Argumentation-based Decision Support in Naval Command & Control

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Abstract. Threat Evaluation and Weapons Assignment (TEWA), a process which is at the heart of tactical naval Command & Control (C2) process, comprises a number of operations that must be performed under time and resource constraints. This article discusses the challenges of decision making in this context, and more particularly the critical issue of target engagement, and shows how this process can be supported by an argumentation-based Decision Support System (DSS). It is shown how the information gathered and analyzed during the execution of the engageability assessment, defined and formalized for the purpose of the paper, can be exploited by an argumentation module. Based on a dialectical model and affording both proactive and reactive interaction modes, the module enables the DSS to anticipate and respond to the operator's objections to its recommendations, and thus substantially enhance the accuracy of its argumentation in a time-constrained decision support context.

Keywords : decision support, argumentation, explanation, threat evaluation, weapons assignment, engageability assessment, Toulmin's model

1 INTRODUCTION

Advances in threat technology, the increasing difficulty and diversity of open-ocean and littoral scenarios, and the volume and imperfect nature of data to be processed under time-critical conditions pose significant challenges for future shipboard Command & Control Systems (CCSs). Among other functionalities, the CCS provides capabilities to allow operators to evaluate the threat level of the different objects within the Volume of Interest (VOI), and when deemed necessary, use the shipboard combat resources to respond to them. This is commonly referred to as the Threat Evaluation & Weapons Assignment (TEWA) problem. It provides a time and resource-constrained application that involves both human and software decision-makers.

Current operational systems generally provide little support for tactical decision making. The need for such support is all the more pressing given the current emphasis on littoral warfare, including asymmetrical threats, that results in reduced reaction time and the need to deal quickly and correctly with complex Rules Of Engagement (ROEs).

The proposed Decision Support System (DSS) is based on a decision-centered perspective. The system assists the operator in making timely, error-free and effective decisions while reducing his cognitive workload. Yet, given the complexity of the problem he has to address, the high level of stress he is exposed to, and finally the fact that he knows that he will be held responsible for his decisions, the operator may discard the system's recommendation if he does not fully understand the underlying rationale, or if the recommendation is different from the solution he had foreseen. To overcome the operator's reluctance or lack of trust, the system has to convince him that its recommendation is based on sound reasoning. To do so, it needs to both retrieve the relevant knowledge structures and present them to the operator in a meaningful manner.

In this paper, we focus on the problem of target engagement, which is one of the most important decision making issues in TEWA. We introduce and define the *engageability assessment* process and show its usefulness in building trust in the system's information processing capability (Section 2). We then propose to organize the engageability assessment's data and results into an argument structure. This is first illustrated using Toulmin's inferential model of argument (Section 3). We then propose a dialectical model that can warrant the system's conclusion by anticipating and responding to the operator's objections to its arguments. Finally, we describe an argumentation module which based on this model, and by affording both proactive and reactive interaction modes, can substantially enhance the accuracy of the system's argumentation in a time-constrained decision support context (Section 4).

2 NAVAL TEWA

Naval Command & Control (C^2) is a very complex problem, and often this complexity arises from the multitude, the heterogeneity and the inter-relationships of the systems and resources involved. The tactical naval C^2 process can be decomposed into a set of generally accepted functions that must be executed within some reasonable delays to ensure mission success. A high-level description of those functions includes surveillance (*i.e.*, detection, tracking, and identification) and Threat Evaluation and Weapons Assignment (TEWA). In this paper, the focus will be on the TEWA process (see Figure 1), and more specifically the engageability assessment functionality, which concerns the evaluation of the feasibility of own-force's engagement options against non-friendly entities within the VOI.

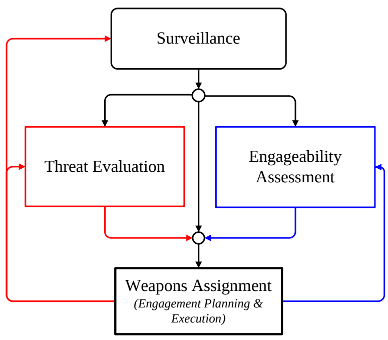

Figure 1. Global view of TEWA process

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2.1 Threat Evaluation

Within the TEWA process, *threat evaluation* establishes the intent and the capability of potential threats within the VOI. The process results in a list $(rank_T)$ of entities ranked according to the level of threat they pose. For two objects O_i and O_j, $rank_T(O_i, t) < rank_T(O_j, t)$ means that O_i is more threatening, at time instant t, than O_j. $\mathcal{O}$ is the set of all objects O_i within the VOI.

2.2 Weapons Assignment

Weapons assignment makes decisions on how to deal with the identified threats. It can be seen as a real-time and constrained resource management problem. During this process, weapons are designated to engage threats. Also are assigned the supporting resources (*e.g.*, sensors, communications, etc.) required for each and every one-to-one engagement. This process results in a ranked list $(rank_E)$ that gives the recommended order of engagements for the threats, *i.e.*, the solution to the TEWA problem. For two objects O_i and O_j, $rank_E(O_i, t) < rank_E(O_j, t)$ means that, at time instant t, decision has been made to engage O_i before O_j. For a single weapon configuration, this boils down to a scheduling problem.

2.3 Engageability Assessment

The common definition of the TEWA process includes, as discussed above, the *threat evaluation* and *weapons assignment*. Nevertheless, one important issue that needs to be addressed is target engageability. Engageability assessment (see Figure 1) can support the *weapons assignment* module by eliminating candidate solutions that violate one or more of the problem constraints, and which for this reason will not be feasible. Several factors can be taken into consideration during this process, such as Rules Of Engagement (ROEs), pairing appropriateness[2], window (range, time, …), blind zones, ammunition availability, etc. (see Figure 2).

The engageability assessment outputs a list of objects ranked according to their engageability score E_s. The latter reflects the availability and feasibility of own-force options against all the non-friendly objects within the VOI. For two objects O_i and O_j, $E_s(O_i, t) > E_s(O_j, t)$ means that own-force has more options, at time t, against O_i than against O_j. Note that the engageability score is non-negative, that is $E_s(O_i, t) >= 0$. $E_s(O_i, t) = 0$ means that there is no solution (option) for engaging O_i at time instant t.

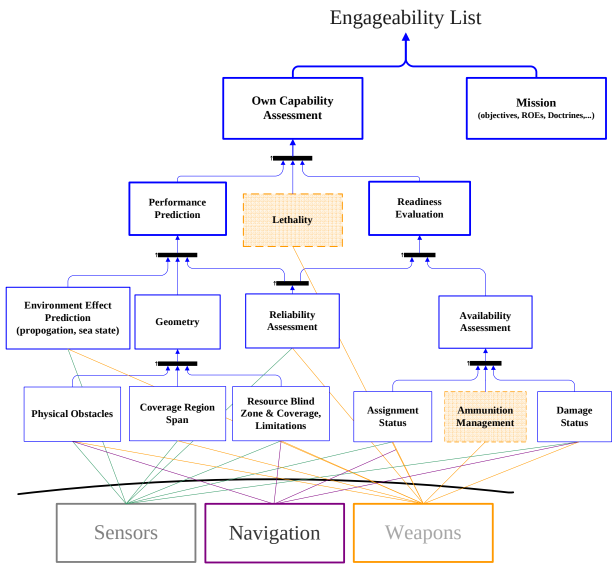

Figure 2. Engageability Assessment Inferential Model

3 ARGUMENTATION-BASED DSS

The TEWA process can be seen as a dynamic decision-making process aimed at the successful exploitation of tactical resources (*e.g.* sensors, weapons) during the conduct of C^2 activities. From this perspective, decision support is defined to be a capability that is meant to assist operators in making well-informed and timely decisions while providing robust error detection and recovery. The DSS must be designed as to reduce the operator's cognitive overload and improve the overall effectiveness of the process [6].

However, the complexity of the TEWA problem, the issues that are at stake, the high level of stress induced by resource and time constraints, the effects of stress and fatigue on attentional resources, and most important of all, the sense of responsibility with regard to one's decisions, can all lead to a situation of under-confidence, where the operator becomes overly concerned with the perils of a course of action [5]. In such a situation, it is unlikely that the operator will accept the system's recommendation if he does not fully understand it or if the recommendation is different from the alternatives he had considered [10], a phenomenon referred to as an *expectation failure*[3].

To be acceptable by the user, the information provided to him needs to be presented in a comprehensible and convincing manner. Indeed, it is not only the quality of the recommendation made by the DSS that needs to be improved through more optimized processing, but also the user's *interpretation* of the quality of the decision [5].

This interpretation can be substantially improved if the system has the capacity to expose its rationale using sound arguments. To address this problem, we need to use an argumentative structure that can capture the inferential nature of reasoning used in TEWA, and more specifically in the engageability assessment process[4]. Toulmin's model of argument [7] or argumentative schemes [8] seem appropriate for this purpose. However, our approach requires a different mechanism since in this context what determines the strength of a support for a claim is how well it can respond to specific objections, and not, for example, how widely accepted it is. In the following, we first show how Toulmin's general model can be used to outline an argument based on the information provided by the engageability assessment. Then we show how the basic inferential structure can be augmented with a dialectical component which is more adapted to a time-constrained decision support context.

3.1 Toulmin's model

Toulmin proposes an argument structure that reflects the natural procedure by which claims can be argued for. The model is composed of six elements that depict the move from a set of premises to a conclusion.

In addition to the premise-conclusion structure, Toulmin identifies several components that support the inferential relation. The warrant

[2] Ensure that the weapon selection corresponds to the threat type.

[3] See Section 4.2 for a more detailed discussion of expectation failure.

[4] Solutions are inferred from the intermediary results input by lower-level processes, as shown in Figure 2.

has the function of a rule of inference, licensing the conclusion on the basis of the arguer's data or grounds. The arguer can invoke a backing if the warrant is challenged or insufficient. The modal qualifier is a word or phrase that indicates the force of the warrant. Finally, the rebuttal accounts for the fact that some exception-making condition might be applicable [2].

The model expresses plausible reasoning, captures inferetial mechanisms, can outline a decision situation and preserve it for future use, and finally, can be used as a basis for explanation facilities [9]. Useless to say that Toulmin's model has been extensively cited in argument studies[5], particularly informal logic, as well as in artificial intelligence, and has even been applied to military problems such as theater missile defense [1].

3.2 Example of Application of Toulmin's Model

Table 1 presents an example of the application of Toulmin's Model to the TEWA problem. The example is based on the concept of engageability assessment, formalized in Section 2.3. The results of engageability assessment, based on constraints violation avoidance, are used as intermediary results to justify recommendations for the weapons assignment phase.

Data	Two objects (O_i, O_j) have been detected within VOI and assessed hostile to ownship. Object O_j has been assessed more threatening than O_i. Options against both objects have been evaluated. As a result, the engagement order (O_j, O_i) has been deemed non-feasible, while (O_i, O_j) offers options.
Qualifier	Supports
Claim	The weapons assignment module recommends the engagement order (O_i, O_j).
Warrant	Since by the end of engagement of O_j, O_i will enter the Fire Control Radar (FCR) blind zone, while by the end of engagement of O_i, O_j will still be within the FCR coverage area.
Backing	The Anti-Ship Missile (ASM) nature of threats requires the use of Surface-to-Air Missile (SAM) to counter them. FCR support is mandatory for the SAM's guidance and threat illumination.
Rebuttal	Unless probability of kill (P_k) on O_i is much lower than for O_j.

Table 1. Example of Toulmin model's application

The controversial nature of the claim requires that the inferential relation be licensed with a warrant. In Toulmin's model, a warrant is a general law ('major premise' in Walton's argumentation schemes) which licenses the move from data to a claim. Here, the system has to warrant the recommendation with specific information. Also, the domain knowledge provided in the backing will be of little use for the operator who will rather want to know what are exactly the factors that the system has considered. As a matter of fact, the warrant may be challenged, not because the reason it provides is not good enough, but because the operator may object that the conditions under which that warrant holds can be modified (see Section 4.2).

Based on these remarks, we propose to augment the premise-conclusion structure with a dialectical component that will enable the DSS to handle such situations.

[5] See the recent OSSA's conference theme.

4 INFERENTIAL MODEL OF ARGUMENT WITH A DIALECTICAL COMPONENT

The functional account of Toulmin's model is a deductive, rather than a dialectical model of argumentation in that it does not take into account the beliefs, opinions or reasoning schemes of the audience it is addressed to. In a dialectical scheme, the arguer has to consider possible counter-arguments. In Toulmin's model, although the rebuttal accounts for the possibility of the defeat of the argument, it simply shows that an exception-making condition might be applicable. This is a condition that the arguer contemplates, but it is not a condition that he considers as being the object of his audience's belief. Reasoning on the beliefs of the audience is the core of dialectical reasoning. As Johnson [4] has argued, because the conclusion may not meet the initial beliefs of the audience, an arguer will need to do more than put forward some supporting statements. He or she will need to respond to objections and alternative positions.

4.1 Model of dialectical argumentation

The dialectical component can be viewed as an *argument-objection-response to objection* sequence. This justificatory triad warrants the inference from data to a claim, which in the case of a decision support system is a solution or recommendation. This is illustrated in Figure 3.

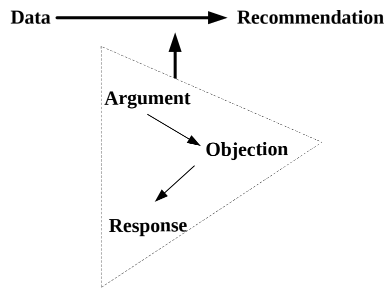

Figure 3. Inferential Model of Argument With a Dialectical Component

Using this model, we propose to design the DSS so that it can anticipate possible objections on the part of the operator and prepare its responses to those objections. This concept is illustrated in the following using the engageability assessment process, where the constraints violation avoidance principle is used as a basis for argument/response generation.

4.2 Use of constraints for argumentation

Most of the time, decision problems such as TEWA that have to be solved under constraint lead to sub-optimal solutions. The set of constraints defines the feasibility space in which the system will have to search for the best solution. The harder are the constraints, the smaller is this space, and the farther can be the solution from the optimal[6]. For the TEWA problem, the feasibility of different options is defined by means of the engageability assessment. The smaller is the engageability score E_s of the objects in the VOI, the smaller will be

[6] Since the optimal may not belong to the feasible solution space.

the solution space for weapons assignment, and the more distant will be the engagement plan from the operator's expected plan, hence the increasing risk of an *expectation failure*.

An expectation failure generally happens when the solution proposed by the system is different from the one the user had predicted. Given the very limited number of constraints he can consider at a time, a human operator often works on simplified representations of problems that capture only a subset of the actual constraints. A DSS, which is not as limited as the human operator in its working memory, can handle a much larger number of constraints. This difference can lead to a situation where the solution foreseen by the operator is closer to the optimal than the one recommended by the DSS. The discordance between the two solutions can be justified by the number and the nature of constraints that would be violated if the DSS tried to get closer to the optimal in order to meet the operator's expectations.

The engageability assessment concept can be used to illustrate the idea. Since engageability assessment is about the evaluation of the feasibility of engagement plans, it mainly boils down to a Constraint Satisfaction Problem (CSP). Examples of such constraints are given in Table 2, among which some are relaxable (considered as soft constraints for which solutions may exist) and some non-relaxable (considered as hard constraints for which no solution exists).

One case where the expectation failure situation may happen is the following. For two objects O_i and $O_j (i \neq j)$

$$rank_T(O_i, t) > rank_T(O_j, t) \;\&\; rank_E(O_i, t) < rank_E(O_j, t)$$

which means that O_j is more threatening than O_i, yet O_i is judged as being of higher priority from the engagement perspective. This situation can be problematic because the operator will be more likely to rely on the threat list ranking ($rank_T$) for the engagement prioritization[7]. Such engagement order cannot be presented to the operator without the support of some credible reasons. The engageability assessment module can justify this outcome. A typical case that can explain the controversial recommendation above is as follows. For two objects O_i and O_j, if

$$rank_T(O_i, t) > rank_T(O_j, t) \quad (1)$$

that is, O_j is more threatening than O_i, and

$$E_s([O_j, O_i], t) = E_s([O_j], t) \times E_s([O_i], t + d_j) < E_s([O_i], t) \times E_s([O_j], t + d_i) = E_s([O_i, O_j], t)$$

which means that the engagement sequence (O_i, O_j) offers more possibilities to own-force than (O_j, O_i). A special case is where $E_s([O_j, O_i], t) = 0$, while $E_s([O_i, O_j], t) \neq 0$, which means that the sequence (O_j, O_i) is not feasible. This can be caused by the loss of opportunity on O_i during the engagement of O_j.

The more and the harder are the constraints that define the feasibility space, the more difficult it will be for the DSS to bridge the gap between the two solutions. In anticipation of the operator's dissatisfaction, those constraints that would be violated if the DSS deviated from its solution, are stored at run-time during the engageability assessment. These are later presented to the operator by the argumentation module (see Section 4.3) in response to his objections.

4.3 Argumentation module

The proposed argumentation module is depicted in Figure 4. The engageability assessment process evaluates the set of possible solutions

[7] This is a common practice in modern navies, where capability limitations are only considered at the later stage of response planning process, with possibility of plan revision in case of an empty feasibility space.

Non-relaxable	**Relaxable**	**How**
-Rules of engagement	-Availability of supporting resources	*-Free resources*
-Availability of ammunition	-Damage status	*-Repair*
-Lethality	-Assignment status	*-Re-assign*
-Appropriateness of resource choice	-Coverage limitations (*Envelope, Blind Zone, Obstruction*)	*-Wait, move*
	- Predicted Performance (e.g. PK)	*-Wait*

Table 2. Examples of constraints considered during engageability assessment for a given resource against a given object, at time instant t.

and discards those which would violate one or more constraints. The results of this constraints violation avoidance process are stored in a database and used as arguments to be presented to the user.

The argumentation module can display its dialectical skills using both proactive and reactive interaction modes. The *response coordinator* selects and coordinates dynamically the two modes. The difference between them lies in the fact that the dialectical cycle is initiated by the argumentation module in the pro-active mode, while it is initiated by the user in the reactive mode. An argument is called response when provided reactively (in response to an objection). The numbers in Figure 4 show the chronology of the events for each mode. The role of the *response coordinator* is twofold: i) receiving the user's objections, and ii) coordinating the deployment of the interaction mode.

Having prepared itself for all possible cases of disagreement, the coordinator will first activate the proactive mode and proceed by presenting its best arguments. These are those arguments that are the most persuasive responses to what it considers to be the most likely objections. It will then shift to a reactive mode and provide justification only upon user's further objections. This will be the case if the operator formulates more specific objections or if more detailed or low-level information is needed.

Naturally the operational context described here, where time is a serious issue, does not allow for a genuine dialogue between the system and the operator and therefore models such as that of the deliberation dialogue [3] cannot be applied.

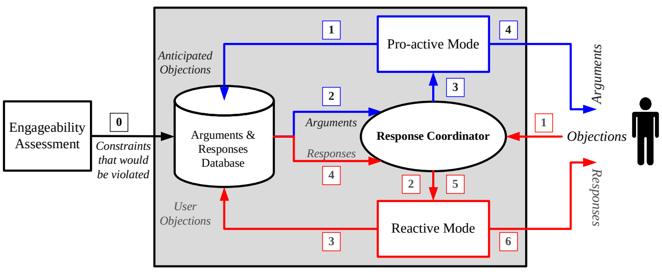

Figure 4. Argumentation Module Architecture

In the above-described process of argumentation, the nature of the constraints plays a major role in the weight of the justification (*i.e.*, its persuasive power). Logically, avoiding the violation of non-relaxable constraints will have a higher justificatory power than avoiding the violation of relaxable ones. From an argumentation perspective, it is assumed that the former constitutes a sufficient condition for the conclusion to obtain, while the latter does not. It is also expected that the user will object to the arguments based on relaxable constraints by asking the system to modify them so that they can be satisfied. Examples of such possible objections are given in the column "How" of Table 2.

For the TEWA problem, the engageability assessment module will have to verify a set of N_R relaxable constraints and a set of N_{NR} non-relaxable constraints, for a total of $N_R + N_{NR}$ constraints. The set of non-satisfied constraints will be used to constitute dynamically the system's arguments/responses database (see Figure 4). Based on the content of this database, the system provides pro-actively a maximum of N arguments to the user. Given their higher justificatory power, priority is given to arguments related to the non-relaxable constraints. The presence of at least one non-relaxable constraint that could be violated eliminates the need to consider arguments related to relaxable constraints. If there is no such non-relaxable constraint, the system will present the N arguments related to relaxable constraints that are deemed most likely to be mentioned by the user. The remaining set of constraints that may not be satisfied will be provided reactively on a one-by-one basis, should the user continue to object to the system's recommendations.

To illustrate the idea, let us take the same example as previously where two objects (O_i, O_j) have been detected within VOI and assessed hostile to own-force. Object O_j has been assessed more threatening than O_i. Engageability for both objects has been evaluated. As a result and based on the different constraints, engagement of O_j is deemed non-feasible (*i.e.*, $E_s(O_j) = 0$) and only O_i is engageable and will be engaged ($E_s(O_i) \neq 0$).

Situation 1 (Sufficient Arguments) – this corresponds to the case where one or more non-relaxable constraints would not be satisfied. For example, if ROEs prevent own-force from engaging O_j, any solution that includes engagement action on O_j will not satisfy this hard non-relaxable constraint. This information can be used as a sufficient argument that cannot be objected to by the user, and no further arguments will be required. This argument is presented pro-actively, and there is no need to consider arguments related to relaxable constraints.

Situation 2 (Non-sufficient Arguments) – this corresponds to the case where all non-relaxable constraints are satisfied and one or more relaxable constraints are not satisfied. Based on the set of constraints that would be violated by engagement action on O_j, the DSS decides to present pro-actively the two ($N = 2$) following arguments, regarding the recommendation of not engaging O_j. These arguments are: i) O_j lies within the blind zone of the only available Fire Control Radar (Coverage limitation constraint), and ii) the other Fire Control Radar is assigned to another target (Assignment status constraint). The other constraints that would be violated, if any, will be used by the reactive mode.

Given the relaxable nature of the constraints they are related to, these arguments are not sufficient. As a consequence, it is expected that the operator will object, asking why the constraints are not relaxed so that the feasibility space can be extended (*i.e.*, the engageability score $E(O_j)$). Examples of objections/responses that may be used in the reactive mode of the system following the first argument, are given below (see Table 2).

1. **Objection 1 (*Wait*)–** meaning: wait until the object O_j gets out of the Fire Control Radar blind zone and provide engagement solution. Example of a possible response to this objection is: *object will get out of the weapon range as well*.
2. **Objection 2 (*Move*)–** meaning: move the ship to clear blind zone. Examples of possible responses to this objection are: *Physical obstacle prevents from moving; Not enough time to move; Jeopardizes other engagements that are in progress; Increases ship's Radar Cross Section (visibility by the enemy sensors); Puts more threatening objects within blind zones*.

The above list gives examples of potential reasons that may render the decision of moving the ship (one of user's anticipated objections) not feasible.

The examples discussed above show how the system can exploit knowledge of the domain and knowledge of the user to justify a recommendation that does not meet the initial beliefs of the operator. They also show how the system can display a strategic behaviour by planning its argumentation.

5 CONCLUSION

The organization of the system's knowledge into argument structures provides insight into the system's states, procedures and goals, and shows the extent of its domain knowledge and capacities. A better understanding of these features will hopefully result in a more efficient use of the system proposed. The argumentation capability described above, not only outlines the system's reasoning process, but it also engages a dialectical exchange by anticipating possible objections and by organizing its responses to them according to their degree of justification. The two-phase approach, proactive and reactive argumentation, can be very effective for handling decision making issues in a time-constrained context such as TEWA. The same analysis as the one described for engageability assessment is being performed for threat evaluation and the whole system is under design for implementation for the Canadian Navy.

REFERENCES

[1] S. Das, 'Symbolic argumentation for decision making under uncertainty', in *Proceedings of Fusion 2005*, Philadelphia, PA, USA, (July 2005).

[2] D. Hitchcock, 'The significance of informal logic for philosophy', *Informal Logic*, **20**(2), (2000).

[3] D. Hitchcock, P. McBurney, and S. Parsons, 'A framework for deliberation dialogues', in *Proceedings of the Ontario Society for the Study of Argumentation*, Windsor, Ontario, Canada, (2001).

[4] R. Johnson, *Manifest Rationality*, Lawrence Erlbaum, 2000.

[5] G.M. Kasper, 'A theory of decision support system design for user calibration', *Information Systems Research*, **7**(2), (1996).

[6] S. Paradis, A. Benaskeur, M. Oxenham, and P. Cutler, 'Threat evaluation and weapons allocation in network-centric warfare', in *Proceedings of Fusion 2005*, Philadelphia, PA, USA., (July 2005).

[7] S.E. Toulmin, *The Uses of Argument*, Cambridge University Press, 1964.

[8] D. N. Walton and C.A. Reed, 'Argumentation schemes and defeasible inferences', in *Proceedings of the 2nd Workshop on Computational Models of Natural Argument*, Lyon, France, (2002).

[9] L.R. Ye and P.E. Johnson, 'The impact of explanation facilities on user acceptance of expert system advices', *MIS Quarterly: Management Information Systems*, **June**, (1995).

[10] M. Zanella and G. Lamperti, 'Justification dimensions for complex computer systems', in *Proceedings of World Multiconference on Systemics, Cybernetics and Informatics*, pp. 317–324, Orlando, Florida, USA, (1999).