9	9	good	Good	good	good	good	bad	1	0.75	1	0.25	0.5	0.75	0.7
10	10	good	Bad	bad	bad	bad	bad	0.75	0.5	0	0	0	0	0.25
11	11	bad	Good	bad	bad	bad	bad	0.5	0.25	0	0	0.25	0.25	0.2
12	12	bad	Bad	good	bad	bad	bad	0.5	0.25	0	0	0	0	0.15
13	13	bad	Bad	bad	good	bad	bad	0.5	0.25	0	0	0	0	0.15
14	14	bad	Bad	bad	bad	good	bad	0.25	0.25	0	0	0.25	0.25	0.15
15	15	bad	Bad	bad	bad	bad	good	0.25	0.25	0	0	0.5	0.25	0.2

*All other options

2.3 Regression results

In order to analyze the relationship among different variables *A*, *B*, *C*, *D*, *F* and *Z* we use logistic regressions. We have performed all possible regression analysis among the variables which would be used as input factors for the proposed system dynamic. Table 2 shows some of the results of the implementation of regression analysis.

Table 2

The results of logistic regressions for A and Q in terms of other variables

A (1) = 0.489 + 0.106 C + 0.0821 E + 0.0979 D + 0.0594 F + 0.140 B - 0.0201 Z
A (2) = 0.0726 + 0.134 C + 0.155 E + 0.112 D + 0.166 F + 0.179 B + 0.132 Z
A (3) = - 0.0715 + 0.285 C + 0.148 E + 0.182 D + 0.0798 F + 0.0124 B + 0.308 Z
A(4) = - 0.0110 + 0.267 C + 0.200 E + 0.282 D + 0.0518 F - 0.0743 B + 0.0178 Z
A(5) = 0.175 + 0.250 C + 0.0162 E + 0.0649 D - 0.0065 F + 0.159 B + 0.0158 Z
A(Med5) = 0.0403 + 0.258 C + 0.158 E + 0.124 D + 0.0898 F + 0.110 B + 0.121 Z
A(Ave5) = 0.130 + 0.208 C + 0.119 E + 0.142 D + 0.0757 F + 0.0853 B + 0.0880 Z
Q (1) = 0.129 + 0.0960 C + 0.221 B + 0.161 E + 0.0502 D + 0.0392 F + 0.174 A
Q (2) = 0.0764 + 0.0960 C + 0.300 B + 0.105 E + 0.118 D + 0.119 F + 0.0863 A
Q (3) = - 0.0626 + 0.0623 C + 0.331 B + 0.0121 E + 0.217 D + 0.233 F + 0.141 A
Q(4) = - 0.115 + 0.0244 C + 0.353 B + 0.137 E + 0.194 D + 0.0131 F + 0.138 A
Q(5) = 0.0033 + 0.133 C + 0.403 B - 0.0200 E + 0.142 D - 0.0376 F + 0.245 A
Q(Med5) = 0.0330 + 0.0638 C + 0.338 B + 0.0383 E + 0.190 D + 0.0979 F + 0.124 A
Q(Ave5) = 0.0062 + 0.0823 C + 0.322 B + 0.0790 E + 0.144 D + 0.0732 F + 0.157 A

As we can see from Table 2 quality can be described as other influencing factors of *A*, *B*, *C*, *D*, *E* and *Z*. We can also see there are some variations in coefficients as a results of the medians and averages of the experts' feedback were significant in some cases. In the further analyses based on this feedback, the median parameter was used to remove the effect of extremes. Next, we explain the details of our finding.

2.3.1 Group A: quality of materials

Group A, expert feedback regarding the quality of materials, produced an equation pertaining to the median feedback as:

A (Med5) = 0.0403 + 0.258 C + 0.158 E + 0.124 D + 0.0898 F + 0.110 B + 0.121 Z. (1)

According to Eq. (1), group C has the highest influencing factor with an impact factor of 0.258, which represents 30% coefficient weights of all variables. The other most influencing factors were E, D, Z and B.

2.3.2 Group B: Performance of related people

The logistic regression model for group B is as follows,

B (Med5) = 0.0018 + 0.174 E + 0.272 C + 0.164 D + 0.0107 F + 0.128 A + 0.131 Z. (2)

Once again, group C, with an impact factor of 0.272, or a 31% weight coefficient has the most impact on group B. After C, groups E and D with 20% and 19% weight coefficients, respectively, have the greatest effects on group B. groups Z and A with 15% weight coefficients are next. Group F has a minimum impact with a rate of 1%. Group Z in this case included job satisfaction, total cost of living, spiritual commitment, and cost-income ratio.

2.3.3 Group C: Performance of related organizations and institutions

The relationship of the median expert feedback to group C, performance of organizations and institutes according to code, is as follows:

C (Med5) =- 0.0464 + 0.344 D + 0.157 B + 0.0329 E + 0.100 F + 0.117 A + 0.214 Z. (3)

Group C was primarily under the influence of group D with about a 36% weight coefficient. The weights for groups Z and B follow group D were at 22% and 16%, respectively. Groups A and F had, respectively, 12% and 10% influence. Group E had the lowest impact at 3%. Group Z included acceptance by parliament, international organizations or manufacturers and the behavior of officials, social justice, job satisfaction, family cost portfolio, spiritual commitment and cost-income ratio.

2.3.4 Group D: Quantity and quality of regulations and technical documents

Group D, quantity and effectiveness of regulations and technical documents associated with expert feedback is as follows,

D (Med5) = 0.0394 +0.688 C - 0.0519 B +0.105 E +0.0959 F +0.0287 A +0.0559 Z. (4)

In addition to the major impact of D on C, group D was also highly affected, 71% positive weight coefficients, by group C. This indicates an interactive relationship between these two important parameters. The influence of groups E and F followed in impact at 11% and 10%, respectively. Groups Z, B, and A had no significant effect on D.

2.3.5 Group E: Quality at educational and cultural levels

Group E, quality at educational and cultural levels, had an expert feedback median as follows:

E (Med5) = 0.0034 +0.432 C +0.149 D +0.0406 F +0.138 B +0.0117 A +0.233 Z. (5)

Group C primarily influenced group E, quality at educational and cultural levels with a 43% weight coefficient. Groups Z at 23%, D at 15% and B at 14% followed this. Experts included media, global cultural and scientific relations, general education, social welfare, scientific progress, and social improvement in group Z as other important factors. Groups F and A had no major impact on E.

2.3.6. Group F: Application of industrial construction

Group F, application of industrial construction, equation is as follows:

F (Med5) = 0.0522 +0.364 C +0.133 E +0.0439 B +0.167 D +0.0003 A +0.129 Z (6)

Once again, group C, with an impact factor of 43%, had the most influence on F. Groups D, E, and Z followed with, respectively, 20%, 16% and 15%. Experts included domestic industrial and economic status, production, government policy, cost-profit analysis, banking system cooperation, customs policies, work regulations and insurance in group Z. Group B had no significant effect on Group F.

2.3.7. Parameter Q: Quality of construction

The relationship of target parameter Q, quality of construction, was as follows:

Q (Med5) = 0.0330 +0.0638 C +0.338 B +0.0383 E +0.190 D +0.0979 F +0.124 A (7)

Apart from interaction parameters, discussed previously, the following groups in order of ranking influenced target parameter Q,

B: 40% D: 22% A: 15% F: 11% C: 7% E: 5%.

It is considered that group B with 40% effectiveness, has the most effect on Q. Ranking 2 belongs to group D with 22% effectiveness. Rankings 3 and 4 with 15% and 11% effectiveness, respectively, belong to groups A and F with almost the same level of importance. Rankings 5 and 6 with 7% and 5% effectiveness coefficients, respectively, were considered to be of the same level of importance and belong to C and E groups.

2.4. Initial values of variables and delay time

Initial values of the variables were chosen as shown in Table 3. The selection of values was based on overall expert feedback during the analysis. The results of the step-by-step process and a comparison of the final results had no significant effects.

Table 3
Initial values of variables (effective groups)

Group	Title	Initial Value
A	Quality of materials	70
B	Performance of related persons (according to law)	40
C	Performance of related organizations and institutions (according to law)	50
D	Quantity and Quality of regulations and technical documents	70
E	Quality at educational and cultural levels	60
F	Application of industrial construction	50
Z	Other effective parameters	100

The length of delay affecting a parameter was considered to be a fixed rate of 6 months for all variables. Although delay time had no effect in comparison with the results, it does indicate the gradual change in variables in a more tangible form.

3. The system dynamics model analysis

In this section, we present the implementation of system dynamic model using the information achieved from the previous section. The structure of system dynamic framework is shown on Fig 1. The implementation was performed using Vensim software package (Sterman, 2000), which is dedicated for the analysis of system dynamic models. We also used experts' suggestions on revising the model and provided some managerial implications. The following delay fixed functions were used for the implementation of our system dynamic modeling.

A = DELAY FIXED (0.0403 * 100 + 0.258 * C1 + 0.158 * E1 + 0.124 * D1 + 0.0898 * F1 + 0.11 * B1 + 0.121 * 100, 6, Aini)
B = DELAY FIXED (0.0018 * 100 + 0.174 * E1 + 0.272 * C1 + 0.164 * D1 + 0.0107 * F1 + 0.128 * A1 + 0.131 * 100, 6, Bini)
C = DELAY FIXED (- 0.0464 * 100 + 0.344 * D1 + 0.157 * B1 + 0.0329 * E1 + 0.1 * F1 + 0.117 * A1 + 0.214 * 100, 6, Cini)
D = DELAY FIXED (0.0394 * 100 + 0.688 * C1 - 0.0519 * B1 + 0.105 * E1 + 0.0959 * F1 + 0.0287 * A1 + 0.0559 * 100, 6, Dini)
E = DELAY FIXED (0.0034 * 100 + 0.432 * C1 + 0.149 * D1 + 0.0406 * F1 + 0.138 * B1 + 0.0117 * A1 + 0.233 * 100, 6, Eini)
F = DELAY FIXED (0.0522 * 100 + 0.364 * C1 + 0.133 * E1 + 0.0439 * B1 + 0.167 * D1 + 0.0003 * A1 + 0.129 * 100, 6, Fini)
Q = 0.033 * 100 + 0.0638 * C1 + 0.338 * B1 + 0.0383 * E1 + 0.19 * D1 + 0.0979 * F1 + 0.124 * A1

The MIN function was used to control the quantity of variables not exceeding 100 as A1 = MIN (A, 100). The MIN function was defined similarly for other groups. Table 4 summarizes the results of our implementation based on expert feedback median. The following conclusions were made based on the results:

- The system dynamic model calculated values based on numerical analysis; the quantity of each variable in every cycle was determined compared with other variables in the previous analysis cycle, which was controlled manually.

- The values of all variables changed in different cycles and gradually converged to their ultimate values. These changes, especially in the primary cycles, could fluctuate.

- The ultimate values of variables created a balance that could not be changed. Assuming the accuracy of the integers, balance was achieved at T = 150.

4. Sensitivity analysis of system dynamics model

In this section, we perform sensitivity analysis on the data based on expert median feedback. We have found different scenarios for our proposed model, which are as follows,

- Initial values: 1 case
- Balance status: 1 case
- One variable in ultimate state: 6 cases
- Several variables in ultimate state: 8 cases
- 10% reduction from original value: 7 cases
- One variable equals zero: 6 cases
- 10% sequential and increase in basic value up to a final value: 19 cases
- Gradual increase in variables with initial value close to ultimate, from zero: 10 cases
- Total cases studied: 58 cases

Table 4
Model analysis for initial values

Time (Month)	A	B	C	D	E	F	Q
0	70.0000	40.0000	50.0000	70.0000	60.0000	50.0000	49.1830
6	56.0800	58.2950	62.2840	54.9580	64.0390	57.7670	52.4814
12	60.7322	58.1735	59.2628	63.2293	69.7816	61.0625	54.9386
18	62.1682	60.3382	63.1519	62.2096	69.8804	62.104	56.0085
24	63.3924	61.4409	63.4163	64.9244	71.7663	63.4579	57.2704
30	64.3381	62.4574	64.864	65.4121	72.5065	64.3071	58.0278
36	65.0771	63.1901	65.4113	66.5416	73.3904	65.0589	58.7241
42	65.6462	63.7806	66.1056	67.0663	73.9354	65.5967	59.2118
48	66.0897	64.229	66.5171	67.6384	74.4235	66.0356	59.6149
54	66.4327	64.5811	66.8962	68.0043	74.7714	66.3657	59.9158
60	66.6992	64.8522	67.1619	68.3249	75.0557	66.6266	60.1548
66	66.9057	65.0634	67.3813	**68.5562**	75.2694	66.8266	60.3375
72	67.0659	65.2268	**67.5453**	68.7437	75.4383	66.9829	60.4804
78	67.1902	65.3537	67.6754	68.8853	**75.5678**	67.1036	**60.5907**
84	67.2866	65.452	67.7749	68.997	75.669	67.1974	60.6765
90	67.3613	**65.5284**	67.8527	69.0828	75.7472	67.2701	60.743
96	67.4193	65.5876	67.9128	69.1497	75.8079	67.3265	60.7946
102	67.4643	65.6335	67.9595	69.2014	75.855	67.3702	60.8346
108	67.4991	65.6691	67.9957	69.2416	75.8915	67.4042	60.8656
114	**67.5262**	65.6967	68.0238	69.2727	75.9198	67.4305	60.8896
120	67.5472	65.7181	68.0456	69.2969	75.9418	67.4509	60.9083
126	67.5635	65.7347	68.0625	69.3156	75.9588	67.4667	60.9228
132	67.5761	65.7476	68.0756	69.3302	75.972	67.479	60.9340
138	67.5859	65.7576	68.0857	69.3414	75.9823	67.4885	60.9427
144	67.5935	65.7653	68.0936	69.3502	75.9902	67.4959	60.9495
150	67.5993	65.7714	68.0997	69.3569	75.9964	**67.5016**	60.9547
156	67.6039	65.776	68.1045	69.3622	76.0012	67.5061	60.9588
162	67.6075	65.7796	68.1081	69.3663	76.0049	67.5095	60.9619
168	67.6102	65.7824	68.1110	69.3694	76.0078	67.5122	60.9643
174	67.6123	65.7846	68.1132	69.3719	76.0100	67.5143	60.9662
180	67.614	65.7863	68.1149	69.3738	76.0117	67.5159	60.9677
186	67.6153	65.7876	68.1162	69.3753	76.0131	67.5171	60.9689
192	67.6163	65.7886	68.1173	69.3764	76.0141	67.5181	60.9697
198	67.6170	65.7894	68.1181	69.3773	76.0149	67.5188	60.9704
204	67.6176	65.7900	68.1187	69.378	76.0156	67.5194	60.9710
210	67.6181	65.7905	68.1192	69.3785	76.016	67.5199	60.9714
216	67.6185	65.7909	68.1196	69.379	76.0164	67.5202	60.9717
222	67.6187	65.7912	68.1199	69.3793	76.0167	67.5205	60.9719
228	67.619	65.7914	68.1201	69.3795	76.0169	67.5207	60.9721
234	67.6191	65.7915	68.1203	69.3797	76.0171	67.5209	60.9723
240	67.6193	65.7917	68.1204	69.3799	76.0173	67.521	60.9724

In order to perform the sensitivity analysis we need to define a fixed measuring index. Therefore, we have used TQu and TSt as time to achieve ultimate quality and balanced status, respectively. In each case, the results derived from system dynamics were reviewed in different cycles from zero to 240 months at intervals of 6 months and the times to achieve TQu and TSt were determined. A summary of the results carried out for the 58 are described in Table 5.

Table 5
Summary of the results for the sensitivity analysis of system dynamics model

Case Description	A	B	C	D	E	F	Z	Q0	Qu value	Qu **TQu**	**TSt**
Initial values	70	40	50	70	60	50	100	49	61	78	150
Balance status	68	66	68	69	76	68	100	61	61	0	12
One variable in ultimate state	68	40	50	70	60	50	100	49	61	78	150
	70	66	50	70	60	50	100	58		72	144
	70	40	68	70	60	50	100	50		54	132
	70	40	50	69	60	50	100	49		78	150
	70	40	50	70	76	50	100	50		72	150
	70	40	50	70	60	68	100	51		72	150
Several variables in ultimate state	70	66	50	70	76	68	100	60	61	60	138
	70	66	68	70	60	50	100	59		42	120
	70	40	68	70	76	50	100	51		48	126
	70	40	68	70	60	68	100	52		48	126
	70	66	68	70	76	50	100	60		24	96
	70	66	68	70	60	68	100	61		24	96
	70	40	68	70	76	68	100	53		30	108
	70	66	68	70	76	68	100	61		0	30
10% reduction from original value	63	40	50	70	60	50	100	48	61	78	150
	70	36	50	70	60	50	100	48		78	150
	70	40	45	70	60	50	100	49		78	156
	70	40	50	63	60	50	100	48		78	156
	70	40	50	70	54	50	100	49		78	150
	70	40	50	70	60	45	100	49		78	150
	63	40	50	63	60	50	100	47		48	156
One variable equals zero	0	40	50	70	60	50	100	41	61	84	162
	70	0	50	70	60	50	100	36		84	156
	70	40	0	70	60	50	100	46		96	174
	70	40	50	0	60	50	100	36		96	174
	70	40	50	70	0	50	100	47		84	162
	70	40	50	70	60	0	100	44		84	156
10% sequential and increase in basic value up to a final value	68	40	50	69	60	50	100	49	61	78	150
	68	40	55	69	60	50	100	49		72	150
	68	40	60	69	60	50	100	49		66	144
	68	40	65	69	60	50	100	50		60	138
	68	40	68	69	60	50	100	50		60	132
	68	44	50	69	60	50	100	50		78	150
	68	48	50	69	60	50	100	51		78	150
	68	52	50	69	60	50	100	53		72	150
	68	56	50	69	60	50	100	54		72	150
	68	60	50	69	60	50	100	56		72	150
	68	64	50	69	60	50	100	57		72	150
	68	66	50	69	60	50	100	58		72	144
	68	40	50	69	60	55	100	49		78	150
	68	40	50	69	60	60	100	50		72	150
	68	40	50	69	60	65	100	50		72	150
	68	40	50	69	60	68	100	51		72	150
	68	40	50	69	66	50	100	49		78	150
	68	40	50	69	72	50	100	49		72	150
	68	40	50	69	76	50	100	49		72	150
Gradual increase in variables with initial value close to ultimate, from zero	0	40	50	70	60	50	100	41	61	84	162
	20	40	50	70	60	50	100	43		84	156
	40	40	50	70	60	50	100	45		78	156
	60	40	50	70	60	50	100	48		78	150
	68	40	50	70	60	50	100	49		78	150
	70	40	50	0	60	50	100	36		96	174
	70	40	50	20	60	50	100	40		90	168
	70	40	50	40	60	50	100	43		84	162
	70	40	50	60	60	50	100	47		78	156
	70	40	50	69	60	50	100	49		78	150

The following regression equations are derived from Table 5.

TQu = 234 - 0.159 A - 0.555 B - 1.05 C - 0.315 D - 0.433 E - 0.528 F

S = 10.4972 R-Sq = 79.4% R-Sq (adj) = 77.0%

TSt = 364 - 0.181 A - 0.869 B - 1.28 C - 0.370 D - 0.663 E - 0.740 F

S = 19.6736 R-Sq = 66.7% R-Sq (adj) = 63.0%

The regression function for Q is also as follows,

Q (Med5) = 0.0330 + 0.0638 C + 0.338 B + 0.0383 E + 0.190 D + 0.0979 F + 0.124 A

S = 0.0999849 R-Sq = 91.8% R-Sq (adj) = 90.4%

The final value of Q for all cases was identical and did not change. In other words, the interactive factors caused the final level of quality to be limited to a specific value, which was equal to 61. On the other hand, other groups tended toward their ultimate values. Final and ultimate values in a group were called “balance". Balance occurs when all parts and components in the systems are stable and the mathematical ideal is not equal to 100. Balance in the analysis was achieved for the following final values:

Group A (quality of materials): 68

Group B (performance of involved people (according to law)): 66

Group C (performance of related organizations and institutions (according to law)): 68

Group D (the quantity and quality of legislation and technical documents): 69

Group E (quality of educational and cultural levels): 76

Group F (using industrial construction): 68

Group Q (quality of construction): 61

The other observation is that the final status of the system does not depend on the initial values of the system. Thus, if one or more groups (variables) improved to higher levels, eventually the group interaction experienced a reduction in value and return to their final status. As a result, the optimal level of cost on improving the affected group was to approach balance without exceeding it. However, any change on the relationships and equations could significantly influence the balance which results to either increase or decrease ultimate values. Since the expert feedback equations depend on the current environment of construction, the equations may be affected by future changes in the environment. In Table 2 for instance, A may interact with other parameters as follows,

A (Med5) = 0.0403 + 0.258 C + 0.158 E + 0.124 D + 0.0898 F + 0.110 B + 0.121 Z

In the above equation, A depends on B by approximately 11%. Obviously, this dependency resulted from expert's feedback to the current environment. If the quality of materials is decreased on the market, the relationship will tend to zero. The new situation changes all the relationships and equations in the system and would affect the whole system and the balance as well. As a result, the system dynamic model must be periodically reviewed and the process must be modified based on the logical feedback. The other observation was the impact of changes of C on TQu and TSt. It was observed that, when one group tended toward its ultimate, as A, B, D, E and F reached their final values, the time to achieve TQu and TSt did not change much, although an increase in C caused a greater reduction. This demonstrates the role of C in the overall model. Other aspects of the influence of C were:

- When a combination of variables tended toward ultimate values, they created synergy and caused decreases in TQu and TSt. The greatest changes occurred when C was part of the combination. The compound synergy of groups (e.g., a simultaneous increase in C, E and F) is important for management decisions.

- The more important roles of C and D in the overall model were reflected in the 10% reduction of a group and when a group approaches zero.

- In cases experiencing a gradual increase and sequential group values that increase from primary to final values, it is important to determine the role of group C. The differences of other groups were tangible on the overall model. The mathematical explanation of this difference will be discussed, subsequently.

A summary of results for TQu, TSt and Q are shown in Tables 6. Although the results are similar but higher values were achieved from R-Sq than TQu regression and the results of TQu are considered as a basis for judgments in subsequent analysis.

Table 6
The summary of effective groups on TQu, TSt and Q

TQu				TSt				Q			
Group	Value	%	Rank	Group	Value	%	Rank	Group	Value	%	Rank
A	0.159	5.2	6	A	0.181	4.4	6	A	0.124	14.6	3
B	0.555	18.3	2	B	0.869	21.2	2	B	0.338	39.7	1
C	1.050	45.5	1	C	1.280	31.2	1	C	0.0638	7.5	5
D	0.315	10.4	5	D	0.37	9.0	5	D	0.19	22.3	2
E	0.433	14.2	4	E	0.663	16.2	4	E	0.0383	4.5	6
F	0.528	17.4	3	F	0.740	18.0	3	F	0.0979	11.5	4
	3.04	100			4.103	100			0.852	100	

A we can observe from Tables 6, the percentage of influence differs clearly for the whole model and for Q. Group C, for instance, had a significant impact of approximately 35% for the total model, but only 8% for Q, which is even less than the effects of A, B, D and F. This means that, in managerial assessments, relying on the direct and linear effects of variables on the objective parameters without considering the interactive effects of variables on each other and the whole system, can lead to incorrect decisions. In summary, the influence of 35% for group C on the whole model means that programs improving the quality of construction should strongly consider the importance and limitations of C factors, including money and time. This is particularly true when these increases accompany the synergy from a combination of different cases. In other words, C significantly affects other parameters. It is essential, in this context, to focus on the factors of this group. The performance of the housing and urban development ministry, construction engineering organization and Tehran municipality were challenged mainly by country's current and governing codes.

4.1 Comparison with DEMATEL

In order to validate the results of our finding from system dynamic we have used DEMATEL technique in this section. Table 7 summarizes the results of the implementation of DEMATEL technique. The most important results of DEMATEL was to determine the effect of different factors on each other and the order of influence based on output parameters of total impact and affectability, R + J. As we can see from the results, DEMATEL and system dynamic confirm their results. However, the results of the implementation of system dynamic seem to be more realistic.

Table 9
The results of the implementation of DEMATEL technique

Sorted based on R+J			
Group	Value	%	Ranking
A	5.3339	15.1	6
B	6.1351	17.4	2
C	6.5972	18.7	1
D	5.7643	16.4	4
E	5.8753	16.7	3
F	5.5314	15.7	5
	35.2372	100	

5. Conclusions

A new methodology for modeling and construction quality analysis in Tehran was presented using a system dynamics model. The proposed model is a causal relationship technique for modeling, analysis and understanding the behavior of complex systems. The case study of this paper gathered the necessary information of 39 factors affecting the quality of private building construction up to five stories in height in Tehran and the groups are divided into six main groups. The information was based on the feedback gathered from experts from different groups. The results of the implementation of system dynamic indicated that group C played an important role on our analysis. In this regard, the performances of the ministry of housing and urban development, construction engineering organization, and Tehran municipality are mainly challenged by experts on the basis of country's current and governing codes.

We have also verified the results of the proposed system dynamic model with DEMATEL technique.

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