Fusion-Based Knowledge Logistics in Network-Centric Environment: Intelligent Support of OOTW Operations

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Abstract – *An efficient knowledge sharing between multiple participating parties is required to provide for situation awareness and consequently to manage any OOTW operation. Thereby it is necessary that the right knowledge from distributed sources is integrated and transferred to the right person within the right context at the right time to the right purpose. The aggregate of these interrelated activities is referred to as knowledge logistics (KL). The paper presents an approach that implements KL for an intelligent support of OOTW. Within the approach KL is coupled with information fusion based on constraint satisfaction methodology. Health service logistics is here considered as one of the approach applications what is illustrated via a case study of on-the-fly portable hospital configuration.*

Keywords: Knowledge logistics, OOTW intelligent support, network-centric environment, information fusion, health service logistics.

1 Introduction

Operations other than war (OOTW) include missions where sides having no direct conflict are required to perform a “neutral third party” operation. They in turn may be further subdivided into war avoidance and humanitarian aid missions. Countering terrorism and international crime may also be considered to lie within such missions because they can also be of a significantly destabilizing influence and may require the cooperation of international agencies in order to limit their insidious effects – OOTW are very likely to be based on a number of different, quasi-volunteered, vaguely organized groups of people, non-government organizations, institutions providing humanitarian aid and also army troops and official governmental initiatives. Here many participants will be ready to share information with some well specified community [1].

OOTW management (command & control) systems can be described as organizational combination of people, technologies, procedures and information. Management systems have to support the OODA-loop (“Observe-Orientate-Decide-Act” cycle / “Command & Control” cycle / “Boyd Cycle” in case of air force) [2].

To manage any OOTW operation an efficient knowledge sharing between multiple participating parties is required. This knowledge must be pertinent, clear, and correct, and it must be timely processed and delivered to appropriate locations, so that it could provide for situation awareness. This is even more important when OOTW involve coalitions uniting resources both of government (military, security service, community service, etc) and non-government organizations.

Thereby, systems aimed at intelligent support of OOTW have to meet a number of requirements including (i) support of knowledge sharing, (ii) distributed architecture for collaborative work, (iii) interoperability with other information systems, (iv) dynamic (on-the-fly) problem solving, (v) ability to work with uncertain information, (vi) constraint satisfaction notation for real-world problem description, and other.

Since successful OOTW can be achieved through knowledge of the status and the dynamics of the situation elements and comprehension of the situation, it can be stated that the right knowledge from distributed sources has to be integrated and transferred to the right person within the right context at the right time to the right purpose. The aggregate of these interrelated activities is referred to as *Knowledge Logistics* [3].

Knowledge logistics (KL) takes place in a network-centric environment. Unlike hierarchical organizations with fixed commander-subordinate relationships, nodes of network-centric environment are autonomous decision making units that can serve other units and also be served by them. With regard to computer systems the network-centric environment is based on advanced information technologies such as intelligent agents, ontology management, Web intelligence, Semantic Web and markup languages. OOTW support in the network-centric environment requires rapid processing and analysis of large body of up-to-date (preferably real-time) information from distributed and heterogeneous sources (experts, electronic documents, real-time sensors, weather forecasts, etc.). Hence, one of the key components of the situational awareness is fusion of information from different sources. The most influential fusion model in the area of information fusion is JDL Data Fusion Model [4]. It combines five levels of fusion: 0) sub-object data assessment, 1) object assessment, 2) situation assessment, 3) impact assessment, and 4) process refinement.

Here proposed approach combines KL and information fusion at level 2 of situation assessment and is based on advanced information technologies such as intelligent agents, ontology management, and markup languages. The aim of the paper is to present the developed approach to intelligent support of OOTW that would enable efficient real time OOTW management on-the-fly.

The rest of the paper is structured as follows. First, descriptions of the fusion-based approach to KL and its implementation as a multiagent system "KSNet" are given. Then, health service logistics (HSL) support selected as a possible approach application is considered. Finally, a case study of an on-the-fly portable hospital configuration problem as one of the major HSL support problems is described. The results and possible future research efforts are discussed in the conclusion.

2 KSNet-Approach & Its Implementation

The KL problem in the here presented approach is considered as a configuration of a network including end-users, knowledge resources, and a set of tools and methods for knowledge processing located in the network-centric environment. Such network of loosely coupled sources will be referred to as a knowledge source network or "KSNet" (detailed description of the approach can be found in [5, 6]), and the approach is called KSNet-approach.

The approach is built upon constraint satisfaction/propagation technology for problem solving since application of constraint networks allows simplifying the formulation and interpretation of real-world problems that are usually presented as constraint satisfaction problems in such areas as management, engineering, etc. (e.g., [7]). ILOG [8] has been selected as a constraint satisfaction/propagation technology for the approach.

As it was mentioned above the KSNet-approach addresses both KL and information fusion based on constraint satisfaction methodology. In accordance with the Endsley's situation awareness model [9] the approach currently covers two first levels: perception of elements in current situation and comprehension of the current situation. The third level of future status projection is planned as the work prospective.

2.1 Ontology-Driven Architecture

Since KL assumes dealing with knowledge contained in distributed and heterogeneous sources, the approach is oriented to ontological model providing for a common way of knowledge representation to support semantic interoperability. A fundamental ontology providing for a common notation implemented through an ontology library lies in the core of framework. The ontology library is a central knowledge storage assigning a common notation and providing a common vocabulary for ontologies that it stores. The common representative aids enable performance of operations on ontology integrations as alignment and merging, and operations on context integrations.

Main components of the ontology library are domain, tasks & methods, and application ontologies. All these ontologies are interrelated so that an application ontology (AO) is a specialization both of domain and tasks & methods ontologies. Tasks in tasks & methods ontology represent types (classes) of formalized problems. Since ontologies of different domains are stored in the ontology library (every domain is represented by its domain ontology) AO can specialize knowledge of several domains. Therefore AO plays two roles: it serves as a cross-domain ontology and represents context of the problem to be solved.

Domain ontologies and tasks & methods ontologies are formed as new knowledge becomes available. The new knowledge here is knowledge provided by experts, retrieved from knowledge sources (KSs), or obtained in a result of users' requests processing. Both new ontologies can be created (if there is no ontology relating to domain / task / method of the new knowledge) and existing ontologies can be expanded (otherwise). Such an arrangement allows to continuously enrich the ontology library with new knowledge, and, consequently, to speak about the system learning capability.

Being a context dependent conceptual model that describes a real-world application domain depending on a specific user request and relevant to its particular domains and tasks AO plays a central role in the request processing; it also represents joint knowledge of the user and KSs. AO is formed by merging the request relevant parts of domain and tasks & methods ontologies into a single ontology. Requested information from KSs is associated with AO formed for the request processing. Request ontologies and KS ontologies are used to translate the users' and KS terms into the AO terms.

In accordance with ontology spectrum represented in [10] the ontologies used in the KSNet-approach correspond to the level of value restrictions, and tasks & methods ontologies can be related to the level of general logic.

2.2 Dealing with Uncertainties

As it was mentioned above the formalism of object-oriented constraint networks has been chosen as the common notation and. According to the chosen formalism an ontology (A) is defined as: $A = (O, Q, D, C)$ where O is a set of *object classes* ("*classes*"), Q is a set of class attributes ("*attributes*"), D is a set of attribute domains ("*domains*"), and C is a set of *constraints* [6]. A comparison of this formalism with DAML+OIL was presented in [11]. However, when dealing with knowledge, uncertainties may arise due to the following reasons [12]: (i) a lack of information, (ii) invalidity of information, (iii) subjectivity, (iv) a lack of knowledge about a problem, (v) unverbalizability of the problem, (vi) imprecision of the problem solving methods. Taking uncertainties into account for estimation of solution reliability is especially important for such operations as disaster response that have to be fast and take place under extreme conditions (e.g., damaged communications).

To process the uncertain knowledge the formalism of fuzzy object-oriented constraint networks described as $(O, Q, D, C_\mu, W, T, I_p)$ has been chosen, where

C_μ is a set of constraints, and each constraint contains a function μ of membership in [0, 1] associated with weight ω_c representing its weight (importance) or priority;

W is a weight scheme, i.e. a function combining satisfaction degree of constraint $\mu(c)$ with ω_c, for estimation of weighted satisfaction degree of $\mu^{\omega}(c)$;

T is an aggregation function, which performs simple partial regulating on defined values, defining C_{μ};

I_p is an information content (instances of classes) of the constraint network, which has a nondeterministic or probabilistic nature.

Constraints of attributes to classes belonging, compatibility structural constraints, hierarchical structural constraints and “one-level” structural constraints are hard constraints. All of them have to be satisfied in the found solution, i.e. for each of them $\omega_c = 1$. Functional constraints and domains to attributes belonging can be considered as soft constraints.

Within the KSNet-approach the following types of uncertainties have been selected (Sec. 4 represents examples of processing some of these uncertainties by the system KSNet): (i) variable contents and structures of KSs, (ii) uncertainty presented in KSs (Sec. 4.3), (iii) low assurance of experts in their knowledge (Sec. 4.4), (iv) complexity of an application domain formalization (Sec. 4.2), (v) terminological conflicts during translation of knowledge from one ontology to another, (v) complexity of a user request recognition, and (vi) incompatibility of knowledge stored in different sources (Sec. 4.5). This list does not pretend to cover all possible types of uncertainties.

2.3 Knowledge Sharing via Ontologies

The classification of knowledge according to the abstraction and types [13] distinguishes *universal*, *shared*, *specific*, and *individual* knowledge abstraction levels. In the knowledge sharing model of the system “KSNet” (Fig. 1) the universal level is considered as the common knowledge representation paradigm. The universal level is based on the formalism of object-oriented constraint networks represented by means of knowledge representation language. The abstractions provided at this level are shared by the ontologies stored in the ontology library. Both shared abstraction level and specific abstraction level are considered sharable and reusable since ontologies of these levels share common representation paradigm and common vocabulary. The detailed description of the KSNet-approach components is given in [5, 6].

The level of knowledge representation provides with a common notation for knowledge description and enables compatibility of different formats (e.g., KIF, DAML+OIL, etc.). Knowledge sharing level focuses on ontological knowledge common regarding a particular area. Knowledge represented by this level suits well for sharing and reuse, since, on the one hand, this level does not concentrate on any specific properties, on the other hand, knowledge of this level is not a universal abstraction rarely taken into account when the case considers practical knowledge sharing and reuse. The knowledge ownership level increases scalability of the system with due regard to number of KSs that can be attached to the system and users that can be served.

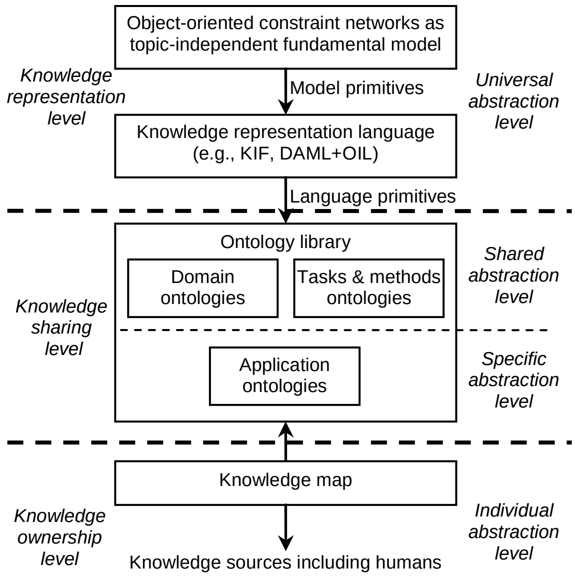

Fig. 1. Knowledge sharing in the system “KSNet”

2.4 Multiagent Architecture of the System "KSNet"

As an implementation of the KSNet-approach the system "KSNet" has been developed. Like some other KM systems (e.g., [12, 13]), the system “KSNet” uses intelligent software agents to provide access to distributed heterogeneous KSs. Multiagent systems offer an efficient way to understand, manage, and use the distributed, large-scale, dynamic, open, and heterogeneous computing and information systems [16]. Multi-agent system architecture based on Foundation for Intelligent Physical Agents (FIPA) Reference Model [17] was chosen as a technological basis for the system, since it provides standards for heterogeneous interacting agents and agent-based systems, and specifies ontologies and negotiation protocols. FIPA-based technological kernel agents used in the system are: wrapper (interaction with KSs), facilitator (“yellow pages” directory service for the agents), mediator (task execution control), and user agent (interaction with users). The following problem-oriented agents specific for KL and scenarios of their collaboration have been developed: translation agent (terms translation between different vocabularies), knowledge fusion (KF) agent (KF operation performance), configuration agent (efficient use of KSNet), ontology management agent (ontology operations performance), expert assistant agent (interaction with experts), and monitoring agent (KSs verifications). The multi-agent architecture is given in Fig. 2 and is described in detail in [6].

2.5 Distributed KF Agent for On-the-Fly Problem Solving

Since OOTW operations take place in a dynamic environment a continuous run-time monitoring and tracing of this environment is one of the key factors of successful situational awareness. On-the-fly problem modification and solving based on adaptive agents is required. For this purpose the described approach implements adaptive

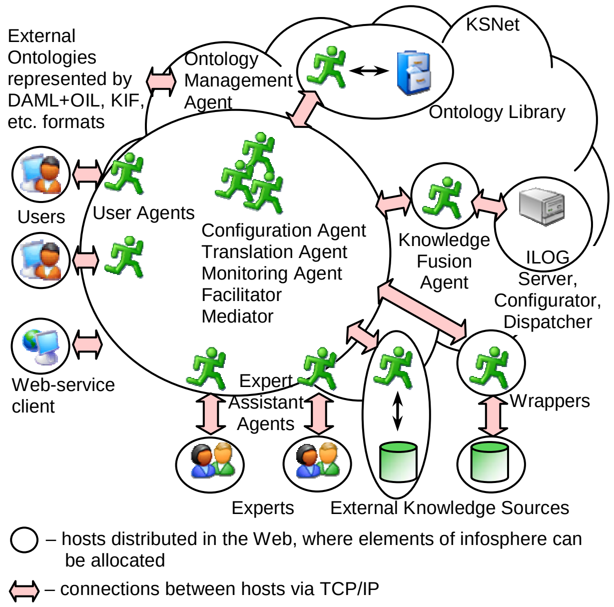

Fig. 2. Main components of the system "KSNet"

agents. These agents may modify themselves when solving a particular problem. For example, within the KSNet-approach there is a KF agent that is responsible for constraint-based problem solving (e.g., configuration problems, routing problems, etc.) based on existing knowledge. The problem is described by AO stored in the ontology library. Upon receiving the request the application loads an appropriate ontology and generates an executable module for its solving on-the-fly. Here the dynamic constraint satisfaction problem is represented as a sequence of static problems. Below a detailed description of the KF agent is given since it plays the key role in on-the-fly problem solving.

In the proposed approach a novel on-the-fly compilation mechanism is proposed to solve such dynamic problems. Roughly outlined this novel on-the-fly compilation mechanism is based on the following ideas (Fig. 3):

- a pre-processed user request defines (1) what ontologies are to be used for the problem domain description, and (2) what KSs are to be used;
- C++ code is generated on the basis of information extracted from (1) the user request (goal, goal objects, etc.), (2) appropriate ontologies (classes, attributes, and constraints), and (3) suitable KSs;
- the compilation is performed in an environment of the prepared in advance C++ project;
- failed compilations/executions do not interrupt the system work on the whole; an appropriate error message is generated.

The essence of the proposed on-the-fly compilation mechanism is to write the ontology elements (classes, attributes, constraints) to C++ file directly so that it could be compiled into ILOG-based program (as it was mentioned above ILOG was chosen as a constraint solver in this approach). The KF agent responsible for the problem solving creates the C++ file based on these data and inserts the program source code to the program (the prepared in advance Microsoft Visual Studio project)

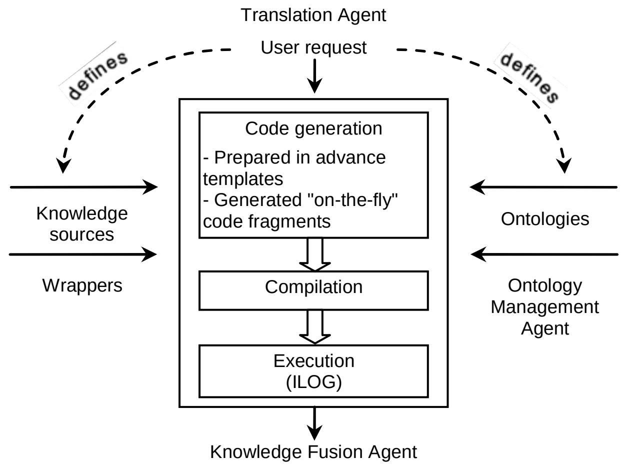

Fig. 3. The concept of the on-the-fly compilation mechanism

prepared in advance. The program is compiled in order to create an executable file in the form of dynamic-link library (DLL). After that the KF agent calls a function from DLL to solve the problem. The experiments showed that for complex problems the compilation time is significantly less than the time of the problem solving by the generated program.

3 Health Service Logistics as a Case Study

OOTW may have different missions. They can be related to disaster relief, noncombatant evacuation, humanitarian assistance, peace operations, and other. For the approach a problem of disaster relief operation from the field of HSL has been chosen. This field includes all services performed, provided, or arranged to promote, improve, converse, or restore the mental or physical well-being of people. Besides, it is a good example of integration of two major Emergency Function of Federal Response Plan (ESF1 "Transportation" and ESF8 "Heath and Medical Service"). As a test problem "Portable Hospital Configuration in Binni Region" was selected.

HSL support in coalition OOTW presents numerous challenges due to a variety of different policies, procedures and practices of the members of the operations, e.g., difference in doctrines, logistics mobility, resource limitations, differing stockage levels, interoperability concerns, competition between participants for common support. In [18] six major principles of joint activities logistics applicable to OOTW are selected. They include: (i) *objective* (there must be a clearly defined, decisive and attainable objective, and all the efforts of each operation member have to be integrated into the total effort of achieving strategic aims and cumulating in the desired end state); (ii) *unity of effort* (there must be a close coordination of all the operation members provided leading toward the main goal and every subgoal); (iii) *legitimacy* (legitimacy involves sustaining the people's willingness to accept the right of the operation leader to make and carry out decisions so that their activities would complement, not detract from, the legitimate authority of the leaders); (iv) *perseverance* (in coalition operations strategic goals may be accomplished by long-term involvement, plans, and programs. Short duration operations may occur, but these operations have to be viewed as to their impact on the long-term strategic goals); (v) *restrain* (coalition OOTW put constraints on potential actions that can be undertaken by the operation's members to achieve their goals); (vi) *security* (security is a very important issue in coalition operations, especially in those related to healthcare and involving military forces: the operation's leaders and members have to ensure that they include security measures). Besides such factors as different goals of operation's members, resource limitations, logistics mobility, etc. have also to be considered.

4 Case Study Implementation

As a case study for experimentation with the system KSNet a problem of on-the-fly portable hospital configuration [19] in the Binni region has been considered. "Binni – Gateway to the Golden Bowl of Africa" is a hypothetical scenario intended to provide a number of exercises typical of those anticipated for future coalition operations. Details of the scenario are given in a comprehensive document developed for the DARPA CoABS (Control of Agent Based Systems) program [20]. This problem correlates with that described in [21] where it deals with a development of transportation plans for evacuation of injured personnel and is solved by Medevac Agent.

Sections 4.2 – 4.5 demonstrate processing uncertainties of different types in the KSNet-approach with simple illustrative examples. These examples consider ad hoc constraints specific to the particular problem described in 4.1. However, the ways of processing uncertainties are generic enough to be applied to other problems.

4.1 Problem Statement

The goal of the here presented scenario is to demonstrate an application of the developed KSNet-approach to intelligent support of OOTW. The following request is considered: "*Define suppliers, transportation routes and schedules for building a hospital of given capacity at given location by given time.*" AO for this humanitarian problem has been built (Fig. 4), and connection to the found KSs has been established.

An analysis of the built AO showed a necessity of finding and utilizing KSs containing the following information/knowledge:

- hospital related information (constraints on its structure, required quantities of components, required times of delivery);
- available the United Nations (UN) and friendly suppliers (constraints on suppliers' capabilities, capacities, locations);
- available the UN and friendly providers of transportation services (constraints on available types, routes, and time of delivery);
- geography and weather of the Binni region (constraints on types, routes, and time of delivery, e.g., by air, by trucks, by off-road vehicles);

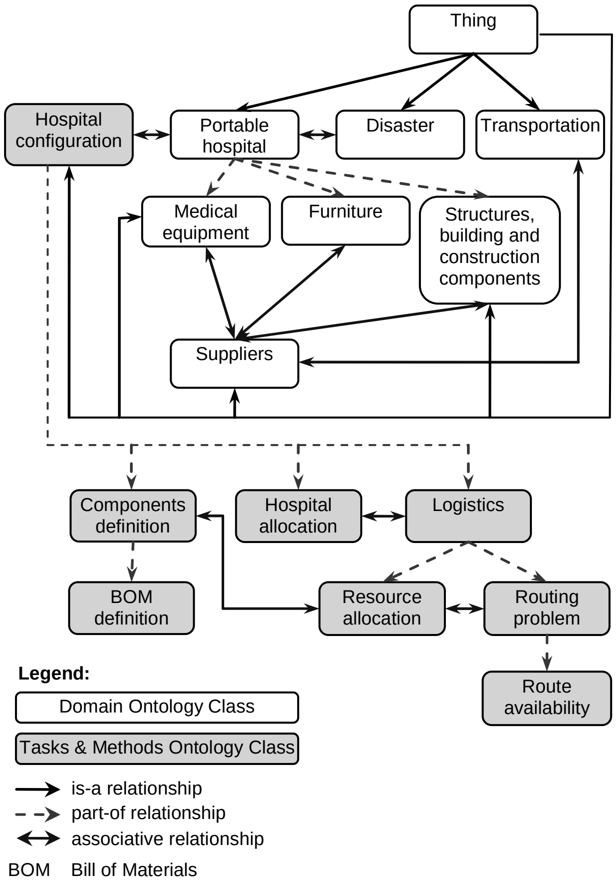

Fig. 4. AO for hospital configuration problem

- political situation, e.g., who occupies used for transportation territory, existence of military actions on the routes, etc. (additional constraints on routes of delivery).

As a result of the analysis of these problems the following major subproblems were selected from the tasks & methods ontology:

- *Portable hospital allocation*. This subproblem is intended to find the most appropriate location for the hospital to be built considering such factors as locations of the disaster, water resources, nearby cities and towns, communications facilities (e.g., locations of airports, roads, etc.) and decision maker's choice and priorities.
- *Routing problem*. This subproblem is intended to find the most efficient ways of delivery of the hospital's components from available suppliers considering such factors as communications facilities (e.g., locations of airports, roads, etc.), their conditions (e.g., good, damaged or destroyed roads), weather conditions (e.g., rains, storms, etc.) and decision maker's choice and priorities.
- *Hospital configuration*. This subproblem is intended to find the most efficient components for the hospital considering such factors as component suppliers, their capacities, prices, transportation time and costs and decision maker's choice and priorities.

The system accounts for the nature of the disaster and in its contexts defines hospital facilities sets to be used.

4.2 Task Complexity Reduction via Constraint Omitting

This example is intended to demonstrate the influence of a constraint omitting on the task's solution. This is achieved by dealing with uncertainties of the domain formalization. In the above given example the constraint that defines whether a certain city can be used for transportation or not (because of the weather or political situation) is considered as fuzzy and can be omitted. Its importance has been defined by the experts to be equal to 0.64.

The case with the omitted constraint is considered. In this case the solution generated assumes that all the cities are enabled for transportation (Fig. 5). It has the following characteristics: Costs = $220,700; Time = 682 min; Reliability = 0.64 or 64%.

The case where the considered constraint is not omitted results in the solution represented in Fig. 6. It has the following characteristics: Costs = $584,500; Time = 1626 min; Reliability = 100%.

The experiment shows that the solution obtained when the considered constraint is omitted is better in regard to the costs and time parameters but has a lower reliability. Though the example considers only one constraint this model can be applied to more complex tasks and omitting several constraints simultaneously.

4.3 Uncertainty Presented in Knowledge Sources

Presented example illustrates dealing with uncertainties presented in KSs. The same case study as in the previous example is considered. However, in this example the reliability of the KS describing availability of the cities for transportation is limited. This KS is a simulated news Web-site that publishes news about the Binni region. Particularly, it publishes warnings about some cities in case of negative weather or political conditions. The reliability of using a city if it has negative conditions is considered to be equal to 70%, otherwise it is 100%.

The example results in two routing plans: one considering all the cities as available (Fig. 5) and the other one considering some of the cities blocked (Fig. 6). The first result has the following characteristics: Costs = $220,700; Time = 682 min; Reliability = 49% (because two potentially blocked cities are used in the solution). The second result has the following characteristics: Costs = $584,500; Time = 1626 min; Reliability = 100%.

The experiment shows that the solutions obtained when required information is available can be optimistic with a lower degree of reliability (49%) and pessimistic with a higher degree of reliability. The model can be extended to taking into account several KSs.

4.4 Expert Estimation of Fuzzy Constraint

This example demonstrates a definition of a fuzzy constraint caused by a low assurance of experts in their knowledge. The bill of material constraint defining the number of operating tables per patient is considered. By default, it sets the amount of 5 operating tables per 50 patients – the crisp constraint.

The experts suggested maximum and minimum values ([2; 8], [4; 6], [1; 7], [3; 6], [4; 8], [2; 7], [3; 7]) that formed the following functional dependence (Fig. 7):

$$\omega(c) = \begin{cases} 0, m \le 1; m \ge 8 \\ \dfrac{m-1}{3}, 1 < m < 4 \\ 1, 4 \le m \le 8 \\ \dfrac{8-m}{2}, 6 < m < 8 \end{cases}, \text{ where}$$

$\omega(c)$ – fuzzy value of the constraint,

m – number of operating tables per 50 patients.

Sec. 4.5 demonstrates how this dependence is used for constraint relaxation.

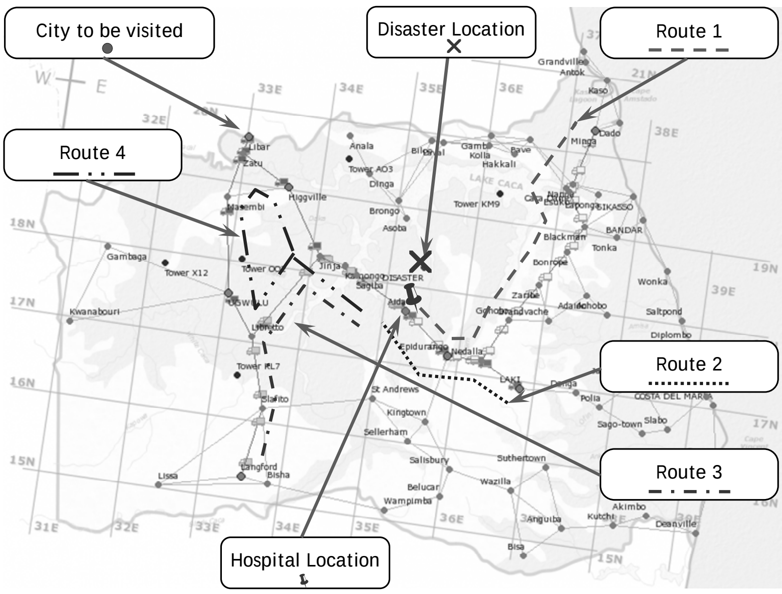

Fig. 5. Routing plan when all cities are considered available

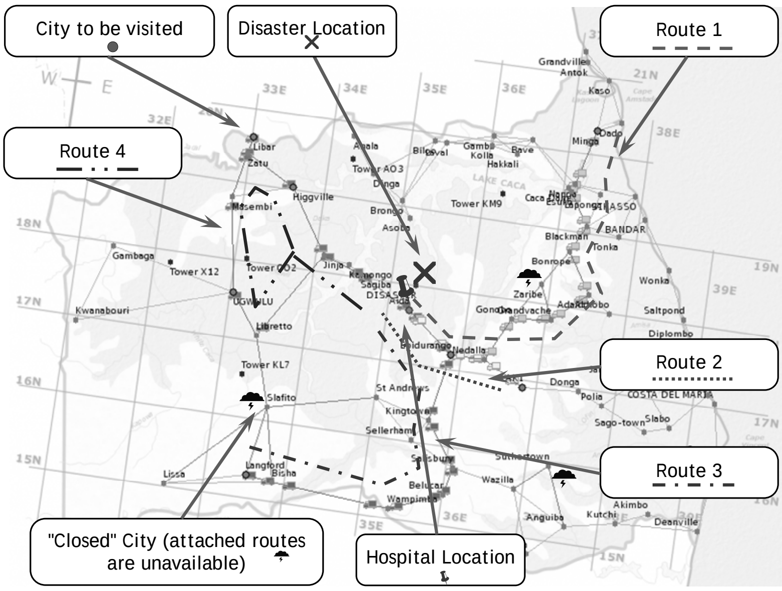

Fig. 6. Routing plan when some of the cities are blocked

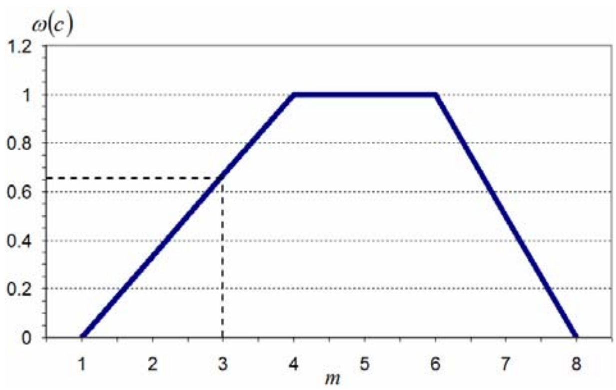

Fig. 7. Expert estimation of the fuzzy constraint

4.5 Constraint Relaxation Using Fuzzy Constraints

This example is intended to demonstrate how a fuzzy constraint can be relaxed. This is achieved by treating uncertainties of the domain formalization. In the example the above constraint defining the number of operating tables per patient is considered.

Let's assume that in the example the capacities of suppliers change so that they cannot provide the required number of operating tables for the hospital to be built. The hospital capacity is 500 patients and suppliers can produce only 30 operating tables.

In this case the constraint defining the number of operating tables per patient is relaxed so that instead of requirements of 5 operating tables per 50 patients (with reliability 100%) only 3 are required (Fig. 7). This leads to a decrease of the solution's reliability down to 66.67%.

5 Conclusions and Future Work

The paper presents an approach that implements KL for an intelligent support of OOTW. Within the approach KL is coupled with information fusion based on constraint satisfaction methodology. Application of constraint networks allows rapid problem manipulation by adding/changing/removing its components (objects, constraints, etc.) and use of such existing efficient constraint satisfaction/propagation technologies as ILOG. Presented mechanism of on-the-fly problem solving allows solving dynamic constraint satisfaction problems as a sequence of static ones. Agent-based architecture increases scalability, efficiency and interoperability of the system "KSNet". Utilizing ontologies and compatibility of the employed ontology notation with modern standards (such as DAML+OIL) enables semantic interoperability with other knowledge-based systems and services and facilitates knowledge sharing.

Applicability of the approach is illustrated via a case study of on-the-fly portable hospital configuration as a problem of health service logistics. Presented examples demonstrate processing uncertainties of different types in the KSNet-approach. Though the presented examples are simple they can be easily extended for significantly more complex real-world problems.

Possible future work on this approach is planned to be based on a combining of the current level 2 "Situation Assessment" (corresponding to the levels 1 & 2 of the Endsley's Situation Awareness model) with level 3 "Impact Assessment" (corresponding to level 3 of the Endsley's model) of the JDL Data Fusion Model, and to incorporate open service-based architecture as well as Web services and Grid standards such as WSDL and DAML-S.

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References

[1] M. Pechoucek, V. Marik and J. Barta. CplanT: an acquaintance model based coalition formation multi-agent system. In *Proc. of the Second Int. Workshop of Central and Eastern Europe on Multi-Agent Systems (CEEMAS'2001)*, pages 209-216, Krakow, Poland, 2001.

[2] A. Voort. Representational aspects of military command and control systems. In *Proc. of the 5th World Multi-Conf. on Systems, Cybernetics and Informatics SCI 2001, and the 6th Int. Conf. on Information Systems, Analysis and Synthesis ISAS 2000*, Orlando, Florida, USA, 2001. (Electronic Proceedings).

[3] A. Smirnov, M. Pashkin, N. Chilov, T. Levashova and F. Haritatos. Knowledge source network configuration approach to knowledge logistics. *Int. J. of General Systems*, 32(3): 251-269, 2003.

[4] J. Salerno, M. Hinman, D. Boulware and P. Bello. Information fusion for situational awareness. In *Proc. of the 6th Int. Conf. on Information Fusion*, pages 507-513, Cairns, Queensland, Australia, 2003.

[5] A. Smirnov, M. Pashkin, N. Chilov and T. Levashova. Knowledge logistics in information grid environment. *The special issue "Semantic Grid and Knowledge Grid: The Next-Generation Web"* (H. Zhuge, ed.) *of Int. J. on Future Generation Computer Systems*, 20(1): 61-79, 2003.

[6] A. Smirnov, M. Pashkin, N. Chilov and T. Levashova. Agent-based support of mass customization for corporate knowledge management. *Engineering Applications of Artificial Intelligence*, 16(4): 349-364, 2003.

[7] H. Baumgaertel. Distributed constraint processing for production logistics. *IEEE Intelligent Systems*, 15(1): 40-48, 2000.

[8] ILOG corporate Web-site, 2004. URL: http://www.ilog.com.

[9] M. Endsley. Theoretical underpinnings of situation awareness: a critical review. In M. Endsley and D. Garland editors *Situation Awareness Analysis and Measurement*, pages 3-32, Lawrence Erlbaum Associates, Mahwah, NJ, 2000.

[10] D. McGuiness. Ontologies for information fusion. In *Proc. of the 6th Int. Conf. on Information Fusion*, pages 650-657, Cairns, Queensland, Australia, 2003.

[11] A. Smirnov, M. Pashkin, N. Chilov, T. Levashova, A. Krizhanovsky. Ontology-Driven Knowledge Logistics Approach as Constraint Satisfaction Problem. In R. Meersman, Z. Tari, D. C. Schmidt, et al. editors *On the Move to Meaningful Internet Systems 2003: CoopIS, DOA, and ODBASE. – Proc. of the Int. Conf. on Ontologies, Databases and Applications of Semantics Information Reuse and Integration (ODBASE'2003)*, *Springer Lecture Notes in Computer Science*, 2888, pages 535-652, Catania, Sicily, Italy, 2003.

[12] S. Parsons. *Qualitative Methods for Reasoning under Uncertainty*. MIT Press, 2001.

[13] R. Neches, R. Fikes, T. Finin, T. Gruber, R. Patil, T. Senator and W. Swartout. Enabling technology for knowledge sharing. *AI Magazine*, 12(3): 36-56, 1991.

[14] P. Visser, D. Jones, M. Beer, T. Bench-Capon, B. Diaz and M. Shave. Resolving ontological heterogeneity in the KRAFT project. In *Proc. of the Int. Conf. On Database and Expert System Applications (DEXA-99)*, pages 668-677. Springer-Verlag (Lecture Notes in Computer Science, 1677), 1999.

[15] M. Nodine, and A. Unruh. Facilitating open communicating in agent systems: the InfoSleuth infrastructure. Technical Report MCC-INSL-056-97, Microelectronics and Computer Technology Corporation, 1997.

[16] G. Weiss (ed.). *Multiagent Systems: a Modern Approach to Distributed Artificial Intelligence*. The MIT Press, Cambridge, Massachusetts, USA; London, England, 2000.

[17] Foundation for Intelligent Physical Agents (FIPA), 2003. URL: http://www.fipa.org.

[18] JTTP for Health Service Logistic Support in Joint Operations, 1997. URL: http://www.dtic.mil/-doctrine/jel/new_pubs/4_02_1.pdf.

[19] The interactive edition of the Pittsburg Post-Gazette, 2002. URL: http://www.post-gazette.com.

[20] Rathmell R.A. A Coalition Force Scenario "Binni – Gateway to the Golden Bowl of Africa. Proceedings on the International Workshop on Knowledge-Based Planning for Coalition Forces (ed. by A/ Tate). Edinburgh, Scotland, 1999. 115—125.

[21] S. Wark, A. Zschorn, D. Perugini, A. Tate, P. Beautement, J. Bradshaw and N. Suri. Dynamic agent systems in the CoAX Binni 2002 experiment. In *Proc. of the 6th Int. Conf. on Information Fusion*, pages 205-212, Cairns, Queensland, Australia, 2003.