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SOLDIER SYSTEM ASSESSMENT UNDER UNCERTAINTY WITH EVIDENTIAL REASONING

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ABSTRACT

Along with the increasing of new equipment based capabilities, the physiological burden on the dismounted soldier keeps on growing, which leads to the limitation in the quantity and types of missions that can be carried out. In this research, a methodology is developed to solve the burden problem from the system assessment point of view. Comparing with other relevant research, the new methodology not only provides quantitative performance estimate of the soldier with the capability of handling fragmentary and incomplete data with hybrid format in nature (qualitative and quantitative), but also restrains the assessment complexity to an acceptable level.

KEYWORDS

Soldier System, Optimization, Uncertainty, Evidential Reasoning (ER).

1. INTRODUCTION

As the consequence of the geopolitical changes in the final decades of the last century, the individual soldier, operating in a small unit, has changed from a “replaceable item” into a valuable military asset, with a large impact on operational performance and mission success. As a result, many leading nations led by the US are investigating the concept of the co-called “future soldier” as their soldier modernization programs that seek to equip the dismounted soldier with every conceivable piece of electro-optical situational-awareness enhancing kit. However, the addition of equipment in isolation has also added to the weight and real estate problems of the soldier. During operations in Iraq for example, soldiers involved in dismounted close combat were often carrying loads in excess of 60kg (Jackson 2004), which seriously impact their endurance, combat effectiveness and resulting in long-term health implications. According to a recent study by Danish Army Combat Centre, a range of physical problems closely associated with weight, with 10-15% of troops suffering long-term injuries and with significant proportions of patrols being on painkillers for parts of their mission (Baddeley 2010).

Weight analysis from the infantry section on operations in Afghanistan show that the dismounted soldier would not always operate carrying all loads and could, for instance, operate in patrol order, carrying in the region of 50kg, or in assault order, carrying in the region of 40 kg (CDE 2009a). Operating in patrol order or assault order means that compromises have to be made in terms of the equipment carried and immediately available and the sustainability of the force. It is recommended that the soldier load should be reduced to no more than one third of lean body weight, which equates to an average load of 25kg. The lighter load could allow, for example (CDE 2009b):

- The agility of the individual soldier to increase.
- The operational tempo of formed bodies to increase.
- Small arms firing accuracy to increase.
- The effects of climate extremes to be reduced.
- Combat and non-combat casualty rates to be reduced.

Hence, considering weight as a key drawback that has to be measured against the return the technology provides to the soldier, a new evaluation methodology is investigated in this paper which provides an alternative in reducing the weight from the system assessment point of view.

The rest of the paper is organized as follows: after a briefly review of the research background, a soldier system hierarchy model are proposed. This is followed by the briefing of Evidential Reasoning approach and illustrating of our assessment process. A case study will be then presented to demonstrate the application of our methodology. Conclusion and future work are provided at the end.

2. BACKGROUND

Common efforts in reducing the burden of soldier include the ergonomics design for different feeling of weight (Datta and Ramanathan 1971), development of load-carriage system (Birrell et al., 2007; Polcyn et al., 2002), advanced power and energy architecture (Nygren et al., 2006; Shaffer et al., 2006), lightweight ensemble and equipment (Abdelkader et al., 2003; Herold et al., 2007). However, the technology advancing is always time consuming and sometimes of reversal. For example, the 5.56mm weapon SA80 was bedeviled by a number of reliability problems, one of which was stoppages caused by damage to its original lightweight aluminum magazines. As a result, in its overhauled version the SA80A2, a switch to all steel magazines was made, which are heavier but less susceptible to damage (Baddeley 2010).

Simulation programs, such as Joint Conflict and Tactical Simulation (JCATS), Joint Capabilities Integration Development System (JCIDS), Small Unit Team Exploratory Simulation (SUTES), Objective OneSAF (OOS), Pythagoras Agent-Based Model (PYT), are typically joint warfighting focus to validate the requirements and evaluate the performance of combined arms forces. The programs specific to the soldier, for example, the Infantry Warrior

Simulation (IWARS), which was continued from the Integrated Unit Simulation System (IUSS), provides an integrated analysis environment at individual and unit levels to combine historically separate, disparate equipment driven models of different aspects of the soldier and the soldier's combat systems. But it pays little attention to the problem of physical burden.

The latest research, taking into account the burden issue in the soldier's simulation domain, comes from Verhagen et al. (2008). Its proposed "Human Centric Model" takes into account the interrelationship between physical characteristics (skills and training), physical load (clothing, equipment), environment (type of terrain and climate) of the soldier and his physical state (fatigue, health state, psychomotor skills etc.) and operational task performance to support optimization of small unit configuration and military operations. To perform well in this kind of analysis, the granularity and accuracy of the simulation plays a vital role. But the complexity of such detailed interrelationship grows exponentially with the number of variables and states defined. It turns out difficulty in balancing the complexity of the model and granularity of the simulation. Our research is to address this deficiency by developing a soldier system assessment methodology with the capability of handling fragmentary and incomplete data with hybrid format in nature (qualitative and quantitative). The new methodology will not only provide quantitative performance estimate of soldier from the system point of view, but also restrain the assessment complexity to an acceptable level.

3. SOLDIER SYSTEM HIERARCHY

The Soldier System includes the Soldier and those items and equipment the Soldier wears, carries, or consumes. It includes all items in the Soldier's load and those items of equipment to accomplish individual tasks and missions that the Soldier must carry (TRADOC, 2006).

In order to improve the effectiveness of soldiers to the greatest possible extent, NATO distinguishes five capability areas: lethality, survivability, mobility, sustainability and C41 (command, control, communications, computers and intelligence). It is recognized that these capabilities are interlinked and should be in balance.

Previous research has identified further sub-capabilities to describe these areas (O'Keefe IV et al., 1992a,b; Victor et al., 2000; CDE 2009c) specific to different focus. On the basis of these literatures, this research proposes a soldier system hierarchical model which constitutes three detailed factors levels. The effects of the soldier's equipment (e.g., performance enhancements or equipment associated constraints) as well as the adverse effects of battlefield stressors can be more directly and easily applied to these factors than to the tasks themselves. By appropriately weighting and propagating these effects up the hierarchy, system level effects can be calculated.

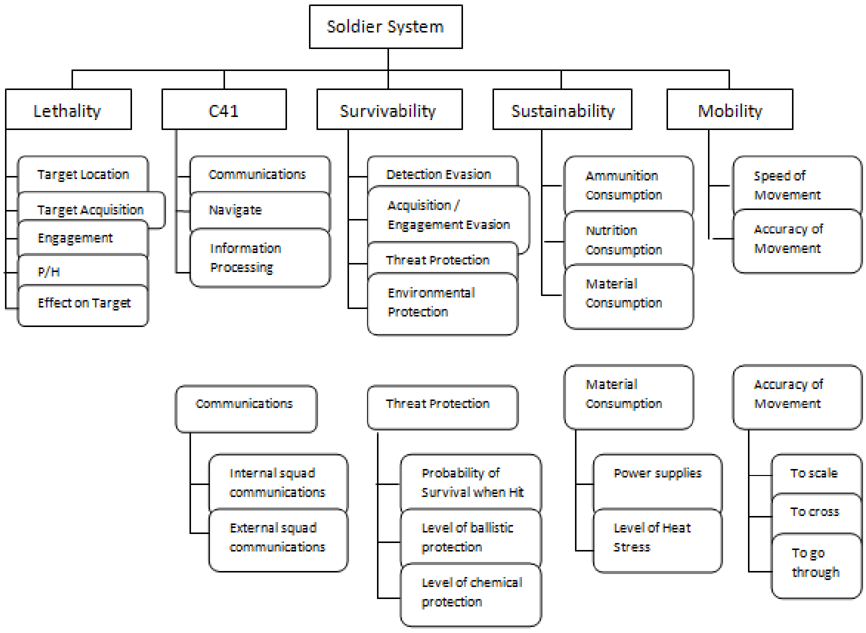


Figure 1. Soldier system hierarchy model

The lethality, is as the name suggests, indicates the ability of the soldier system to destroy, neutralize, suppress, or bring desired effects on a threat, through the employment of organic and coordinated use of non-organic weapon systems. It further constitutes five sub-capabilities, including the ability to locate/position targets, to acquire enemy targets/info, to engage enemy, to incapacitate/destroy targets, and the probability of Hit/Shot (P/H).

The C41 refers to the soldier's ability to direct, coordinate and control personnel, weapons, equipment, information and procedures necessary to accomplish the mission. It can be further determined by the internal and external squad communication, capability of navigation and information processing.

The survivability describes the degree to which a soldier system is able to avoid or with stand a natural and manmade hostile environment, without suffering an abortive impairment to accomplish its designated mission, such as the ability to avoid detection, to disperse, and the protection accomplished.

The sustainability refers to the ability of the soldier system to sustain operations and be logistically supported in order to accomplish its assigned tasks. It includes areas such as power supplies with the system, availability and maintainability factors.

The mobility suggest the quality that permits soldier system to move from place to place or perform individual tasks in a timely fashion, while retaining the ability to fulfill their primary mission. It can be further broke down into four components: to scale (climbing over walls, ascending & descending cliffs), to cross (gaps, rivers, mine fields), to go through (walls, tunnels and doors etc.), and to move (speed on all surfaces, e.g., road, stones, sand, snow, marsh, slope).

4. EVIDENTIAL REASONING & ASSESSMENT PROCESS

It is important to note that the evaluation of the soldier system hierarchy model will involve both of the quantitative and qualitative information in the form of the results of technical assessment, human factors assessment, operational assessment, and simulation/modeling as well as the incorporation of experts' input with respect to importance of different capability characteristics. The common difficulties in making such evaluations are: the human cognitive limitations in dealing with multiple factors, the need to combine different type of scales and the lack of any meaningful scale for the qualitative attributes. Thus the selected evaluation methodology should allow combing quantitative and qualitative data in a formal manner and it should have a meaningful scale that allows description of intensity of preferences.

Evidential Reasoning (ER) approach, developed by Yang et al. in the 1990's (Yang and Singh 1994; Yang and Sen 1994; Yang 2001; Yang and Xu 2002a,b), is one of the main competing views in decision analysis which is widely used for multi-attribute evaluation and choice (Chin et al., 2009a, b; Liu et al., 2004; Shan et al., 2010; Si et al., 2010; Wang et al., 2006).

It enables decision makers to structure a complex problem in the form of a hierarchy, and is capable of dealing with hybrid nature of information (qualitative and quantitative) and various types of uncertainties (ignorance, fuzziness, e.g.).

As depicted in Figure 2, the ER approach begins with the collection of information which covers all the measureable factors. The approach is capable of dealing with both precise numbers and belief structures which represent an assessment as a distribution. For example, an expert can judge the attribute 'Environmental Protection' to be 2 (probability = 30%) or 3 (probability = 70%) using a 1-7 scale. The sum of the probability assigned to each attribute could be between 0 and 1. If sum = 1, it indicates a complete assessment that the expert is 100% sure about the judgment. If sum < 1, it is an incomplete assessment which reveal that the expert is not fully confident about the assessment due to a lack of evidence or understanding. The capability of cater both precise numbers and belief structures simultaneously significantly help improve assessment accuracy without having to make unnecessary assumptions for incomplete or missing information.

The next step of ER approach is assessment transformation. Inputs of different formats are transformed to the ER format for subsequent assessment aggregation. For qualitative assessment, the transformation refers to transform the multiple sets of evaluation standards to a unified set. For quantitative assessment, the transformation refers to rescale the multiple ranges of numerical data to a unified scale. Further detailed of transformation technique can be referred in paper (Yang 2001).

Then, the transformed inputs of all the assessment criteria are aggregated using the ER algorithm to generate assessment results. Finally, different assessment options can be prioritized and selected based on the overall scores, and the distributed assessment structure provides the basis in identifying limitation of specific criterion for further improvement.

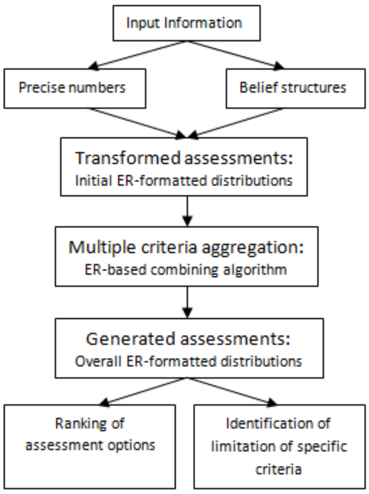


Figure 2. Multiple criteria ER aggregation process

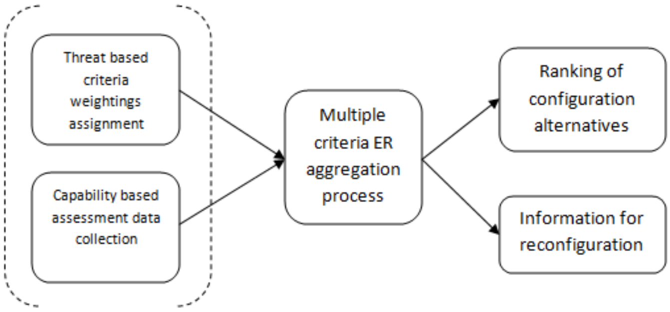


Figure 3. Soldier system assessment methodology

Based on the ER approach and the Soldier System Hierarchical Model, our soldier system assessment methodology is developed. As illustrated in Figure 3, two considerations drive the assessment – one is threat based, the other is capability based. The assessment begins by identifying the mission or military problem to be assessed. This is reflected by the determining of the importance weightings of each criterion. The weightings aligned with the assigned mission objectives to be achieved, the roles and responsibilities of tasked organizations, and their associated environmental circumstance, which may vary from task to task. For example, for long time patrol task, mobility of soldiers is apparently the key issue to be considered in the evaluation. While for specific assault task, traditional operational performance such as lethality and personal protection would play a vital role. In determining the importance weightings, multiple of methods can be used, such as simple direct rating by an expert, or more elaborate methods based on the pair-wise comparison technique (Saaty 1988).

Simultaneously, the relevant data of each measureable factor will be collected based on soldier’s ability in the area of the criterion specified. Our methodology also support uncertainties caused by partial or missing data which is sometimes essentially inherent and inevitable in human being’s subjective judgment.

Once the criteria’s weightings have been obtained and assessment data has been collected, the assessment comes into the aggregation step through a bottom-up approach, in which, pieces of data for the lowest level attributes are aggregated as input for the second lowest level attributes, which is, in turn, aggregated to produce scores for higher level attributes.

Finally, different components configurations can be prioritized and selected based on the overall scores, and the distributed assessment structure provides the basis in identifying capabilities for further improvement.

5. CASE STUDY

In order to demonstrate the application of our methodology, a case study was conducted specific to two soldier tasks: assault and patrol. It is recognized that the assault task and patrol task are the two most commonly implemented tasks for soldiers. In assault task, two armies would maneuver to contact, at which point they would form up their infantry and other units opposite each other. Then one or both would advance and attempt to defeat the enemy force. It is both mentally and physically demanding activity, though may be of short duration. While in patrol task, the soldier has to be able to walk for a certain amount of distance for security or reconnaissance purpose, looking out for anything out of the ordinary – which if found will be reported for assistance or dealt with as appropriate.

To reflect the requirements of these two tasks, importance weightings of each assessment criterion were first determined by our interviewee, an ex-soldier, respectively. With the assignment, two assessment models are set up. We name them as: model of assault task and model of patrol task. The weighting results are depicted in Table 1.

Table 1. Importance weighting of the assessment criteria

Criterion (Importance weighting for assault task/patrol task)		
Level 1	Level 2	Level 3
1. Lethality (30%/30%)	1.1 Target Location (30%/10%)	
	1.2 Target Acquisition (10%/10%)	
	1.3 Engagement (30%/20%)	
	1.4 P/H (10%/20%)	
	1.5 Effect on Target (20%/40%)	
2. C41 (20%/30%)	2.1 Communications (30%/40%)	2.1.1 Internal Squad Communications (70%/40%)
		2.1.2 External Squad Communications (30%/60%)
	2.2 Navigate (20%/20%)	
	2.3 Information Processing (50%/40%)	
3. Survivability (20%/20%)	3.1 Detection Evasion (40%/40%)	
	3.2 Acquisition / Engagement Evasion (30%/30%)	
	3.3 Threat Protection (20%/10%)	3.3.1 Probability of Survival when Hit (30%/40%)
		3.3.2 Level of ballistic protection (40%/40%)
		3.3.3 Level of chemical protection (30%/20%)
	3.4 Environmental Protection (10%/20%)	
4. Sustainability (10%/10%)	4.1 Ammunition Consumption (60%/80%)	
	4.2 Nutrition Consumption (30%/10%)	
	4.3 Material Consumption (10%/10%)	4.3.1 Power Supplies (60%/60%)
		4.3.2 level of Heat Stress

		(40%/40%)
5. Mobility (20%/10%)	5.1 Speed of Movement (40%/60%)	
	5.2 Accuracy of Movement (60%/40%)	5.2.1 To scale (30%/40%) 5.2.2 To cross (30%/30%) 5.2.3 To go through (40%/30%)

In level 1, the weightings assignment results show that from our interviewee's perspective, patrol task may have a higher demand in command control (C41), but the capability emphasis between the two types of tasks is not so different. Further examine the detailed level 2 and 3 factors, we find the requirement difference between two types of tasks is more reflected in these low level factors. In the lethality category, assault task pays much attention in the ability to position targets and engage enemy, while patrol task relatively emphasizes on the capability of 'Effect on target'. As the objective of assault task is to defeat and dislodge the enemy force, thereby establishing control of the area. While patrol task is typically conducted by small unit of soldiers, their instant reaction in coming across enemy activity is to report to camp and waiting for support. Their individual firepower is relatively most important. This is also reflected in the C41 category, in which internal squad communication is more important for assault task, while external squad communications is comparatively essential to patrol task. In the sustainability category, ammunition consumption occupies almost all the weighting partitions in patrol task. As common patrol task is typically conducted in turn, in which each unit is responsible for 3 hours' duration. Nutrition and material consumption are not so relevant to the task. In addition to these, the focus of mobility is also different, in which the accuracy of movement is comparatively more important to assault task due to its relevance in the performance of close combat.

With respect to these two types of tasks, two components configurations are designed to be assessed. They are presented in Table 2 below.

Table 2. Design of components configurations

Subsystems	Components Set 1	Components Set 2
1. Integrated Headgear Subsystem (IHS)	*Soldier-to-soldier communications	*Weapons interface (M16A2-mounted thermal sight and laser aiming light)
2. Advanced Clothing Subsystem (ACS)	*Integrated body armor/ammunition carriage *Handwear (combat, chemical/biological) *Footwear (integrated combat boot, gaiter)	*Integrated body armor/ammunition carriage *Handwear (combat, chemical/biological) *Footwear (integrated combat boot, gaiter) *Uniform components (chemical vapor undergarment, advanced combat uniform, advanced shell garment) *Passive cooling T-shirt
3. Microclimate Conditioning/Power Subsystem (MC/PS)	*Blower	*Filter
4. Weapon Subsystem (WS)	*M16A2 (standard	* M16A2 (standard

	infantryman's rifle)	infantryman's rifle) *Aim-1D laser aiming light
5. Individual Soldier Computer (ISC)	*Message management/reporting	*Global positioning system/digital mapping
6. Others	*Helmet	*Vest with dagger and 2 liter water pack
	*Protection vest with 1 liter water pack	*Bag with supplies for 48 hours

The design of configurations is based on the recommendation of the Soldier Integrated Protective Ensemble (SIPE) program (Victor et al., 2000), in which a components set was composed of a number of subsystems. In our design, the set 1 covers the components that a sergeant commonly has, and is estimated to be weight around 50kg. The set 2 includes the components with more advanced and comprehensive configuration, but is estimated to be weight around 65kg.

These two components sets were then assessed by our interviewee based on the soldier system hierarchy we proposed. The assessment is conducted to all the measureable factors by a five grade scale from Very Good (VG) to Very Poor (VP). Comparatively, more uncertainties are noticed in the assessment of set 1 due to its relatively simplicity. These assessments are illustrated in Table 3 below.

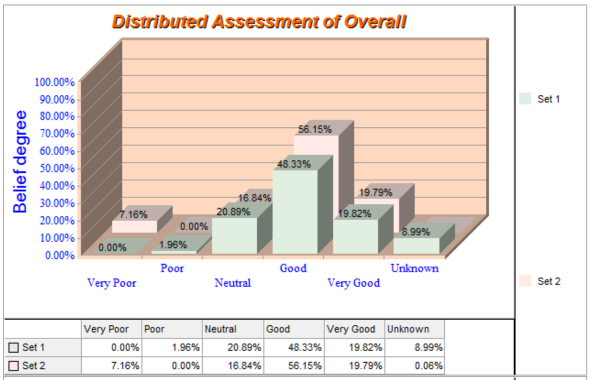
Table 3. Assessment data recorded

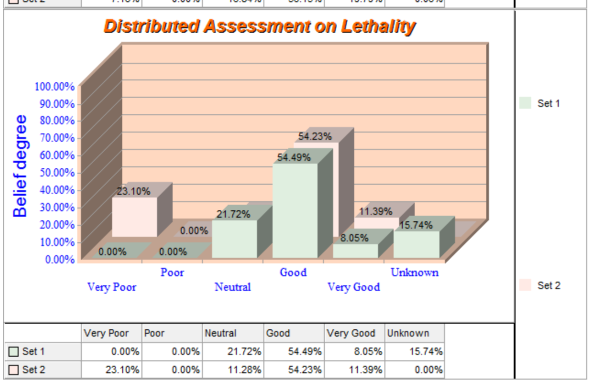
Level 2	Level 3	Set 1	Set 2
1.1 Target Location		{(G, 0.3), (VG, 0.7)}	{(G, 0.6), (VG, 0.4)}
1.2 Target Acquisition		{VG, 1.0}	{G, 1.0}
1.3 Engagement		{G, 1.0}	{(N, 0.3), (G, 0.7)}
1.4 P/H		{G, 0.8}	{(N, 0.1), (VP, 0.9)}
1.5 Effect on Target		{*}	{(N, 0.1), (VP, 0.9)}
2.1 Communications	2.1.1 Internal Squad Communications	{(G, 0.6), (VG, 0.4)}	{(N, 0.1), (VG, 0.9)}
	2.1.2 External Squad Communications	{*}	{(N, 0.1), (VP, 0.9)}
2.2 Navigate		{VG, 1.0}	{(G, 0.7), (VG, 0.3)}
2.3 Information Processing		{G, 1.0}	{G, 1.0}
3.1 Detection Evasion		{(N, 0.4), (VG, 0.6)}	{N, 1.0}
3.2 Acquisition / Engagement Evasion		{N, 1.0}	{G, 1.0}
3.3 Threat Protection	3.3.1 Probability of Survival when Hit	{P, 1.0}	{N, 1.0}
	3.3.2 Level of ballistic protection	{P, 1.0}	{N, 1.0}
	3.3.3 Level of chemical protection	{N, 1.0}	{N, 1.0}
3.4 Environmental Protection		{N, 1.0}	{N, 1.0}
4.1 Ammunition Consumption		{*}	{VG, 1.0}
4.2 Nutrition Consumption		{G, 1.0}	{VG, 1.0}
4.3 Material Consumption	4.3.1 Power Supplies	{*}	{(G, 0.4), (VG, 0.6)}
	4.3.2 level of Heat Stress	{*}	{*}
5.1 Speed of Movement		{VG, 1.0}	{(G, 0.2), (VG, 0.8)}
5.2 Accuracy of Movement	5.2.1 To scale	{G, 1.0}	{G, 1.0}
	5.2.2 To cross	{(G, 0.4), (VG, 0.6)}	{G, 1.0}
	5.2.3 To go through	{{N, 0.4}, (G, 0.6)}	{G, 1.0}

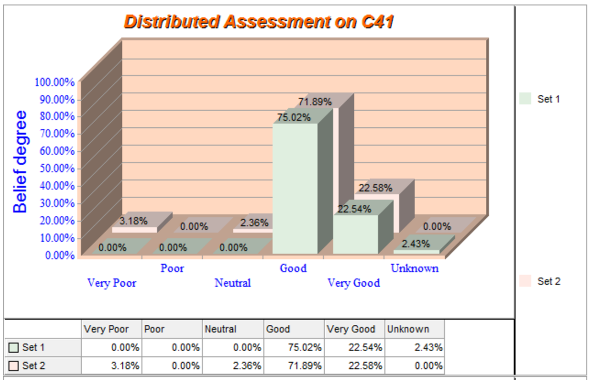
(The assessment grades are defined as VP – very poor, P – poor, N – neutral, G – good and VG – very good. The number behind the assessment grade is its associated belief degree. Missing judgment is represented with symbol *, in which our interviewee has no idea of its assessment based on the information he obtained.)

The collected data are in the format of complete judgment, incomplete judgment and missing judgment. These data are then aggregated with ER algorithm in the model of assault task and model of patrol task respectively.

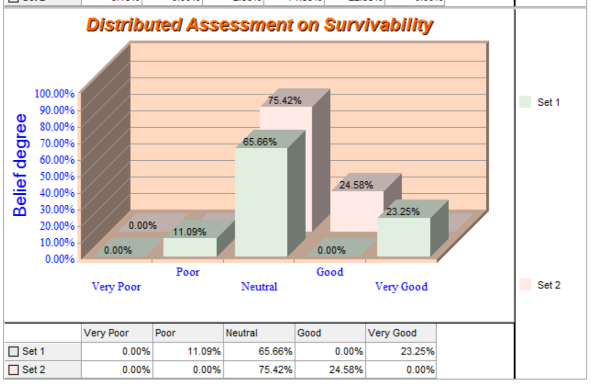
The ER algorithm has been implemented into a window based software package named the Intelligent Decision System (IDS). Figure 4 and 5 below illustrate the initial aggregation results produced by IDS with the format of distributed belief degrees.







	Very Poor	Poor	Neutral	Good	Very Good	Unknown
Set 1	0.00%	0.00%	0.00%	75.02%	22.54%	2.43%
Set 2	3.18%	0.00%	2.36%	71.89%	22.58%	0.00%



	Very Poor	Poor	Neutral	Good	Very Good
Set 1	0.00%	11.09%	65.66%	0.00%	23.25%
Set 2	0.00%	0.00%	75.42%	24.58%	0.00%

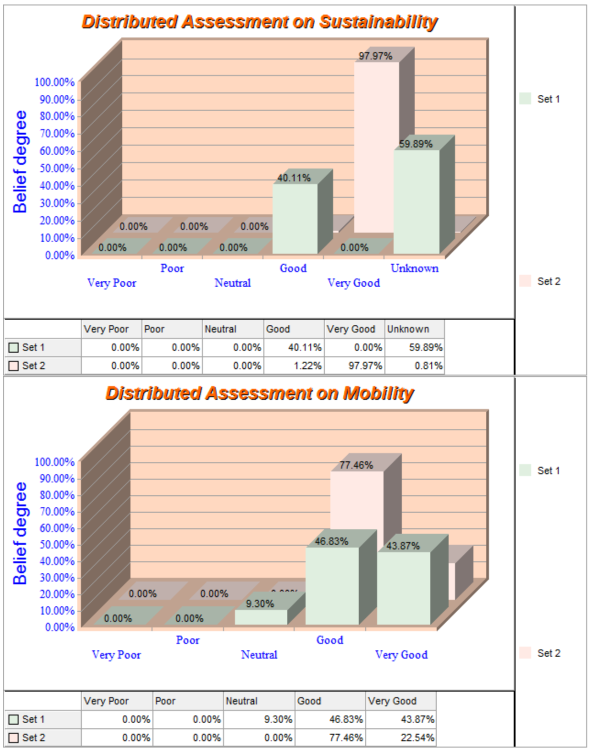
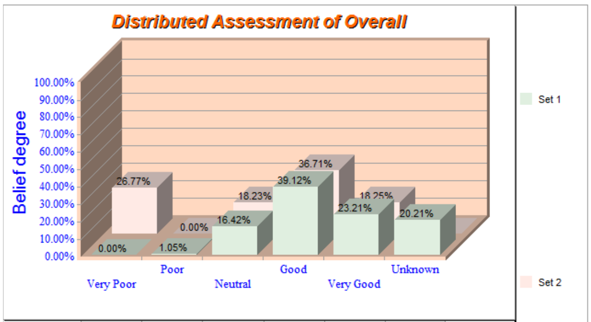
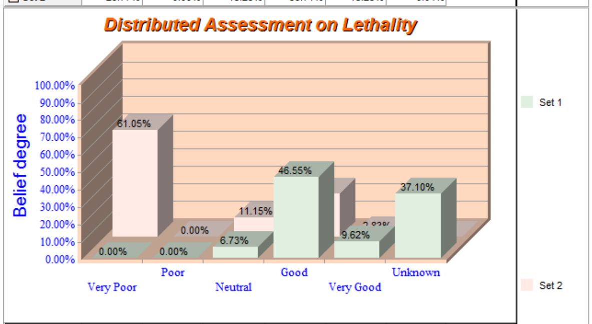


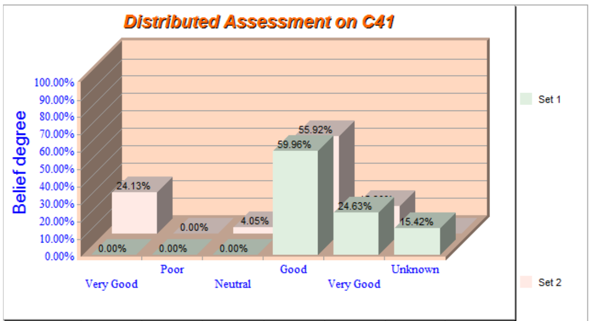
Figure 4. Distributed assessment results of assault task



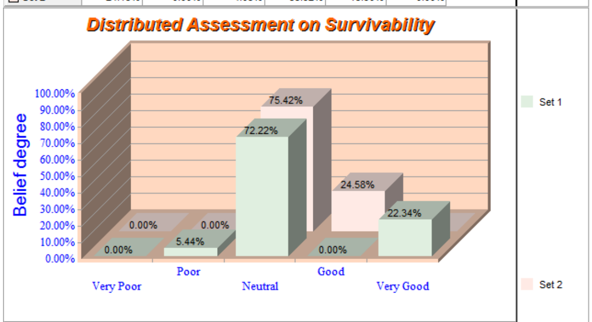
	Very Poor	Poor	Neutral	Good	Very Good	Unknown
Set 1	0.00%	1.05%	16.42%	39.12%	23.21%	20.21%
Set 2	26.77%	0.00%	18.23%	36.71%	18.25%	0.04%



	Very Poor	Poor	Neutral	Good	Very Good	Unknown
Set 1	0.00%	0.00%	6.73%	46.55%	9.62%	37.10%
Set 2	61.05%	0.00%	11.15%	24.97%	2.83%	0.00%



	Very Good	Poor	Neutral	Good	Very Good	Unknown
Set 1	0.00%	0.00%	0.00%	59.96%	24.63%	15.42%
Set 2	24.13%	0.00%	4.05%	55.92%	15.90%	0.00%



	Very Poor	Poor	Neutral	Good	Very Good
Set 1	0.00%	5.44%	72.22%	0.00%	22.34%
Set 2	0.00%	0.00%	75.42%	24.58%	0.00%

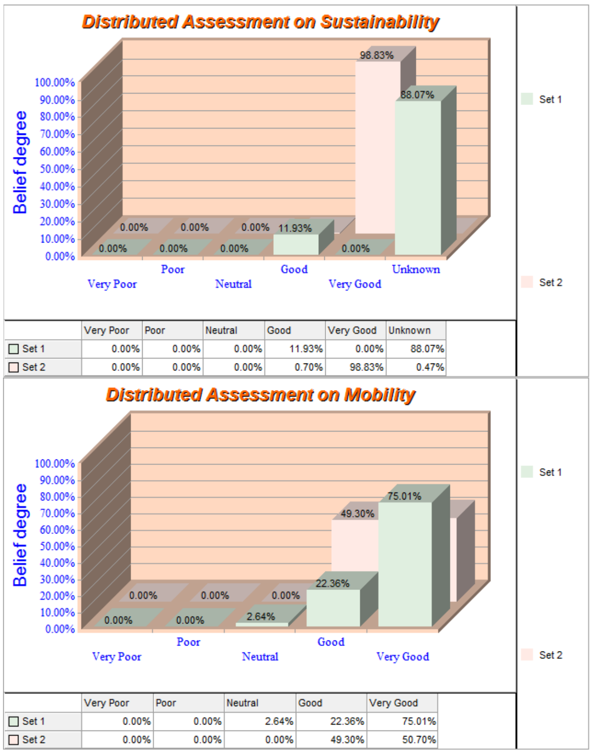
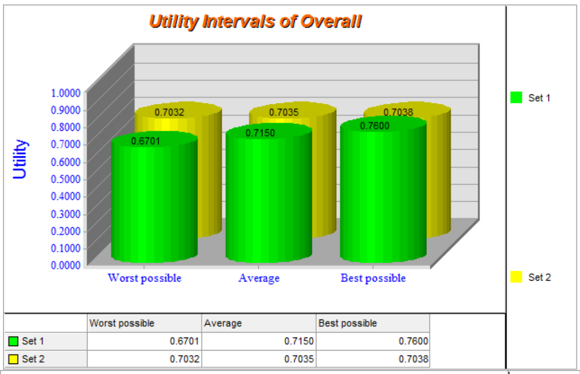


Figure 5. Distributed assessment results of patrol task

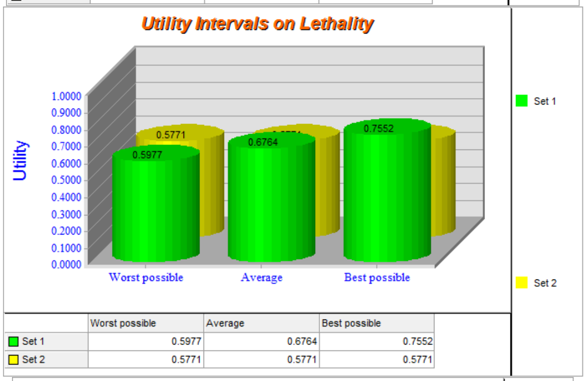
The initial distributed assessment results provide a structured view of how the aggregation output is laid out, but the preference order is not easy to be observed. Hence the utility analysis procedures are selected to compare the alternatives. Given the utility scale

$$U = [0 \quad 0.25 \quad 0.5 \quad 0.75 \quad 1]$$

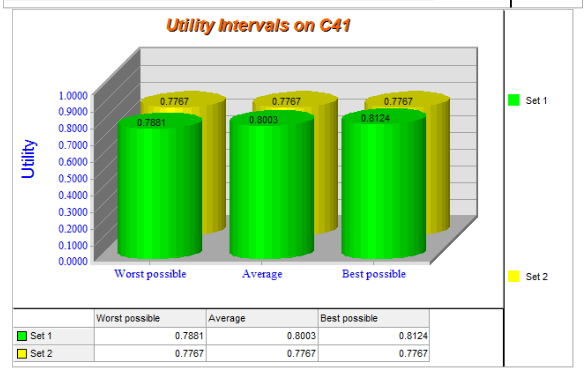
where VP has the utility value of zero and VG has utility value of one, then the utility value of the distributed assessment results can be calculated. In addition, as the belief degree of unknown portion could be assigned either to the best grade VG in the best cases or to the worst grade VP in the worst cases, the utility interval would be obtained for the assessment results with unknown portions. The utility comparisons are depicted in Figure 6 and 7 below.



	Worst possible	Average	Best possible
Set 1	0.6701	0.7150	0.7600
Set 2	0.7032	0.7035	0.7038



	Worst possible	Average	Best possible
Set 1	0.5977	0.6764	0.7552
Set 2	0.5771	0.5771	0.5771



	Worst possible	Average	Best possible
Set 1	0.7881	0.8003	0.8124
Set 2	0.7767	0.7767	0.7767

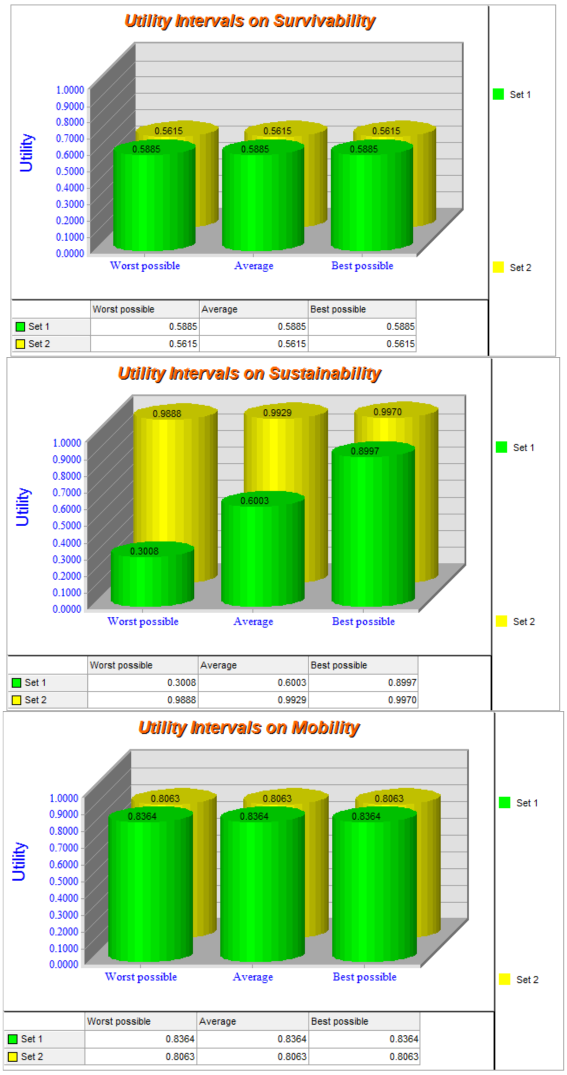
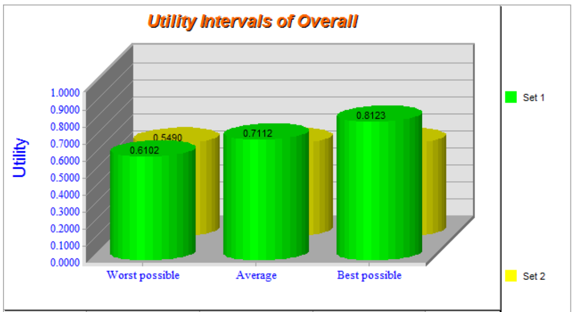
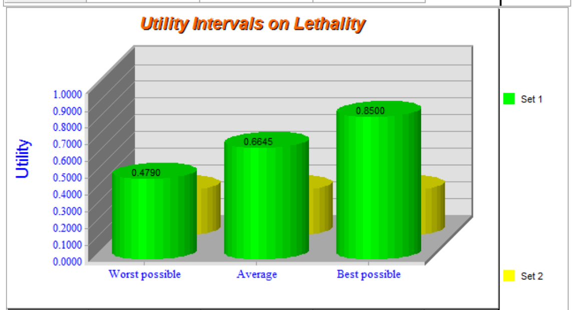


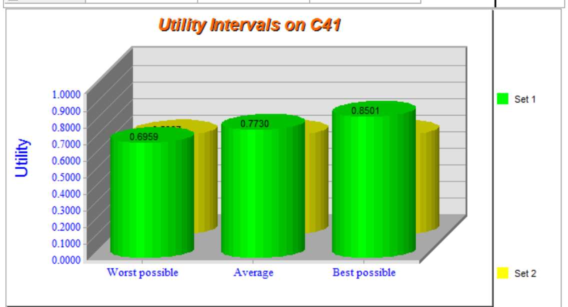
Figure 6. Utility comparison of assault task



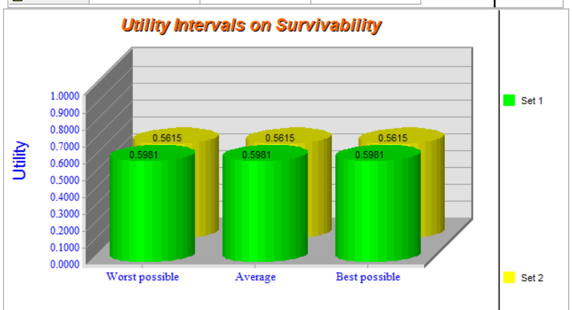
	Worst possible	Average	Best possible
Set 1	0.6102	0.7112	0.8123
Set 2	0.5490	0.5492	0.5494



	Worst possible	Average	Best possible
Set 1	0.4790	0.6645	0.8500
Set 2	0.2713	0.2713	0.2713



	Worst possible	Average	Best possible
Set 1	0.6959	0.7730	0.8501
Set 2	0.5987	0.5987	0.5987



	Worst possible	Average	Best possible
Set 1	0.5981	0.5981	0.5981
Set 2	0.5615	0.5615	0.5615

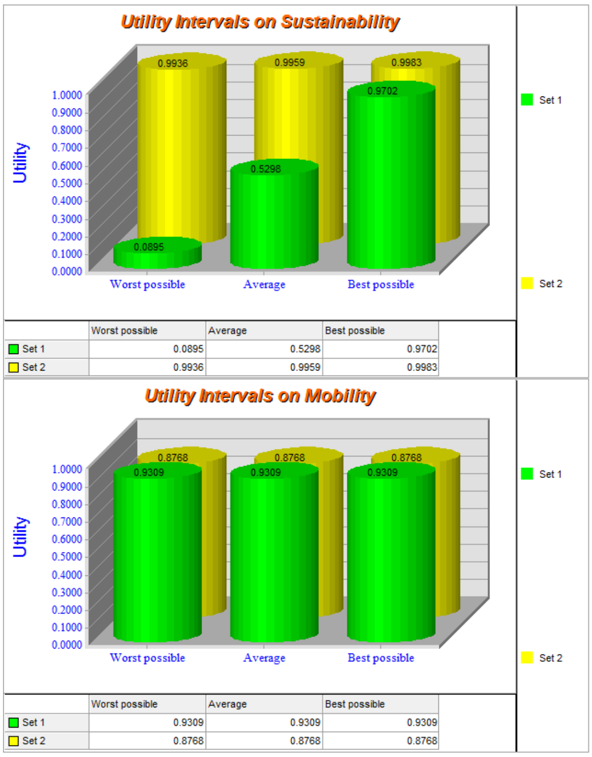


Figure 7. Utility comparison of patrol task

It could be found that set 1 performs dominantly better than set 2 in patrol task, for

$$u_{min}(set\ 1\ for\ patrol) = 0.6102 > u(set\ 2\ for\ patrol) = 0.5494.$$

But there is no strict preference between two components sets in assault task, as

$$u_{min}(set\ 1\ for\ assault) = 0.6701 < u(set\ 2\ for\ assault) = 0.7035$$
$$u_{max}(set\ 1\ for\ assault) = 0.7600 > u(set\ 2\ for\ assault) = 0.7035$$
$$u_{avg}(set\ 1\ for\ assault) = 0.7150 \approx u(set\ 2\ for\ assault) = 0.7035.$$

These results give the expert support to make the choice between two configurations specific to different tasks. It is also noted that, in the cases like the assessment of assault task, the result may be not so clear because of the uncertainties of initial collected data (unknown, incomplete judgements, etc.). In these cases, the initial assessment data should be re-assessed by the expert, and then the earlier ER aggregation process should be applied again to obtain a better or dominant result. For more detail, refer to work of Guo et al. (2007).

In addition, the detailed distributed assessment results of each high level capability provide expert the basis for further reconfiguration and trade-off analysis.

6. CONCLUSION

This paper presents the authors' new development of a novel rigorous assessment methodology to improve the soldier system analysis. The research is motivated by the concept of "soldier as a system" and the individual burden issue encountered by the operations of modern soldiers. To illustrate the contribution of this research to the practice, we formulate a soldier system assessment framework incorporated with the ER algorithm for the implementation through a case study. A soldier system hierarchical model that consists of 23 evaluation factors in three levels is proposed, and the developed methodology is capable of handling fragmentary and incomplete data with hybrid format in nature (qualitative and quantitative). The case study, however, is not a full validation of the methodology, as it demonstrates its applicability only with input from expert's subjective judgments. Therefore, for future work, the methodology will be validated with more comprehensive data. The research in the relationship among the soldier task requirements, soldier performance capabilities, and soldier equipment characteristics would be possible a direction. Such three dimensional interaction would provide the baseline in producing the objective assessment data.

REFERENCES

Abdelkader, M., Withers, J.C., Loutfy, R.O., Moravsky, A., Sennett, M., 2003. The investigation of carbon nanotubes for lightweight armor materials. *Proceedings of the 23rd Army Science Conference, Orlando.*

Baddeley, A., 2010. "Lightening The Soldier Platform", *Defence Director.*, Jan 2010, pp. 21-22.

Birrell, S.A., Hooper, R.H., Hasiam, R.A., 2007. The effect of military load carriage on ground reaction forces. *Gait and Posture, 26: 611-614.*

Centre for Defense Enterprise (CDE) Call, 2009a. Reducing the Burden on the Dismounted Soldier (RBDS) Capability Vision Task 4 – Stage 1 Assisted Carriage. London: Ministry of Defence (MOD).

Centre for Defense Enterprise (CDE) Call, 2009b. Reducing the Burden on the Dismounted Soldier (RBDS) Capability Vision Task 2 – Stage 1 Reduced Weight Ammunition Proof of Principle. London: Ministry of Defence (MOD).

Centre for Defense Enterprise (CDE) Seminar, 2009c. A Strategy for Soldier System Integration, Integrated Soldier System Executive (ISSE). Harwell: Ministry of Defence (MOD).

Chin, K.S., Yang, J.B., Guo, M., Lam, J., 2009a. An evidential reasoning-interval based method for new product design assessment.. *IEEE transactions on Engineering Management, 56(1), 142-156.*

Chin, K.S., Wang, Y.M., Yang, J.B., Poon, K., 2009b. An evidential reasoning based approach for quality function deployment under uncertainty. *Expert Systems with Applications 36(2009), 5684-5694.*

Datta, S.R. and Ramanathan, N.L., 1971. Ergonomic comparison of seven modes of carrying loads on the horizontal plane. *Ergonomics 14(2): 269-278.*

Guo, M., Yang, J.B., Chin, K.S., Wang, H.W., 2007. Evidential reasoning based preference programming for multiple attribute decision analysis under uncertainty. *Eur. J. Oper. Res., vol. 182, no. 3, pp. 1294-1312.*

Herold, D., Griffiths, Fung, T.Y., 2007. Lightweight High-Bandwidth Conformal Antenna System for Ballistic Helmets. *MILCOM 2007, Orlando, FL, U.S.A., pp. 1-6.*

Jackson, M. 2004, "Soldier Systems - The British Future Integrated Soldier System (FIST)", *Military technology.*, vol. 28, no. 11, pp. 71.

Liu, J., Yang, J.B., Wang, J., Sii, H.S., Wang, Y.M., 2004. Fuzzy rule-based evidential reasoning approach for safety analysis. *Int. J. Gen. Syst., vol. 33, no. 2/3, pp. 183-204.*

Nygren, K.P., Massie, D.D., Kern, P.J., 2006. Army Energy Strategy for the end of cheap oil. *Proceedings of the 25th Army Science Conference, Orlando.*

O'Keefe IV, J.A., Mcintyre III, R.T., Middleton, V.E., 1992a. Modelling and Simulation of the Soldier as a System. *Technical Paper NATICK/TP-10/005.* Massachusetts: U.S. Army Natick Soldier Research, Development and Engineering Center Natick.

O'Keefe IV, J.A., Porter, C.D., 1992b. Soldier System Modelling and Integrated Unit Simulation System (IUSS). *Technical Paper NATICK/TP-10/002.* Massachusetts: U.S. Army Natick Soldier Research, Development and Engineering Center Natick.

Polcyn, A.F., Bensel, C.K., Harman, E.A., Obusek, J.P., Pandorf, C., Frykman, P., 2002. Effects of weight carried by soldiers: combined analysis of four studies on maximal performance, physiology, and biomechanics. *Technical Report No TR-02/010,* US Army Research Institute of Environmental Medicine, MA.

Saaty, T.L., 1988. The analytic hierarchy process. *University of Pittsburgh.*

Shaffer, E.C., Massie, D.D., and Cross, J.B., 2006. Power and Energy Architecture for Army Advanced Energy Initiative. *Proceedings of the 25th Army Science Conference, Orlando.*

Shan, Y.X., Yang, L.L., Kalawsky, R., 2010. Exploration of Quantitative Assessment in Systems Architecture using Evidential Reasoning. *In Proceedings of IJCCI (ICEC), 2010, pp. 146-152.*

Si, X.S., Hu, C.H., Zhou, Z.J., 2010. Fault prediction model based on evidential reasoning approach. *Science China: Information Sciences, 53(10), 2032-2046.*

TRADOC Pamphlet 525-97, 2006. Military Opereations Soldier as a System. Virginia: Department of the Army Headquarters, United States Army Traing and Doctrine Command Fort Monroe.

Verhagen, T.L.A., Woering, A.A., Ubink, E.M., Knijnenburg, S.G., de Jong, K.Y. & van Helden, H.P.M. 2008, "Technical Optimisation of the ``Soldier System" The Physical Human Centric Modelling Approach", *MILITARY TECHNOLOGY,* vol. 32, no. 6, pp. 144-151.

Victor, M., Ken, S., Bob, M., John, O.I., 2000. Soldier Integrated Protective Ensemble (SIPE) Advanced Technology Demonstration (ATD). *Technical Report NATICK/TR-00/019.*

Wang, Y.M., Yang, J.B., Xu, D.L., 2006b. Environmental impact assessment using the evidential reasoning approach. *European Journal of Operational Research 174: 1885-1913.*

Yang, J.B., 2001. Rule and utility based evidential reasoning approach for multiple attribute decision analysis under uncertainty. *European Journal of Operational Research 131 (1), 31-61.*

Yang, J.B., Sen, P., 1994. A general multi-level evaluation process for hybrid MADM with uncertainty. *IEEE Transactions on Systems, Man, and Cybernetics 24 (10), 1458-1473.*

Yang, J.B., Singh, M.G., 1994. An evidential reasoning approach for multiple attribute decision making with uncertainty. *IEEE Transactions on Systems, Man, and Cybernetics Part A: Systems and Humans 32(3), 289-304.*

Yang, J.B., Xu, D.L., 2002a. On the evidential reasoning algorithm for multiattribute decision analysis under uncertainty. *IEEE Transactions on Systems, Man, and Cybernetics Part A: Systems and Humans 32(3): 289-304.*

Yang, J.B., Xu, D.L., 2002b. Nonlinear information aggregation via evidential reasoning in multiattribute decision analysis under uncertainty. *IEEE Transactions on Systems, Man, and Cybernetics Part A: Systems and Humans 32(3): 376-393.*