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Interaction among the Criteria Affecting Main Battle Tank Selection: An Analysis with DEMATEL Method

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ABSTRACT

Main battle tanks (MBTs) have always been in the heart of all military campaigns and have enabled armies to fight across the full spectrum of war. Countries need to consider the complex interactions between subsystems of MBTs in the decision phase of a design process or MBT acquisition. In order to define the interaction among the subsystems of 'system of systems', which is MBT system for this case, this study aims to determine the criteria and their sub criteria affecting MBT selection problem and to analyse the cause and effect relations among these criteria. The criteria and the complex interaction among them have been determined by consulting a group of experts. Because of multiple complex criteria interactions in MBT selection problem, decision making trial and evaluation laboratory (DEMATEL) method is used as a multiple criteria decision making method. DEMATEL method is applied on the main and the sub criteria separately to understand the cause and effect relations. The results show that Survivability main criterion has the strongest central role among the main criteria for MBT selection, while the followers are firepower, mobility and command and control (C2). It is also shown that, in terms of sub criteria for MBT selection, ballistic protection, a sub criterion of survivability main criterion, has the highest degree of influence over most of the other sub criteria. However, physical dimensions/silhouette, another sub criterion of survivability, is the most affected sub criteria. The top five sub criteria in terms of central role are determined as physical dimensions/silhouette, ballistic protection, power/weight ratio, ground pressure and suspension system.

Keywords: Main battle tank, weapon system selection criteria, defence technology, DEMATEL method, multi criteria decision making, MCDM

1. INTRODUCTION

Main battle tanks (MBTs) symbolise the great power of army and have played a key role since they were first introduced on the battlefield during the World War I[1]. The main purpose of a tank is to carry the firepower (main gun) into the battlefield with an enormous armour protection to close with and destroy the enemy.

The capabilities of tanks are being questioned more than ever with the increasing use of long-range precision-guided weapons[2] or potentially more effective weapon systems such as attack helicopters and new anti-tank weapons[3]. There is also the wheel versus track dilemma which is always at the surface with the development of any new armoured combat vehicle[4].

Ogorkiewicz[2] indicates that the answer to 'the need for tank' question lies in the capabilities of tanks and the likely demand for such capabilities in the future. Anthony[5], discussing Leopard-2 MBT use by Canadian Army in Afghanistan, concludes that MBTs have enabled Canadian Army to fight across the complete spectrum of conflict in order to achieve operational level objectives. Supporting this conclusion, Ogorkiewicz[2] comments that MBTs remain as effective counter tank weapons and for that reason, close combat will require the continued use of MBTs. Furthermore, Foss[3] argues that MBTs have proven their adaptability in evolving battlefield requirements, which results in the countries' willingness of retaining MBTs as part of manoeuvre capability. Thanks to the advances in technology, MBTs will remain as decisive as they have been in the future, because of their impressive capabilities such as cross-country mobility, heavy direct firepower and armour protection.

A weapon systems selection problem has always taken academics attention since it is a strategic decision with likely significant impacts on the efficiency of the whole defence system[6]. Weapon systems are getting more sophisticated and expensive as the military technologies rapidly develop, which accelerates research on methods for selection of these systems[7]. Multiple criteria decision making (MCDM) methodologies can be used to address this problem. Among few quantitative decision making studies focused on MBT selection problem are listed in the literature[8-11]. Due to the complex structures of MBTs, forming a 'System of Systems', the criteria affecting MBT selection should be investigated together with the MBT selection methods. Within this perspective, in this study, the literature is simultaneously reviewed in terms of both the methods for selecting MBTs and the criteria used in the selection process.

Gupta and Bhushan[8] developed a model to evaluate the performance of MBTs using analytic hierarchy process (AHP) focusing on the relative performance of five MBTs in terms of

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mobility, firepower, survivability and some other sub-factors. They ranked the performance factors as firepower, mobility and survivability in terms of effectiveness. However, this study does not include any analysis of the sub factors other than the ones forming mobility criterion.

As another study, Cheng and Lin[9] applied fuzzy decision theory to evaluate three different MBTs (M1A1, Challenger-2, and Leopard-2). They investigated four main capabilities to evaluate the MBTs. These capabilities were mobility, communication and control, self-defence and attack capabilities. However, when quantifying these capabilities, Cheng and Lin[9] considered only the basic performance data of MBTs, failing both to consider the interaction among the capabilities and to break these factors into sub factors. They listed the capabilities affecting the MBT evaluation as mobility, attack, self-defence and communication and control. In a subsequent research, Yong and Cheng[10] evaluated Cheng and Lin's[9] fuzzy group decision-making method and used fuzzy number arithmetic operations proposed to be more efficient according to fuzzy sets theory. The results about the weights of criteria and the selection of MBTs coincide with the results presented by Cheng and Lin[9].

In their study, Jiang[11], *et al.* built a capability assessment hierarchy for weapon system capability assessment (WSCA). They handled the MBT selection criteria, which are attack, mobility, defence and C2 in a hierarchical structure. These capabilities were broken down into some sub-capabilities. Jiang[11], *et al.* categorised the attack and mobility capabilities into eight and nine sub criteria, respectively. Additionally, defense capability was investigated in three and C2 capability was analysed in four sub criteria.

A research[12], based on a survey among professionals within the global market of armoured vehicles, similar platforms with MBTs, identified 13 key attributes over the next decade naming 'protection' as first on the list. The analysis of the data in this research shows that the technologies to be granted with the most significant levels of investment are the counter-improvised explosive devices (IED) measures and the blast protection systems.

Although there are some researches focusing on MBT selection problem, the literature lacks scientific studies that include interactions of complex criteria and cause-effect relations among them. On the other hand, the MBT as a 'System of Systems' includes many interdependent sub systems that interact with each other. The importance and complex nature of MBT selection problem dictates considering the complex interactions between subsystems of MBTs in the decision phase of a design process or MBT acquisition. To define the interaction among the subsystems of 'system of systems', this study aims to determine the criteria and their sub criteria affecting MBT selection problem and to analyse the cause and effect relations among these criteria.

Due to the complex criteria interactions in the MBT selection problem, DEMATEL, a multiple criteria decision making method, is applied on the main and the sub criteria separately to understand the interrelations. DEMATEL not only allows confirmation of the interdependence among the selection criteria but also considers the interrelationships[13]. Contrary to the AHP method, which treats the criteria as independent of each other, DEMATEL method tackles with interdependent factors and determines the level of interdependence among them[14].

2. METHODOLOGY

2.1 Evaluation Framework

In this study MBT selection problem is investigated DEMATEL methodology, in a three-phase framework as presented in Fig. 1. In the first phase, the decision goal is determined. The second phase of this framework includes determining the main criteria and sub criteria that affect the decision-making problem through literature review and expert opinion. Finally, DEMATEL method is used for analysis and evaluation of the criteria affecting MBT selection problem.

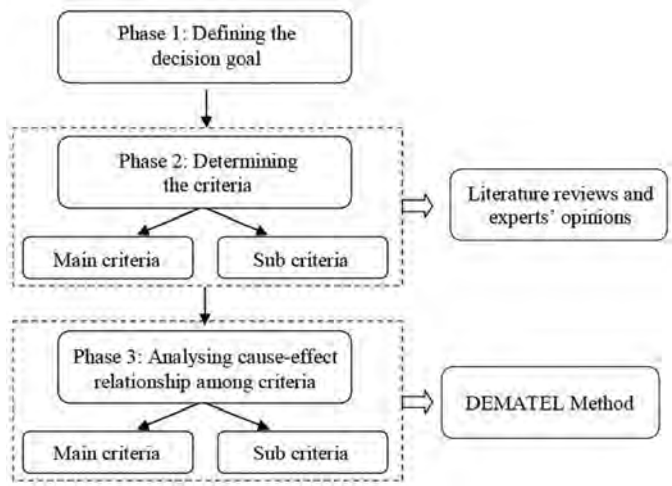

Figure 1. Evaluation framework for MBT decision problem.

2.2 DEMATEL Method

Decision making trial and evaluation laboratory (DEMATEL) method was developed by the science and human affairs program of the Battelle Memorial Institute of Geneva[15,16]. DEMATEL can be used to check interdependence among the criteria used in a decision-making problem and to form an interrelationship chart between the criteria[13]. Contrary to the analytical hierarchy process (AHP) method, which treats the criteria as independent of each other, DEMATEL method tackles with interdependent factors and determines the level of interdependence among them[14]. As Wu[17] states, 'DEMATEL is a comprehensive method for building and analysing a structural model involving causal relationships between complex factors'. The final output of the DEMATEL method is the 'impact versus relation' map, which represents the experts' mind-sets in the real world[13].

DEMATEL method is widely used in many areas including information security risk control assessment[18], analysing the patent citation for prioritising a portfolio of investment projects[19], evaluating intertwined effects in e-learning programs[20], choosing knowledge management strategies[17] and analysing the casual relations on technological innovation capability[21].

DEMATEL method can also be used in fuzzy environment, which is called fuzzy DEMATEL and is based on the fuzzy set theory, proposed by Zadeh[22]. In literature, there are many applications of fuzzy DEMATEL method, including prediction of technology commercialisation of investment projects[23], human resource for science and technology[24], facility layout problem[25] and risk assessment[26].

Since this study utilises DEMATEL method, no further details are presented on the fuzzy version of the methodology.

Methodology of DEMATEL is explained more in depth based on the scientific works published in literature[13,17,18,20,27].

2.2.1 Step-1: Gathering Expert's Perception and Calculating the Average Matrix

In a MCDM problem, the interrelations among the criteria are revealed in this step. The subject matter experts (or the decision makers) determine the degree of influence among the criteria using the scale shown in Table 1.

Using the scale shown in Table 1, a direct relations matrix, **X** is obtained, where the matrix has a dimension of n-by-n, n denoting the number of criteria.

Table 1. Scale used in DEMATEL method

Score	Definition
0	No influence
1	Low influence
2	Medium influence
3	High influence
4	Very high influence

The values of **X** matrix can be shown as x_{ij}, indicating the degree of influence of the criterion i over criterion j. Naturally, the diagonal values of **X** matrix are all set to zero.

When there are multiple subject matter experts (or decision makers), an average matrix, **A** is the arithmetic mean of the individual direct relations matrices. The resulting matrix, **A**, shows the direct relations as the group decision.

2.2.2. Step-2: Calculating the Normalised Initial Direct-relation Matrix

In this step, the average matrix, **A,** is normalised by applying Eqns (1) and (2) consecutively to obtain the normalised direct relations matrix, **D.** Matrix **D** is the normalised direct relations matrix with all elements between 0 and 1.

$$D = k\,.A \tag{1}$$

$$k = \frac{1}{\max\limits_{1<i<n} \sum_{j=1}^{n} a_{ij}} \qquad i, j = 1, 2, ..., n \tag{2}$$

2.2.3 Step-3: Calculating the Total Relations Matrix

This step obtains total relations matrix, **T**, which shows both direct and indirect relations among the criteria. The direct and indirect effects of criteria are shown in Fig. 2, where, criteria are depicted with letters i, j, k and l. The arrows between i and j, as well as i and k mean that criterion i affects j and k criteria directly. Similarly, the arrow between j and l shows that criterion j directly affects criterion l. Figure 2 also shows that criterion i affects criterion l indirectly, via criterion j.

Having explained the direct and indirect effects between

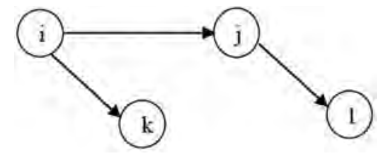

Figure 2. Direct and indirect effects.

criteria, these effects are compiled and shown in one matrix, which is the output of this step, using Eqn (3). In Eqn (3) the unit matrix, an n-by-n matrix, is shown as **I**, where total relations matrix and direct relations matrices are shown as **T** and **D**, respectively.

$$T = D\,(\,I - D\,)^{-1} \tag{3}$$

2.2.4 Step-4: Calculating the Sums of Rows and Columns of Matrix T

In this step, the sums of rows and columns are calculated using total relations matrix shown in Eqn (4) and **R** and **C** matrices are obtained as shown in Eqns (5) and (6). **R** and **C** matrices are n-by-1 in dimension.

$$T = \left[t_{ij}\right]_{nxn}, \qquad i, j = 1, 2, ..., n \tag{4}$$

$$R = \left[r_i\right]_{nx1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{nx1}, i = 1, 2, ..., n \tag{5}$$

$$C = \left[c_j\right]_{nx1} = \left[c_j\right]_{1xn}^{t} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1xn}^{t}, j = 1, 2, ..., n \tag{6}$$

In Eqn (5), r_i shows the sum of direct and indirect effects of the i^{th} criterion over the other criteria. Similarly, in Eqn (6), c_j shows the effects of other criteria over j^{th} criterion. Therefore, r_i is the i^{th} criterion's degree of affecting other criteria and c_j is the j^{th} criterion's degree of being affected. When $i=j$, $r_i + c_i$ is the i^{th} criterion's degree of the central role, which is basically the sum of the strength of influences given and received. On the other hand, r_i - c_i indicates the i^{th} criterion's net effect. If r_i - c_i value is positive, then it means that the i^{th} criterion is affecting other criteria. Alternatively, if r_i - c_i value is negative, it means that the i^{th} criterion is being influenced by the other criteria.

2.2.5 Step-5: Setting a Threshold Value and Obtain the Impact Diagram Map

In this step, the impact diagram map is obtained. However, it is important to include only the significant effects into the impact diagram map. In order to filter the insignificant effects among the criteria, a threshold value is determined by the decision maker. As suggested by Sumrit and Anuntavoranich[21] and Yang[18], *et al*. a method of calculating the threshold value is shown in Eqn (7). Here N denotes the total number of elements in matrix **T** and α is the suggested threshold value.

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij}}{N} \tag{7}$$

Using only the values that are above α in the matrix **T**, the impact-relations diagram is drawn. This diagram shows $r_i + c_i$ values on the horizontal axis where r_i - c_i values are indicated on the vertical axis.

3. APPLICATION AND RESULTS

3.1 Defining the Decision Goal

In order to analyse the interaction among the criteria used in MBT selection problem, the methodology shown in Fig. 1 is used. At the first phase, the goal of this MCDM problem is determined as 'to determine the criteria affecting MBT selection and to analyse the cause-effect relation among the criteria'.

3.2 Determining the Criteria

Determining the criteria that should be used in MBT selection is of great importance. The criteria should be wisely chosen and structured to allow the investigation of the complex interactions among them. It is important that these criteria should be consistent with the elements of combat power as defined in four primary elements in FM 100-5[28]: manoeuver, firepower, protection, and leadership.

Consequently, in this research, in order to realise the decision goal, at the second phase, through literature review and expert opinions, the criteria that can be used in MBT selection problem are determined. The subject matter experts are chosen amongst Armor Branch Officers who have at least fifteen years of experience on Main Battle Tanks and Under Secretary of Defense Associates capable of analysing the land platforms technically.

As shown in Table 2, the main criteria for MBT selection problem are mobility, firepower, survivability and command and control (C2). Table 2 also presents the sub criteria determined for each main criterion.

3.3 DEMATEL Method: Analysing the Relationships Among the Criteria

Since the criteria used in MBT selection problem shows a complex structure and there are many interrelations among them, DEMATEL is used to analyse the problem. At this phase of the methodology, DEMATEL is applied on main criteria and sub criteria separately to understand the interactions among them.

3.3.1 Using DEMATEL for the Main Criteria

Following the steps explained in Section 2.2, firstly, total five subject matter experts were asked to compare the main criteria in pairs using the scale shown in Table 1. For every subject matter expert, one 4-by-4 matrix is obtained. Subsequently, these matrices used to calculate the average matrix **A**, which is basically the arithmetic mean of the five matrices.

After calculating normalised initial direct-relation matrix using Eqns (1) and (2), the total relation matrix **T** is obtained in accordance with Eqn (3). Since there are four main criteria, a 4-by-4 matrix is used as the unit matrix in Eqn (3). After applying Eqns (5) and (6) to the total relation matrix **T**, R_i, C_i, R_i+C_i and R_i-C_i values are calculated and shown in Table 3.

Since all values in matrix T are $t_{ij} > 0$, although the effects of criteria may differ, it can be concluded that there are both direct and indirect relations among all of the criteria. On the other hand, ranking in terms of R_i and C_i values as shown in Table 4 to understand the relationships among the main criteria for MBT selection problem.

Table 4 shows that survivability criterion affects the other criteria with the highest R_i of 2.072 where mobility and firepower criteria follow it with 1.127 R_i value. C2 criterion observed to have the least degree of impact on the other criteria with the lowest R_i value of 0.743. Moreover, as C_i values shown in Table 4 indicate, survivability criterion has the highest value of 1.570, which means that it is affected by the other criteria more than any other one. C_i values for firepower, mobility and C2 are 1.388, 1.101 and 1.008, respectively.

Table 2. The main and sub criteria for MBT selection

Main criteria	Sub criteria	
1. Mobility	1.1Vertical obstacle/trench crossing	1.6 Auxiliary power unit
	1.2 Gradeability and side-slope performance	1.7 Suspension system
	1.3 Fording capacity	1.8 Ground pressure
	1.4 Cruising range	1.9 Power/weight ratio
	1.5 Maximum speed	
2. Fire power	2.1 Main gun effectiveness	2.6 Commander panoramic sight
	2.2 Secondary armament effectiveness	2.7 Fire control system
	2.3 Automatic target tracker	2.8 Automatic loading system
	2.4 Main gun ammunition load	2.9 Firing area
	2.5 Gun and turret drive system	2.10 Antitank guided missile capability
3. Survivability	3.1 Physical dimension s/Silhouette	3.6 Chemical, biological, radiological and nuclear survivability
	3.2 Ventilating and air -conditioning system	3.7 Fire detection and suppression system
	3.3 Smoke grenade effectiveness	3.8 Radar warning system
	3.4 Active protection system	3.9 Laser warning system
	3.5 Ballistic protection	
4. C2	4.1 Command and control system	4.2 Battle field identification device

Table 3. Total-relation matrix and influence values for main criteria

		Total-relation matrix (T)				Influences			
		MC- 1	**C-2**	**MC-3**	**MC-4**	R_i	C_i	R_i-C_i	R_i+C_i
Mobility	MC-l	0.190	0.228	**0.443**	0.266	1.127	1.101	0.025	2.228
Fire power	MC-2	0.190	0.228	**0.443**	0.266	1.127	1.388	-0.262	2.515
Survivability	MC-3	**0.608**	**0.662**	**0.418**	**0.384**	2.072	1.570	0.502	3.641
C2	MC-4	0.114	0.270	0.266	0.093	0.743	1.008	-0.266	1.751

Table 4. Ranking of R_i and C_i values for the main criteria

R_i	C #	Criteria	#	Criteria	C #	C_i
2.072	MC-3	Survivability	1	Survivability	MC-3	1.570
1.127	MC- 1	Mobility	2	Fire power	MC-2	1.388
1.127	MC-2	Fire power	3	Mobility	MC- 1	1.101
0.743	MC-4	C2	4	C2	MC-4	1.008

In order to investigate the net effects, as discussed in Section 2.2., R_i+C_i and R_i-C_i values are calculated, ranked and shown in Table 5.

As shown in Table 5, survivability and mobility criteria have positive R_i-C_i values, indicating that they are net affecting criteria. On the other hand, with negative R_i-C_i values, firepower and C2 are the criteria that are net affected.

Since, R_i+C_i values provide an index of the strength of influences given and received; the ranking shown in Table 5 explains the central role for each criterion. As depicted in Table 5, survivability has the strongest central role among the main criteria. It is followed by firepower, mobility and C2 criteria in terms of their roles.

Table 5. Ranking of R_i+C_i and R_i-C_i values for the main criteria

R_i-C_i	C #	Criteria	#	Criteria	C #	R_i+C_i
0.502	MC-3	Survivability	1	Survivability	MC-3	3.641
0.025	MC-l	Mobility	2	Fire power	MC-2	2.515
-0.262	MC-2	Fire power	3	Mobility	MC- I	2.228
-0.266	MC-4	C2	4	C2	MC-4	1.751

For the sake of simplicity, it is recommended to use threshold values to ease interpretation of the results obtained from DEMATEL method. The values in total relation matrix **T**, shown in Table 3, can be investigated using a threshold value. Using Eqn (7) from Section 2.2., the threshold value is calculated as 0.32 as shown below.

$$\alpha = \frac{5.068}{16} \cong 0.32 \quad (8)$$

Using the highlighted values in Table 3 which are above the threshold value (0.32), the impact-relations diagram is depicted in Fig. 3. It can be clearly seen that the survivability criterion affects all others, mostly firepower criterion. On the other hand, it is also clear that, mobility and firepower criteria affect the survivability of MBTs.

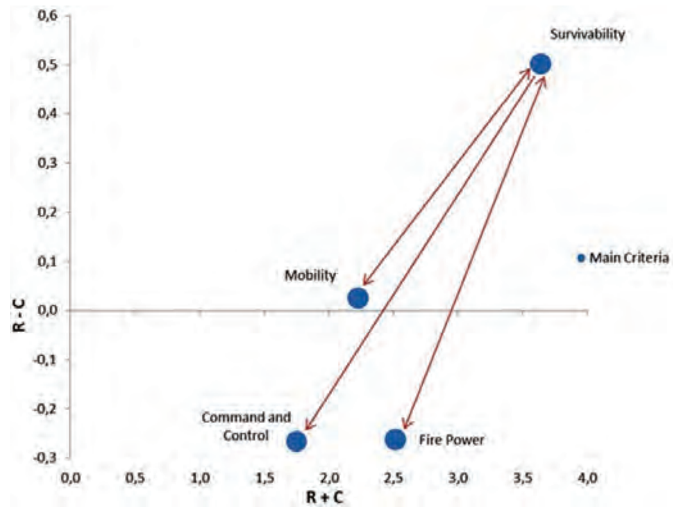

Figure 3. The influence relationship map of the main criteria.

3.3.2 Using DEMATEL for the Sub Criteria

Similar to the steps followed for the main criteria, the same five subject matter experts were tasked to compare the sub criteria in pairs using the scale shown in Table 1. For every subject matter expert, one 30-by-30 matrix is obtained. Subsequently, these matrices used to calculate the average matrix **A**, which is basically the arithmetic mean of the five matrices.

After calculating normalised initial direct-relation matrix using Eqns (1) and (2), the total relation matrix **T** is obtained in accordance with Eqn (3). The total relation matrix **T** for the sub criteria is shown in Annex 2. After applying Eqns (5) and (6) to the total relation matrix **T**, R_i, C_i, R_i+C_i and R_i-C_i values are calculated and shown in Table 6.

When matrix **T** (Annex 2) is examined, among the sub criteria that are positive ($t_{ij} > 0$) have direct and/or indirect relations among them. On the other hand, there is no interaction among the sub criteria with $t_{ij} = 0$ value. Using Eqn (7), the threshold value for total relation matrix **T** for the sub criteria set is calculated as follows:

$$\alpha = \frac{9.219}{900} \cong 0.01 \quad (9)$$

The values above the threshold (0.01) in matrix **T** are highlighted in Annex 2. It is seen that there is no relation with the sub criteria of mobility (C 1.1 - 1.9) and the sub criteria of firepower (C 2.1 - 2.10). There is no relation with the sub criteria of C2 (C 4.1, 4.2) and the sub criteria of mobility (C 1.1 – 1.9), either. On the other hand, all other possible sub criteria pairs seem to have some sort of interaction. In order to investigate the net effects, as discussed in Section 2.2., R_i and C_i values are ranked and shown in Table 7.

Table 7 shows that 23 out of 30 sub criteria seem to be affecting other sub criteria with different strengths, whereas the remaining 7 sub criteria do not affect the others. Ballistic protection (C 3.5), power/weight ratio (C 1.9) and physical dimensions/silhouette (C 3.1) are the top three sub criteria, significantly affecting the other sub criteria with R_i values of 1.443, 1.046 and 1.003 respectively. The criteria that don't affect the others are vertical O/T crossing (C 1.1), fording capacity (C 1.3), cruising range (C 1.4), maximum speed (C 1.5), smoke grenade effectiveness (C 3.3), CBRN survivability (C 3.6) and fire detection and suppression system (C 3.7), since their R_i values are equal to zero.

As shown in Annex 2, total relation matrix **T**, Ballistic Protection sub criterion, which has the highest R_i value, affects all of the sub criteria except for C 1.6, C 2.8, C 2.10, C 3.2 and C 3.6 sub criteria.

Among the top five sub criteria, ballistic protection (C 3.5), physical dimensions/silhouette (C 3.1) and active protection S. (C 3.4) sub criteria falls under survivability main criterion, where power/weight ratio (C 1.9) and ground pressure (C 1.8) sub criteria are under mobility main criterion.

As also shown in Table 7, with zero C_i value, automatic loading system (C 2.8), ATGM capability (C 2.10) and CBRN survivability (C 3.6) sub criteria are not affected by the other sub criteria. The other 27 sub criteria have different degrees of being affected. Physical dimensions/silhouette (C 3.1), suspension system (C 1.7), maximum speed (C 1.5), main gun effectiveness (C 2.1) and fire control system (C 2.7) sub criteria are the highly affected ones by C_i values of 0.798, 0.737, 0.668, 0.583 and 0.575, respectively.

As shown in Annex 2, total relation matrix **T**, physical dimensions/silhouette sub criterion, which has the highest C_i value, is affected by all of the sub criteria except for C 1.1, C 1.3, C 1.4, C 1.5, C 2.3, C 2.10, C 3.3, C 3.6 and C 3.7 sub criteria.

Table 6. Influence values for the sub criteria

	Criteria	C #	R_i	C_i	R_i-C_i	R_i+C_i
Mobility	Vertical obstacle/ trench crossing	C 1.1	0.000	0.380	-0.380	0.380
	Gradeability and side-slope per.	C 1.2	0.220	0.524	-0.304	0.745
	Fording capacity	C 1.3	0.000	0.159	-0.159	0.159
	Cruising range	C 1.4	0.000	0.538	-0.538	0.538
	Maximum speed	C 1.5	0.000	0.668	-0.668	0.668
	Auxiliary power unit	C 1.6	0.220	0.056	0.164	0.275
	Suspension system	C 1.7	0.275	0.737	-0.462	1.011
	Ground pressure	C 1.8	0.537	0.512	0.025	1.050
	Power/weight ratio	C 1.9	1.046	0.224	0.822	1.271
Fire power	Main gun effectiveness	C 2.1	0.069	0.583	-0.515	0.652
	Secondary armament effectiveness	C 2.2	0.072	0.217	-0.146	0.289
	Automatic target tracker	C 2.3	0.068	0.298	-0.230	0.367
	Main gun ammunition load	C 2.4	0.323	0.294	0.029	0.618
	Gun and turret drive system	C 2.5	0.464	0.259	0.205	0.724
	Commander panoramic sight	C 2.6	0.363	0.460	-0.097	0.823
	Fire control system	C 2.7	0.297	0.575	-0.278	0.872
	Automatic loading system	C 2.8	0.341	0.000	0.341	0.341
	Firing area	C 2.9	0.290	0.095	0.195	0.384
	ATGM Capability	C 2.10	0.124	0.000	0.124	0.124
Survivability	Physical dimensions/silhouette	C 3.1	1.003	0.798	0.205	1.800
	Ventilating and air-conditioning system	C 3.2	0.170	0.056	0.114	0.225
	Smoke grenade effectiveness	C 3.3	0.000	0.355	-0.355	0.355
	Active protection	C 3.4	0.635	0.321	0.315	0.956
	Ballistic protection	C 3.5	1.443	0.234	1.209	1.677
	CBRN survivability	C 3.6	0.000	0.000	0.000	0.000
	Fire detection and suppression system	C 3.7	0.000	0.095	-0.095	0.095
	Radar warning system	C 3.8	0.497	0.150	0.347	0.646
	Laser warning system	C 3.9	0.391	0.216	0.175	0.607
C2	Command and control system	C 4.1	0.069	0.189	-0.121	0.258
	Battle field identification device	C 4.2	0.302	0.226	0.076	0.528

Table 7. Ranking of R_i and C_i values for the sub criteria

R_i	C#	Criteria	#	Criteria	C#	C_i
1.443	C 3.5	Ballistic protection	1	Physical dimensions/silhouette	C 3. 1	0.798
1.046	C 1.9	Power/weight ratio	2	Suspension S.	C 1.7	0.737
1.003	C 3.1	Physical dimensions/silhouette	3	Maximum speed	C 1.5	0.668
0.635	C 3.4	Active protection S.	4	Main gun Ef.	C 2.1	0.583
0.537	C 1.8	Ground pressure	5	Fire control S.	C 2.7	0.575
0.497	C 3.8	Radar warning S.	6	Cruising range	C1.4	0.538
0.464	C 2.5	Gun and turret drive S.	7	Gradeabiliry and side-slope P.	C 1.2	0.524
0.391	C 3.9	Laser warning S.	8	Ground pressure	C 1.8	0.512
0.363	C 2.6	Commander panoramic sight	9	Commander panoramic sight	C 2.6	0.460
0.341	C 2.8	Automatic loading S.	10	Vertical O/T Crossing	C 1.1	0. 380
0.3 23	C 2.4	Main gun ammunition load	11	Smoke grenade Ef.	C3.3	0.355
0.3 02	C 4.2	Bartle field identification device	12	Active protection S.	C 3.4	0.32 1
0.297	C 2.7	Fire control S.	13	Automatic target tracker	C 2.3	0.298
0.290	C 2.9	Firing area	14	Main gun ammunition load	C 2.4	0.294
0.275	C 1.7	Suspension S.	15	Gun and turret drive S.	C 2.5	0.259
0.220	C 1.2	Gradeability and side-slope P.	16	Ballistic protection	C 3.5	0.234
0.220	C 1.6	Auxiliary power unit	17	Bartle field identification device	C 4.2	0.226
0. 170	C 3.2	Ventilating and AC S.	18	Power/weight ratio	C 1.9	0.224
0. 124	C 2.10	ATGM capability	19	Secondary armament Ef.	C 2.2	0.217
0.072	C 2.2	Secondary armament Ef.	20	Laser warning S.	C 3.9	0.216
0.069	C 2.1	Main gun Ef.	21	Command and control S.	C 4.1	0.189
0.069	C 4.1	Command and control S.	22	Fording capacity	C 1.3	0.159
0.068	C 2.3	Automatic target tracker	23	Radar warning S.	C 3.8	0.150
0.000	C 1.1	Vertical O/T crossing	24	Firing area	C 2.9	0.095
0.000	C 1.3	Fording capacity	25	Fire Det. and suppress ion S.	C 3.7	0.095
0.000	C 1.4	Cruising range	26	Auxiliary power Unit	C 1.6	0.056
0.000	C 1.5	Maximum speed	27	Ventilating and AC S.	C 3.2	0.056
0.000	C3.3	Smoke grenade Ef.	28	Automatic loading S.	C 2.8	0.000
0.000	C 3.6	CBRN survivability	29	ATGM capability	C 2. 10	0.000
0.000	C 3.7	Fire Del. and suppression S.	30	CBRN survivability	C 3.6	0.000

In order to investigate the net effects, as discussed in Section 2.2., R_i+C_i and R_i-C_i values are calculated, ranked and shown in Table 8. Annex 1 presents the graphical representation as well.

Table 8 shows that 15 sub criteria with positive R_i-C_i values are the net affecting criteria, top three of which are ballistic protection (C 3.5), power/weight ratio (C 1.9) and radar warning system (C 3.8). It is also shown that with a zero R_i-C_i value, CBRN survivability (C 3.6) sub criterion is neutral. The 14 sub criteria with negative R_i-C_i values are the net affected sub criteria.

The ranking of the sub criteria in terms of R_i+C_i values, shown in Table 8, indicate that physical dimensions/silhouette (C 3.1), ballistic protection (C 3.5), power/weight ratio (C 1.9), ground pressure (C 1.8) and suspension system (C 1.7) form the top five sub criteria with R_i+C_i values of 1.800, 1.677, 1.271, 1.050 and 1.011 respectively. Among these sub criteria, physical dimensions/silhouette (C 3.1) and ballistic protection (C 3.5) is under survivability main criterion, where power/weight ratio (C 1.9), ground pressure (C 1.8) and suspension system (C 1.7) are under mobility main criterion.

4. DISCUSSIONS AND CONCLUSIONS

The criteria affecting MBT selection problem have been determined and analysed the cause-effect relation among main criteria and sub criteria separately by utilising DEMATEL method.

The relationship among the main criteria of MBT selection problem can be summarised as survivability criterion having the strongest central role among the main criteria. Results show that survivability is followed by firepower, mobility and C2 criteria in terms of their roles.

Considering the evolution of conventional battle into countering terrorism and operations other than war, the main risks towards MBTs are becoming IEDs and short-range antitank weapons such as rocket propelled grenades (RPGs). In connection and consistent with this evolution the survivability criterion ranks at the top of the other criteria. This

Table 8. Ranking of R_i+C_i and R_i-C_i values for the sub criteria

R_i-C_i	C#	Criteria	#	Criteria	C#	R_i+C_i
1.209	C 3.5	Ballistic protection	1	Physical dimensions/silhouette	C 3.1	1.800
0 .822	C 1.9	Power/Weight ratio	2	Ballistic protection	C 3.5	1.677
0.3 47	C 3.8	Radar warning S.	3	Power/weight ratio	C 1.9	1.271
0.341	C 2.8	Automatic loading S.	4	Ground pressure	C 1.8	1.050
0.3 15	C 3.4	Active protection S.	5	Suspension S.	C 1.7	1.011
0.205	C 2.5	Gun and turret drive S.	6	Active Protection S.	C 3.4	0.956
0.205	C 3.1	Physical dimensions/Silhouette	7	Fire Control S.	C 2.7	0.872
0 .195	C 2.9	Firing area	8	Commander panoramic sight	C 2.6	0.823
0.175	C 3.9	Laser warning S.	9	Gradeability and side-slope P.	C 1.2	0.745
0.164	C 1.6	Auxiliary power unit	10	Gun and turret drive S.	C 2.5	0.724
0.124	C 2.10	ATGM capability	11	Maximum speed	C1.5	0.668
0.114	C 3.2	Ventilating and AC S.	12	Main gun Ef.	C 2.1	0.652
0.076	C 4.2	Bartle field identification device	13	Radar warning S.	C 3.8	0 .646
0.029	C 2.4	Main gun ammunition load	14	Main gun ammunition load	C 2.4	0.618
0 .025	C 1.8	Ground pressure	15	Laser warning S.	C 3.9	0607
0.000	C 3.6	CBRN survivability	16	Cruising range	C 1.4	0.538
-0.095	C 3.7	Fire Det. and suppress ion S.	17	Bartle field identification device	C 4.2	0.528
-0.097	C 2.6	Commander panoramic sight	18	Firing area	C 2.9	0.384
-0.121	C 4.1	Command and Control S.	19	Vertical *O/T* crossing	C 1.1	0.380
-0.146	C 2.2	Secondary Armament Ef.	20	Automatic target tracker	C 2.3	0.367
-0.159	C1.3	Fording capacity	21	Smoke grenade Ef.	C 3.3	0.355
-0.230	C 2.3	Automatic target tracker	22	Automatic loading S.	C 2.8	0.341
-0.278	C 2.7	Fire control S.	23	Secondary armament Ef.	C 2.2	0.289
-0.304	C 1.2	Gradeabiliry and side-slope P.	24	Auxiliary power unit	C 1.6	0.275
-0.355	C 3.3	Smoke Grenade Ef.	25	Command and control S.	C 4.1	0.258
-0.380	C 1.1	Vertical *OIT* Crossing	2.	Ventilating and AC S.	C 3.2	0.225
-0.462	C 1.7	Suspension S.	27	Fording capacity	C1.3	0.159
-0.515	C 2.1	Main gun Ef.	28	ATGM capability	C 2.10	0.124
-0.538	C 1.4	Cruising range	29	Fire Del. and suppression S.	C 3.7	0.095
-0.668	C1.5	Maximum speed	30	CBRN survivability	C 3.6	0.000

fact is expected to yield some innovative technologies to be developed for lighter protection while putting the survivability on the top central role of the criteria.

The importance of the survivability criterion may also be explained with the changing perception of the battlefield not only by the soldiers, but also by the public. Casualties in operations create great pressure over the governments, resulting in that the governments take some precautions to decrease the number of casualties.

With close central role degrees, firepower and mobility criteria follow the survivability criterion. This result can be explained within the main purpose of MBTs in a battlefield: 'carrying the firepower (main gun) into the battlefield with armour protection to close with and destroy the enemy'.

Without using threshold value, among all main criteria there are cause and effect relationships both active and passive. This means that all main criteria are affecting one another and being affected by other criteria. This result is fully consistent with the holistic approach that underlines the importance of the interaction and the coherence among the criteria. Moreover, it is shown that since the results of the analysis are consistent with the theory of the battlefield, DEMATEL method is proved to be an effective method for this research.

C2 systems are essentials for any combat operations and these systems can be mounted onto MBTs even after design processes are finished. Therefore, such systems can be called as 'add-on systems' which have the weakest central role among all other components.

Comparing the results with the literature, contrary to previous research, the results shows that the main criteria survivability has the strongest central role among the main criteria, followed by firepower, mobility and command and control. Survivability was determined as the least affecting factor by Gupta and Bhushan[8] and the third effective capability by Cheng and Lin[9], whereas Jiang[11], *et al.* claimed that survivability (defence) and mobility were the second effective capabilities, only after attack capability. On the other side of the coin, the results reached in this study are mostly consistent with Global Armoured Vehicles Market Report 2015[12] .

According to results within the sub criteria, ballistic protection, sub criterion of survivability, has the highest degree of influence over most of the other sub criteria while physical dimensions/silhouette, another sub criterion of survivability, is the most vulnerable criterion. Since ballistic protection has the highest degree of influence over others during design phase of MBTs ballistic requirements should be carefully selected. Physical dimensions/silhouette is the result of other design decisions and can be called a 'passive criterion'. Therefore it is obvious that Physical Dimensions/Silhouette is the most vulnerable criterion among all other criteria while Ballistic Protection is the most affecting criterion with its weight percentage.

As discussed in the previous sections, the interrelations among the criteria are determined in accordance with subject matter expert opinions. The subject matter experts are chosen amongst armor branch officers who have at least fifteen years of experience on main battle tanks and Defense Associates capable of analysing the land platforms technically. Therefore, the findings from DEMATEL method are limited within the number of subject matter experts consulted in this study.

The results of this paper can be used in future MBT design projects at preliminary design and critical design review phases decisions. The results can also be used for future MBT and other land platform project evaluation matrices. For a future research, the results are planned to be used in a MBT selection problem to evaluate multiple MBTs.

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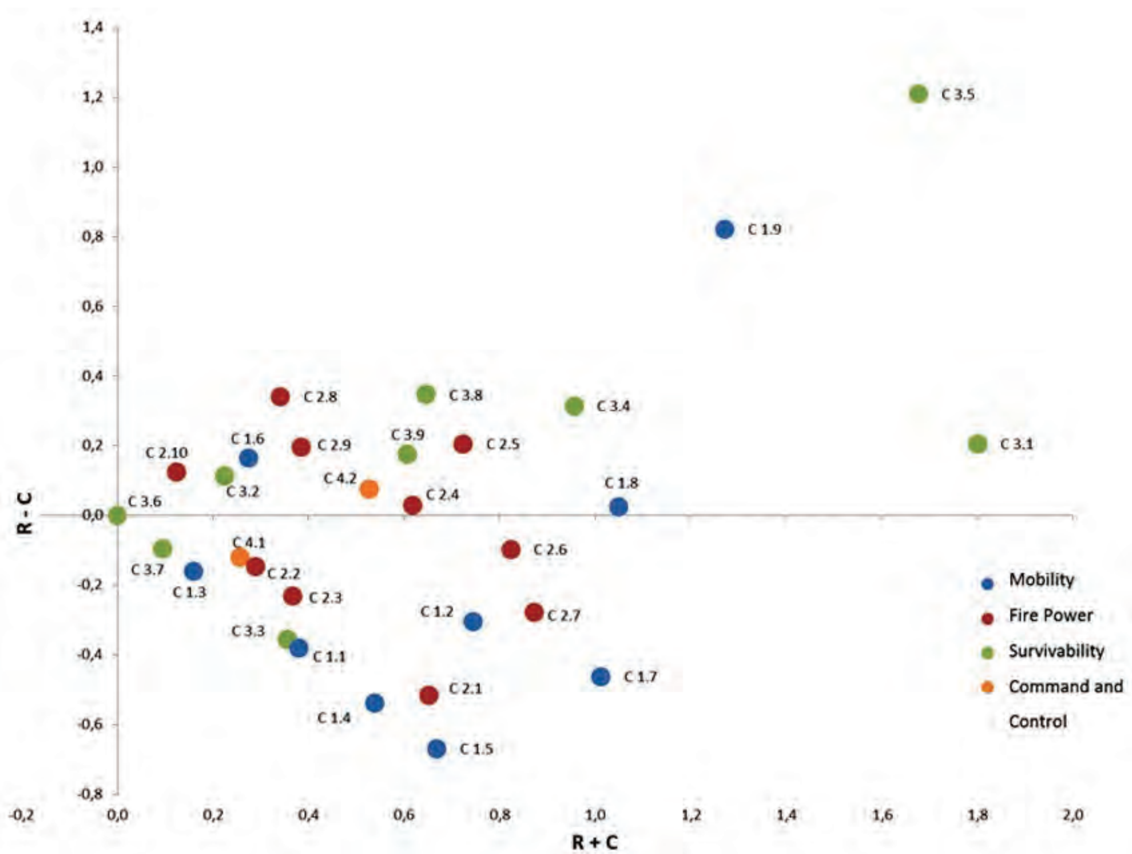
Annex 1. Graphical representation for the sub criteria



Annex 2. Total relations matrix for the sub criteria

	Mobility									Fire Power										Survivability									C2	
	C 1.1	C 1.2	C 1.3	C 1.4	C 1.5	C 1.6	C 1.7	C 1.8	C 1.9	C 2.1	C 2.2	C 2.3	C 2.4	C 2.5	C 2.6	C 2.7	C 2.8	C 2.9	C 2.10	C 3.1	C 3.2	C 3.3	C 3.4	C 3.5	C 3.6	C 3.7	C 3.8	C 3.9	C 4.1	C 4.2
C 1.1	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
C 1.2	0,000	0,000	0,000	0,000	0,001	0,000	0,001	0,001	0,000	0,007	0,001	0,001	0,001	0,001	0,009	0,009	0,000	0,000	0,000	0,007	0,000	0,006	0,006	0,001	0,000	0,000	0,053	0,053	0,008	0,053
C 1.3	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
C 1.4	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
C 1.5	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
C 1.6	0,004	0,002	0,003	0,054	0,005	0,003	0,008	0,007	0,003	0,001	0,000	0,000	0,006	0,000	0,000	0,000	0,000	0,003	0,000	0,057	0,053	0,003	0,000	0,003	0,000	0,003	0,000	0,000	0,000	0,000
C 1.7	0,056	0,055	0,003	0,001	0,057	0,000	0,007	0,007	0,003	0,001	0,000	0,000	0,006	0,000	0,001	0,001	0,000	0,003	0,000	0,054	0,000	0,003	0,001	0,003	0,000	0,003	0,003	0,003	0,000	0,003
C 1.8	0,006	0,164	0,000	0,105	0,111	0,000	0,106	0,001	0,000	0,001	0,000	0,000	0,001	0,000	0,001	0,002	0,000	0,000	0,000	0,007	0,000	0,001	0,001	0,000	0,000	0,000	0,009	0,009	0,001	0,009
C 1.9	0,115	0,140	0,053	0,175	0,185	0,000	0,176	0,159	0,001	0,001	0,000	0,000	0,001	0,000	0,001	0,001	0,000	0,001	0,000	0,010	0,000	0,001	0,001	0,001	0,000	0,001	0,007	0,007	0,001	0,007
C 2.1	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,003	0,003	0,000	0,000	0,000	0,003	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,003	0,053
C 2.2	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,003	0,003	0,001	0,000	0,003	0,053	0,003	0,000	0,000	0,000	0,003	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
C 2.3	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,003	0,003	0,006	0,000	0,000	0,003	0,053	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
C 2.4	0,007	0,004	0,006	0,003	0,009	0,000	0,015	0,013	0,006	0,107	0,000	0,000	0,011	0,001	0,001	0,000	0,000	0,006	0,000	0,109	0,000	0,006	0,001	0,006	0,000	0,006	0,000	0,000	0,000	0,006
C 2.5	0,001	0,001	0,000	0,001	0,001	0,000	0,002	0,002	0,001	0,010	0,007	0,113	0,001	0,004	0,060	0,068	0,000	0,000	0,000	0,007	0,000	0,059	0,057	0,006	0,000	0,000	0,003	0,056	0,003	0,001
C 2.6	0,004	0,002	0,003	0,002	0,005	0,000	0,008	0,007	0,003	0,057	0,056	0,012	0,006	0,053	0,009	0,057	0,000	0,003	0,000	0,055	0,000	0,006	0,003	0,003	0,000	0,003	0,000	0,003	0,000	0,003
C 2.7	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,056	0,056	0,107	0,000	0,003	0,056	0,009	0,000	0,000	0,000	0,003	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,003
C 2.8	0,001	0,000	0,001	0,000	0,001	0,000	0,002	0,001	0,001	0,067	0,003	0,012	0,107	0,053	0,006	0,057	0,000	0,001	0,000	0,012	0,000	0,004	0,003	0,001	0,000	0,001	0,000	0,003	0,000	0,004
C 2.9	0,004	0,002	0,003	0,002	0,005	0,000	0,008	0,007	0,003	0,057	0,056	0,001	0,006	0,003	0,056	0,003	0,000	0,003	0,000	0,057	0,000	0,003	0,001	0,003	0,000	0,003	0,000	0,000	0,000	0,003
C 2.10	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,056	0,003	0,006	0,000	0,000	0,003	0,053	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,003
C 3.1	0,071	0,036	0,057	0,028	0,090	0,000	0,139	0,123	0,060	0,015	0,003	0,001	0,108	0,006	0,004	0,001	0,000	0,054	0,000	0,028	0,000	0,055	0,006	0,055	0,000	0,054	0,002	0,003	0,000	0,003
C 3.2	0,004	0,002	0,003	0,004	0,005	0,053	0,008	0,007	0,003	0,001	0,000	0,000	0,006	0,000	0,000	0,000	0,000	0,003	0,000	0,057	0,003	0,003	0,000	0,003	0,000	0,003	0,000	0,000	0,000	0,000
C 3.3	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
C 3.4	0,013	0,012	0,005	0,016	0,022	0,000	0,030	0,022	0,015	0,010	0,004	0,008	0,008	0,012	0,010	0,061	0,000	0,004	0,000	0,071	0,000	0,064	0,018	0,111	0,000	0,004	0,054	0,055	0,006	0,002
C 3.5	0,083	0,098	0,013	0,140	0,157	0,000	0,207	0,139	0,114	0,004	0,002	0,013	0,013	0,108	0,009	0,015	0,000	0,007	0,000	0,127	0,000	0,020	0,114	0,019	0,000	0,007	0,011	0,017	0,002	0,006
C 3.6	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
C 3.7	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
C 3.8	0,005	0,003	0,003	0,002	0,006	0,000	0,009	0,008	0,004	0,060	0,006	0,007	0,006	0,004	0,057	0,060	0,000	0,003	0,000	0,061	0,000	0,059	0,054	0,009	0,000	0,003	0,003	0,003	0,053	0,006
C 3.9	0,001	0,001	0,000	0,001	0,001	0,000	0,002	0,002	0,001	0,059	0,006	0,007	0,001	0,004	0,057	0,060	0,000	0,000	0,000	0,007	0,000	0,056	0,054	0,006	0,000	0,000	0,003	0,003	0,053	0,006
C 4.1	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,003	0,003	0,000	0,000	0,000	0,003	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,003	0,053
C 4.2	0,004	0,002	0,003	0,002	0,005	0,000	0,008	0,007	0,003	0,007	0,006	0,006	0,006	0,003	0,056	0,056	0,000	0,003	0,000	0,057	0,000	0,003	0,001	0,003	0,000	0,003	0,000	0,000	0,053	0,003

NOTE: The highlighted cells indicate the values above the threshold (0.01).