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Knowledge-Based Approach for Military Mission Planning and Simulation

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1. Introduction

One of the most complicated and complex decision processes concerns military applications. Military command and control processes are information intensive activities, involving many variables (tasks of friendly forces, expected actions of opposite forces, environmental conditions – terrain, weather, time of the day and season of the year, current state of own (friend) and opposite forces in the sense of personnel, weapon systems and military materiel, etc.) with strong interrelationships and uncertainty. Two of the factors which are especially essential in military decision-making are human battlefield stress and a limited time. Therefore, it is very important to provide, for military decision-makers, computer tools, which support their decisions and try to partially eliminate the negative impact of their stress on the decision being made and shorten the decision-making time (Najgebauer, 1999; Tarapata, 2011). These tools should be a knowledge-based (Tarapata, 2011). An example of a knowledge-based decision support system schema for military applications is presented in Fig.1. There are illustrated two elements, which contain a knowledge base (KB): operational-tactical KB and terrain KB. The first one is used to collect knowledge being used to express the character of the digital battlefield during automation of military decision-making: military rules, decision situation patterns and recognition rules, course of action (CoA) patterns, etc. The second one (terrain KB) collects pre-processed information from the terrain database.

The typical military decision planning process contains the following steps:

- estimation of power of own and opposite forces, terrain, and other factors, which may influence on a task realization,
- identification of a decision situation,
- determination of decision variants (Course of Actions, CoA),
- variants - evaluation (verification),
- recommendation of the best variant (CoA) of the above-stated points, which satisfy the proposed criteria.

Simulation and verification of course of actions (CoA) is considered in many systems and aspects (Antkiewicz et al., 2011a; 2011b; Barry & Koehler, 2005; Mathews, 2004; Najgebauer 2004; Ross et al., 2004; Sokolowski, 2002; Tarapata, 2008; Pierzchała et al., 2011). The most important step of decision planning process is an identification of a decision situation problem: this problem is that we must find the most similar battlefield situation (from earlier defined or ensuing situations, e.g. in battlefield situation knowledge) to current one. Afterwards, the decision situation being identified is a basis for choosing CoA, because with each decision situation a few typical CoA frames are connected. In the chapter we will present a network model of the terrain (with rule-based functions described on the network's nodes and arcs) which is based on pre-processed information from the terrain database, and we will show how to use the operational-tactical KB to identify decision situations.

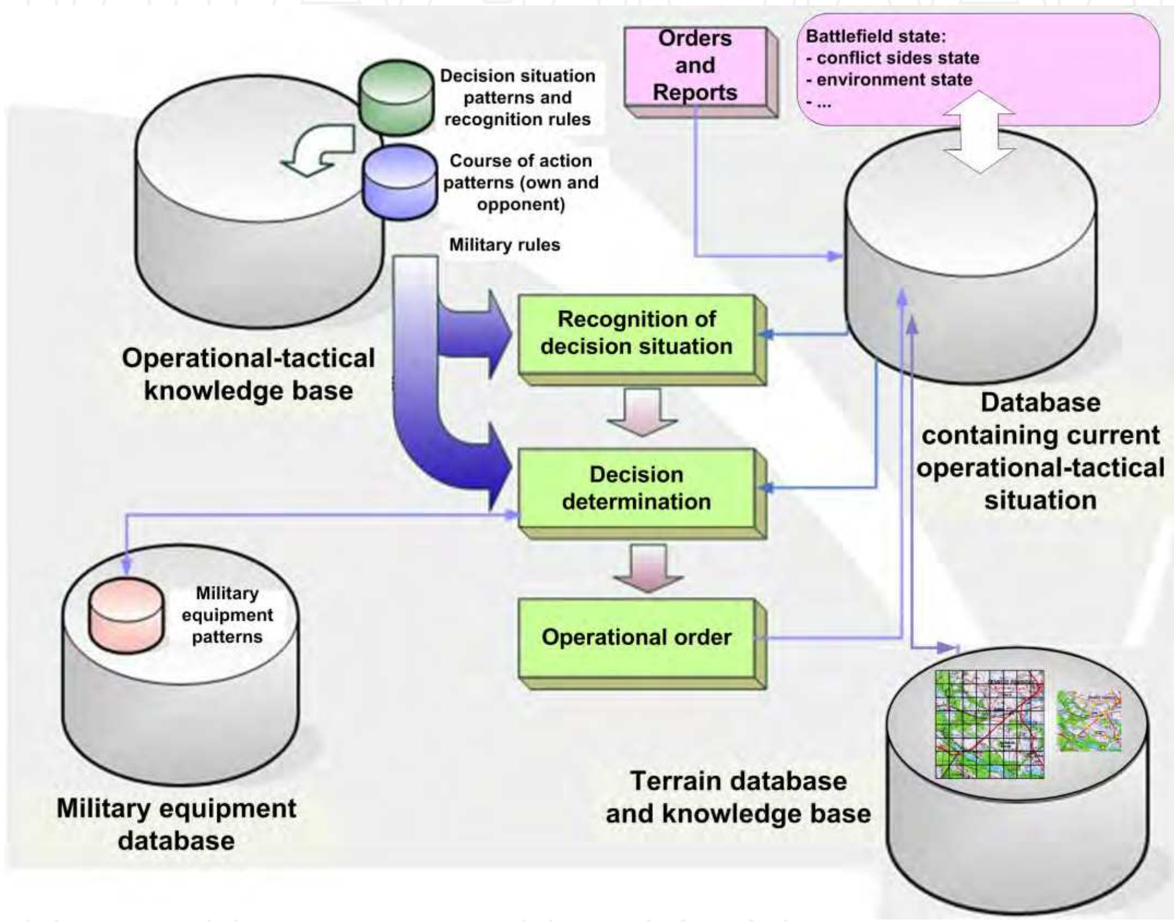

Fig. 1. An example of a knowledge-based decision support system schema for military applications (Tarapata, 2011)

The chapter is organized as follows: in section 2 we present problems connected with modelling the semantics of military domain, section 3 contains battlespace ontology model, in section 4 we present ontology-based reasoning, section 5 contains ontology-based decision situation model and section 6 and 7 present some example of using tool for identification of decision situations.

2. Modelling the semantics of military domain

Recently, knowledge representation in military operations is addressed by application of Network Enabled Capabilities concept. Data, information and knowledge can be distinguished as the following steps in environment understanding. Russell Ackoff defines the content of the human mind separated into: data (basic representation mainly symbols), information (which is data that has been given meaning by definition of relationships), knowledge (appropriate intentional collection of information), understanding (is an interpolative and probabilistic process based on cognitive and analytical characteristics) which synthesize new knowledge. Based on the above definitions the knowledge representation for military domain should be concerned with representing pre-processed inferred information addressing the scenario or course of action. In the following chapter we will discuss the importance of such representations and usefulness of their applications in decision support systems.

In any domain there exists a need to formulate unified semantics shared across multiple heterogeneous components or even systems. The more concealed and specific the domain is, the more detailed terminology we can define. Military domain model is a good example of such case, as the vocabulary is explicit and well-defined moreover the domain experts exchange information using abbreviations and terminology strongly related to this semantic only. Ontology is a model which can be used to achieve this task. It is based on a conceptualisation process and can be understood as a task of identifying and extracting concepts from given domain and formulating their semantics through definitions of binary relationships or axioms. Ontologies can be often regarded as informal or semiformal models of human readable knowledge representations, however in our understanding the need to present such formalisms is to develop model for agent processing.

In the following work, formally we will define ontology as:

"Domain model formulated for the purpose of describing shared knowledge about specific modelling area. Ontology provides both lexical and conceptual point of view separating human view and automata understating of the domain in terms of semantics."

Available in many sources verbal definitions contain blurred vision therefore we can formalise ontology as following tuple:

$$O = \left\langle C, R_C, H_C, R_{\mathrm{Rel}}, A^O \right\rangle \qquad (1)$$

Consisting of concept set, binary relationships sets defined on that set, characteristics of structural relationships and axiom set containing complex model expressivity. Structural relations between them $R_C = \{r_C : r_C \in C \times C\}$, taxonomical relationships providing information on super-/sub- concepts $H_C = \{h_C : h_C \in (C \setminus \{c_0\}) \times C\}$. To provide capability of describing correspondences between structural relations we provide R_{Rel} which is able to describe inverse relationships, possible relationship taxonomies along with symmetry, transitivity, reflexivity etc. relationship characteristics. The last but not least are the axiom definitions which consist of logical statements describing model restrictions formulated with concept and structural relationship references and involving statements in one of logic based formalisms (First-Order Logic, Description Logic) $A^O = \left\langle L\left(G^A\right), I^L \right\rangle$. Axioms therefore are defined by the syntax and interpretation function which binds the syntax categories into set of objects forming concepts. The axiom set definition is intentionally generalised as the ontology definitions and can be formulated in any of formal languages meeting the description requirements and offering various expressiveness.

Ontology having those characteristics is a formal model with strong constraints supported by logic languages such as first-order logic (FOL) and description logic (DL). We can also recall other methods (frame representation, topic maps) of such specifications but there are not in the scope of the following work.

We apply ontologies for domain description to:

- Unify understanding of given vocabulary and terminology by formulating concept and relationship semantics inside the domain;
- Use the inference abilities of ontology languages to verify the instance data correctness according to specified in ontology constraints (model consistency, calculate instance membership);
- Merge and map varying data schemas into one unified meaning, integrating multiple representation schemes and standards JC3IEDM, APP-6A, TIDE-BRITE etc.
- Define semantic background for semantic pattern recognition methods applied in decision support procedures;

Specificity of data standards in military systems offer syntactically different representations which correspond to almost the same information scope. The standards themselves have been developed to support various tasks in C2 systems such as: data integration (JC3IEDM), tactical symbology (APP-6A), interoperability services (TIDE-BRITE) and provide specific view on data, its ranges, enumeration types, etc.

Conducted research on the ground of knowledge representation for military applications is mainly concerned with situation awareness assessment and development of common operational picture components. Each of those abstracts require set of techniques which offer inference and cognition in terms of battlespace information discovery. Ontology applications in such areas can help to organise the inference process by application of axiom definitions used by logic reasoners. Depending on the applied ontology language we can obtain domain description with characteristics depending on the utilised language expressivity.

Model expressivity is affected by the language and complexity of constructs contained in the model where the language defines the maximal available expressivity. To sustain traceability and efficiency of reasoning algorithms a set of logic formalisms have been designed called conceptual languages (attributive languages) (Baader et al., 2000). Description Logic is de facto a subset of First-Order Logic designed to restrict some of the constructs which causes undesirability but mostly based on the paper (Baader et al., 2000) we can provide efficient reasoning mechanisms which consider terminology in instance base inference. Synthetic characteristics of such attributive languages, their semantics and inference tasks have been presented in (Baader et al., 2000; Pan, 2004). Study on the complexity of reasoning mechanisms and reasoning capabilities of DL dialects have been described in many publications and summarised on interactive webpage containing synthesised knowledge on that matter - http://www.cs.man.ac.uk/~ezolin/dl.

3. Battlespace ontology model

Ontology design guidelines, which is fairly new discipline, have been gathered on the basis of Tom Gruber's publications (Gruber, 1995; 2009) defining main characteristics of such models and steps of conceptualisation process. Consideration of those guidelines assures model validity and consistency, however it should be remembered that axiom formulation depends on knowledge engineer intent to state stronger ontology commitments which is not always required.

Applied UBOM (Chmielewski, 2009) modelling approach is a result of available in military domain standards for data representation and inference capabilities utilised in prepared decision support procedures. C2 system decision support can specify set of decision and optimisation problems which can be used in situation awareness identification and assessment by inferring possible course of action based on prepared reasoning rules and semantic patterns representing tactical templates and valid blue forces reactions. Many of decision support tasks can be represented in a form of algorithms which we attempt to formalise or provide rules which decision makers should incorporate. Unfortunately, in many cases crisp reasoning methods are not suitable to provide correct answers, therefore the semantic similarity between current scenario and templates in knowledge base provide distance measures which can be adjusted depending on the situation needs.

UBOM design guidelines required to use JC3IEDM similar semantics as this standard is recognised model for C2 systems integration. Having well-defined structures, conceptual model and the most of all meta-model representation JC3 has been chosen as a source which ontology generation process should be implemented on. Having chosen representation language and dialect (OWL DL, $SHOIN^{+}$(D)) we have designed set of transformation rules to reflect the core model entities and their attributes, relationships into corresponding ontology elements. The generation process have been iteratively tuned in order to adjust the final model form, correct domain definitions and a level of model inference capabilities. Early generation attempts showed that JC3 is a very large model and it is not sufficient to reflect the whole model and its elements, instead we have been able to choose the most important elements and their inheritance trees. JC3 is very a specific, sophisticated domain description of battlespace entities, designed to unify meaning in various heterogeneous systems. It uses E-R modelling and OOM design imposing a very rich set of enumeration types and business rules. UBOM ontology is developed using OWL DL language in $SHOIN^{+}$(D) dialect which defines available language expressivity. To provide extensive ontology statements, model extends base attributive language *ALC* with relationship hierarchy *H*, nominals - enumeration concepts *O*, inverse roles *I*, cardinality restrictions *N* and data types support D.

From the beginning of model analysis we have been able to extract true meaning concealed in the model by studying the model's domain types, which turned out to be the most important carriers of semantics. Domains, containing domain values and defined business rules formulate the combinations of allowed, valid values for battlespace entities reflected in the model's structures. Therefore process of designing the ontology axiom set depended in majority on identification of domain values usage and formulation of concept taxonomy tree based on required precision for OBJECT-ITEM and OBJECT-TYPE taxonomies. Due to the large scale of the model and all available descriptions provided by MIP we have chosen a metamodel database MIRD in order to transform chosen entities and relations to the form of semantic model. This operation required extended analysis of the JC3 semantics:

- to choose the most important parts of the model to be transformed;
- to identify transformation rules for JC3 relational model to ontology;
- to filter ontology classes and extract only needed elements.

JC3 model structure consists of entities, composed of attributes. In the most cases, types of attributes are defined by domains. They are composed of domain vales which create similar structure as enumeration types. JC3 defines also business rules which are used to obtain valid domain values combinations for selected attributes. For the purpose of this work we utilize business rules for UNIT-TYPE, EQUIPMENT-TYPE entities to construct available variants of defined units and equipment. The domain knowledge used in this process has been described in MIR Annex G - Symbology Mapping documents and can be used in form of guidelines for extracting meaning from wide range of domain values. Definitions of model transformation rules has been identified for:

- generic guidelines to obtain schematic algorithm for relational model elements transformation into ontology;
- identification of excess relational model elements associated with physical model representation not dealing with its semantic contents;
- definition of uniform naming conventions for generated semantic model elements based on relational model predecessors unifying the element vocabulary;
- development of additional business rules validation scheme to identify combinations of valid domain values and their reflection in form of Description Logic class constructors or SWRL reasoning rules;
- definition of optimal and relevant range of JC3IEDM elements to be transformed providing required ontology expressiveness with compact size and processing efficiency.

Generation of JC3 ontology has been executed several times with different set of transformation rules. The main cause of such approach has been ontology refinement process and optimization of ontology OWL language constructs.

The transformation process assumes that the main goal is to reflect the semantics of the model and not its structure. Due to this fact some of the entities defined on the level of conceptual model have been erased and replaced by the relations between concepts, e.g. associations between OBJECT-TYPE are represented by the OBJECT-TYPE-ASSOCIATION entity which holds additional enumerated meaning of the relation, to enable reasoning abilities in designed ontology we propose to define set of relations between OBJECT-ITEM stating their hierarchy.

The presented process delivers an interactive algorithm of extending base ontology by generation of JC3IEDM parts in a form of integrated ontology modules. Integration of ontology modules generated on the basis of user request is conducted using a mapping strategy. Time generation of the ontology (ontology module) depends on the number of elements which must be reflected in resulting semantic model. The research shows that generation delays differ depending on the required JC3 model entities (domains) that needed to be reflected but also additional restrictions that are formulated on the basis of object properties defined in ontology. We should point out that tests covered also transformation of the model which required introduction of n-ary relationship pattern.

Knowledge in terms of UBOM model reflects the taxonomy of units, military equipment and conducted activities which are used by aggregation to developed a scenario composed of:

- units and their full identification, type description and spatial location;
- unit's equipment and its characteristics affecting the combat potential;
- Comand&Controll chain following the decision process responsibilities;
- unit activities and assigned tasks, objectives;
- unit's activity constraints regarding the collaboration within the task formation.

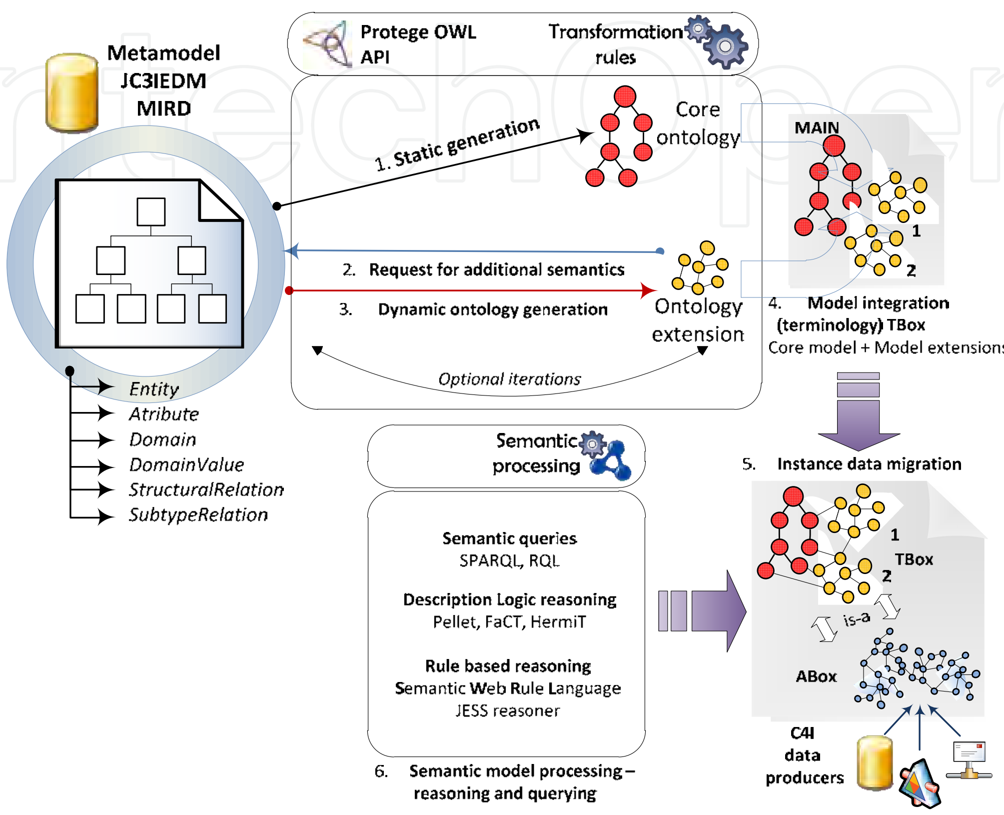

Fig. 2. The ontology adaptive generation process, developing parts of JC3IEDM terminology integrated into the UBOM semantic model

Based on those elements, a part of JC3IEDM description definitions have been reflected and extended in order to match situation assessment requirements. A semantic model therefore needs to reflect meaning of military unit formation, its configuration and potential placement. Those elements, with human and terrain analysis characteristics, may be used to infer some scenario courses or vignettes. Considering such knowledge military experts can evaluate possible hostile forces courses of action therefore preparing variants of counter actions.

Main concepts in UBOM ontology (Chmielewski & Gałka, 2010) following JC3IEDM vocabulary are presented in Fig. 2. Intent of transformation process was to represent the core elements of the data model and its semantics used in data exchange process across multiple functional areas of military domains. Referenced data model version 3.1b consisted of: 290 entities, 1594 attributes, 533 domains (enumeration types), 12409 - domain values, 259 associations, 166 hierarchy relations. Implementation of this model as an ontology in OWL language in the most simplified dialect required more than 20000 ontology constructs (CEA, restrictions, and other axioms). When we additionally consider domain closure axioms - class disjointness, instance uniqueness, etc. - this element count brings us up to 30000 elements. The generated ontology with annotated elements serialised in RDF/OWL requires almost 52456 kB. When we consider that the semantic processing environment must load the model and create additional structures required in reasoning processes the volume of data causes technical issues. Usage of more complex dialect required further ontology refinement towards more restrained logical conditions (existential and cardinality restrictions) and brings the model to even larger size (72213 kB – depending on the quantity of restrictions).

The applied generation process assumed that there is a need for an ontology documentation and reflection of all JC3IEDM entities. However, we can filter the model to consider only necessary elements with minimal annotations requirements, limiting the outcome model size. The core JC3IEDM model after application of those rules consists of base 94 concepts which are mainly associated with OBJECT-ITEM, OBJECT-TYPE hierarchies, CAPABILITIES, ACTION, HOLDING, CONTEXT, REPORTING-DATA. Iterative ontology generation produced ontologies which in majority cases lacked of basic characteristics required by this type of model, mainly in terms of inference capabilities. Therefore a manual knowledge engineering have been additionally applied as a refinement process emphasising those model elements.

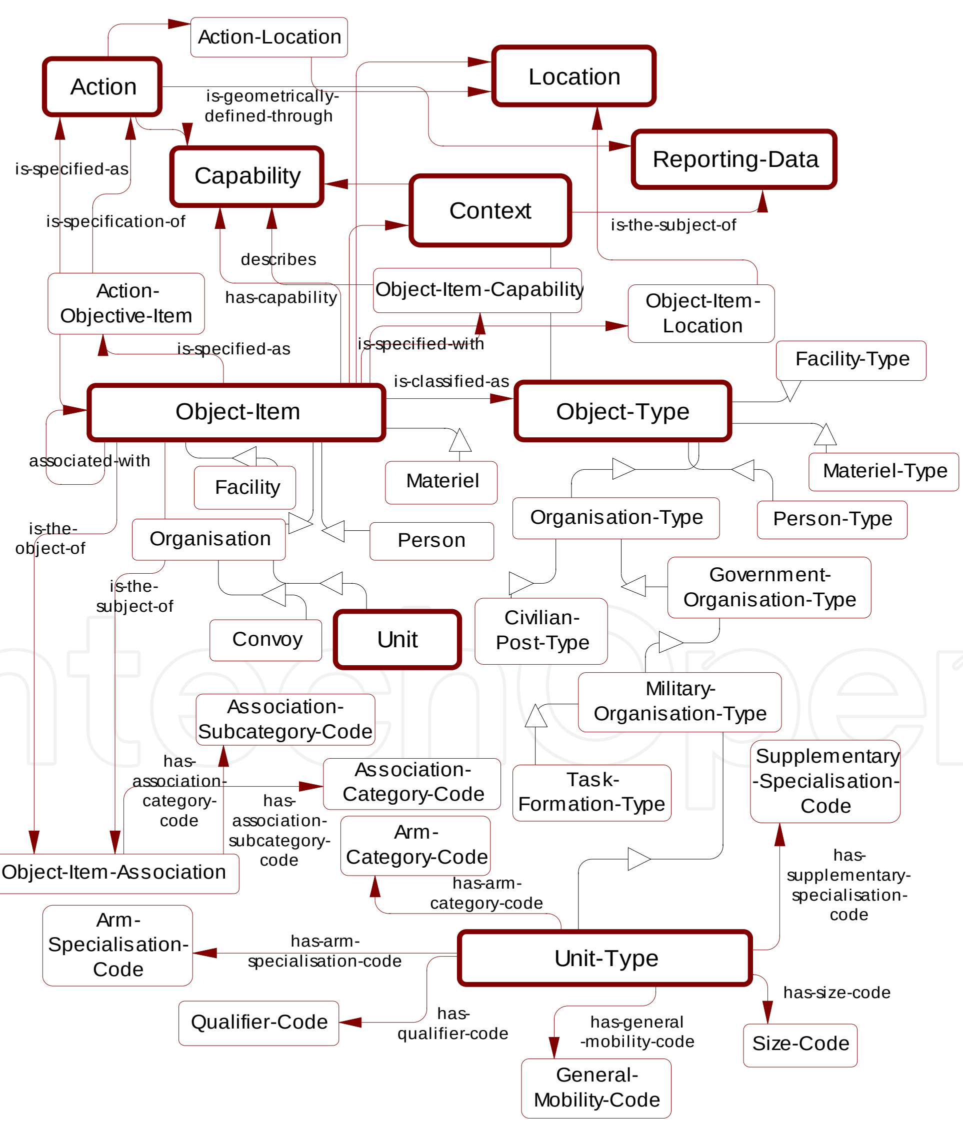

Fig. 3. JC3IEDM based ontology module incorporated into UBOM model

Main entities have been additionally thickened to emphasise important semantics represented in the scenario description. UBOM ontology separates descriptions of military organisations (*Units*, *TaskForces*) from *Equipment* and *WeaponPlatform* descriptions. This separation is done due to the need for ontology mapping into APP-6A symbology techniques used in Common Operational Picture product composition. We also managed to provide a weaponry branch of a knowledge representation which considers *DamagingFactor*, *Ammunition*, *WeaponComponents* in *WeaponPlatform* classification which is not reflected in the JC3IEDM standard. We intentionally choose to present ontology in a form of conceptual graph specifying structural relationships (dark arrows) and concept subsumption (inheritance) empty arrows (also dashed lines). However, such representation cannot provide axiom definitions stated in KB but example definitions will be recalled later in the chapter.

The presented ontology relationships define terminology of *WeaponPlatform* and composition strategies of *Weapons* and other *Equipment* elements forming consistent *DamagingFactor* carrier, affecting specified *Targets*. This way we are able to distinguish *Human* and *Infrastructure* effects, potential *WeaponPlatform* outcomes for both kinetic and non-kinetic engagements. Semantics contained in such definitions allow weapon taxonomy formulation for both conventional and NCB weapons with distinction of multiple *DamagingFactors* and their harming potential in given environment. It is also noticeable that we perceive *WeaponPlatform* as composition of *Equipment*, *Vehicles*, *Targeting&AquisitionSystems*, *Ammunition* and *Weapon* itself resulting in producing a multiple *DamagingFactors* carrier affecting the *Environment* and exploiting given *Target* vulnerabilities.

4. Ontology-based reasoning

Ontology based reasoning techniques are closely connected with the reasoning abilities of language used to express given terminology. We should note that many of available notations and dedicated languages move towards utilising logic based representations and general inference algorithms. Considering such language features as decidability, traceability and efficiency of reasoning, the family of Description Logic languages is most widely used. We should also recognise specific semantics of DL languages, identified reasoning tasks found in DL knowledge bases and how are they coupled in algorithms used by reasoning facilities. Modelling environments and semantic information processing frameworks utilise DL features to perform model consistency checking along with concept and instance classification.

Tasks performed by the reasoning services consist of:

- *Satisfiability of a concept* - determine whether a description of the concept is not contradictory, i.e., whether an individual can exist that would be instance of the concept;
- *Subsumption of concepts* - determine whether concept C subsumes concept D, i.e., whether description of C is more general than the description of D;
- *Consistency of ABox with respect to TBox* - determine whether individuals in ABox do not violate descriptions and axioms described by TBox;
- *Check an individual* - check whether the individual is an instance of a concept;
- *Retrieval of individuals* - find all individuals that are instances of a concept;
- *Realization of an individual* - find all concepts which the individual belongs to, especially the most specialised (leaf classes) ones.

To demonstrate the axiom definitions we can provide simplified DL symbology and semantics which will affect final set of reasoning tasks. Semantics behind such notation come from DL formalisms and have been summarised for convenience of reading.

Using interpretation *I* for C, D being *ALC*- concepts and role name $r \in N_R$ we formulate:

$$\text{Concept conjunction } (C \sqcap D)^I = C^I \cap D^I$$

$$\text{Concept disjunction } (C \sqcup D)^I = C^I \cup D^I$$

$$\text{Universal value restriction } (\forall r.C)^I = \left\{ a \in \Delta^I : \forall b \in \Delta^I (a,b) \in r^I \Rightarrow b \in C^I \right\}$$

$$\text{Existential value restriction } (\exists r.C)^I = \left\{ a \in \Delta^I : \exists b \in \Delta^I (a,b) \in r^I \wedge b \in C^I \right\}$$

$$\text{Concept subsumption axiom } (C_{subsumption} D)^I = C^I \subseteq D^I$$

$$\text{Concept equivalence axiom } (C_{equivalent} D)^I = \left(C^I \subseteq D^I \wedge D^I \subseteq C^I \right)$$

Following the above formalisms we can recall set of UBOM defined axioms providing ground for ontology-reasoning features.

jc3: Unit-Type *equivalent* ∃ *has-Unit-Type-Supplementary-Specialisation-Code*.**UTSSCode** ⊓ ∃ *has-Unit-Type-General-Mobility-Code*.**UTGMCode** ⊓ ∃ *has-Unit-Type-ARM-Category-Code*.**UTACCode** ⊓ ∃ has-Military-Organization-Type-Service-Code.**MOTSCode**
jc3:MechanisedInfantry-Unit-Type *subsumption* **jc3:Unit-Type** **jc3:MechanisedInfantry-Unit-Type** *equivalent* ∃ *has-Unit-Type-Supplementary-Specialisation-Code*.{Ground-UTSSC} ⊓ ∃ *has-Unit-Type-General-Mobility-Code*.{Land-Tracked-UTGMC} ⊓ ∃ *has-Unit-Type-ARM-Category-Code*.{Armour-UTACC} ⊓ ∃ has-Military-Organization-Type-Service-Code.{Army-MOTSC}

Table 1. Example UBOM based *MilitaryUnit* definitions expressed in JC3 based terminology following unit taxonomy tree Military-Organization-Type-> Unit-Type-> MechanisedInfantry-Unit-Type

Another view represented in UBOM ontology axiom definitions with more human readable meaning can be presented in form of following statements:

MilitaryMan *equivalent* **BattlespaceActor** ⊓ ∃ *Person-member-of-Organisation*. **MilitaryOrganisation**
Commander *equivalent* **MilitaryMan** ⊓ ∃ *Person-manages-Organisation*. **MilitaryOrganisation**
OilRafinery *equivalent* **Infrastructure** ⊓ ∃ *Infrastructure-produces-Supplies*. **FosilFuel**

5. Ontology-based decision situation model

Military unit representation is based on recognised in NATO standards attributes distinguishing battlespace dimension, unit type its rank, affiliation, hostility status etc.

Based on such descriptions we can classify each of the C2 command chain elements and provide detailed information on given formation placed within the battlespace.

Using the *MilitaryUnit*'s relationships between other elements we can establish its function within the command chain, and infer possible responsibilities in combat formation predicting possible intentions. Ontology representation of military units can also be used as a reconnaissance support tool permitting representation of iterative information upgrades on the basis of ReportingData records.

The UBOM ontology does not contain pure OBJECT-TYPE specification – instead proposed taxonomy contains *TargetEffects* form *WeponPlatforms* on specified *Resources*. As the Environment perceived in Network Enabled Capabilities can contain asymmetric threats additional broader approach have been applied through formulation of effect probability *TargetEffect* recorder on some *Resources*. The model itself have been created to place significant interest on the "weapon platform" effects and reflecting those effects depending on the *DamagingFactor* which can be either conventional, psychological or NCB weapons based.

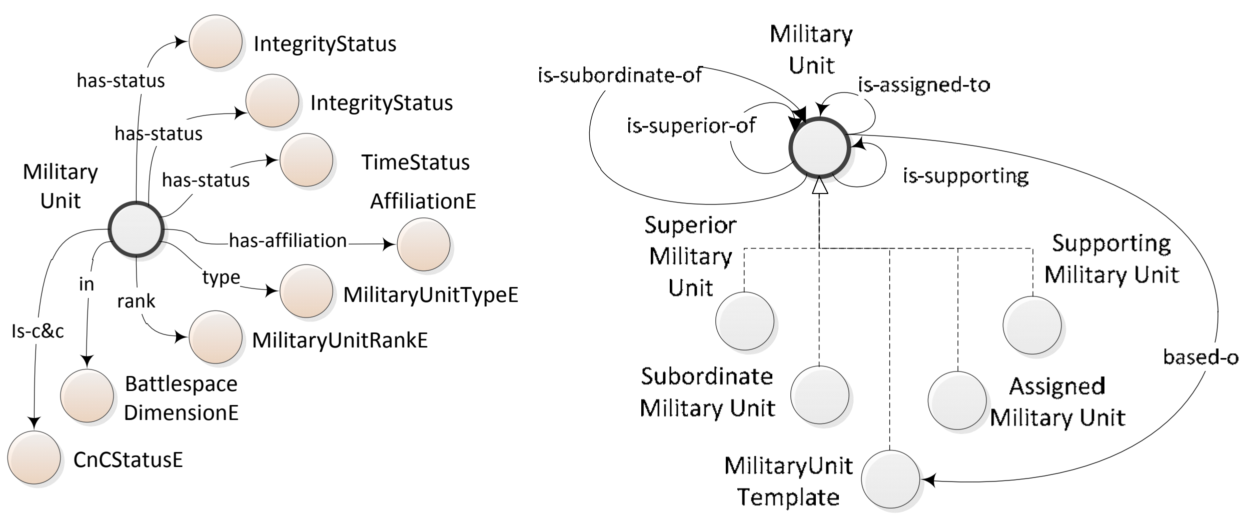

Fig. 4. UBOM *MilitaryUnit* description containing JC3 based attributes (left) and taxonomy reflecting *MilitaryUnit* function in formation and C&C decision chain

UBOM contains also the part of *WeaponPlatform* classification which based on weapon *DamagingFactor* characteristics (*Vulnerability* of *Target*, class of the factor, aim at damaging abilities) permits to model the effects on the *Environment* consisting of *LivingForce*, *Equipment* and *Infrastructure*. Ontology design approach applied in our case was a confrontation of JC3 capacities and terminology used across the other military applications.

Representation of dynamic UBOM constructs affecting the scenario inference have been demonstrated in the Fig. 5. Purpose of such definitions is to describe the nature of activity specification along with classification of conducted tasks their importance in a combat operation implying unit's status in given scenario. Evaluation of prepared instance graphs describing scenarios placed in proper annotated terrain data helps to extend the perception of given scenario and distinct unit roles.

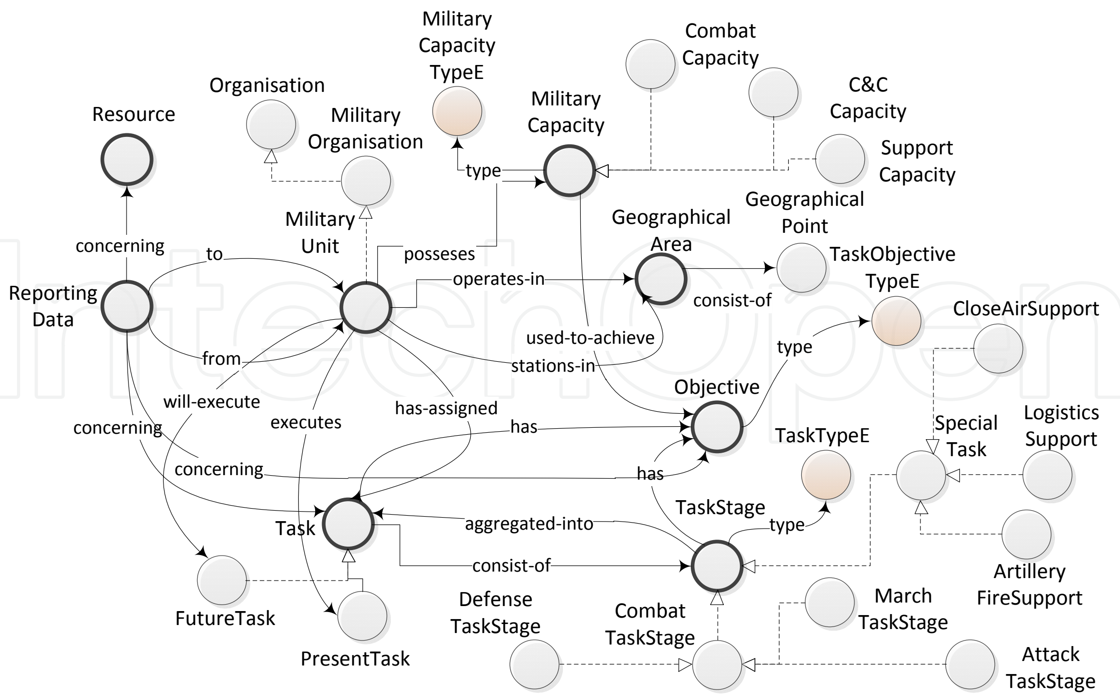

Fig. 5. UBOM decision situation model semantically describing *MilitaryUnits* their *CombatCapacities*, *Task* formation with executed *Tasks.*

The model addresses also elementary *Organisation* taxonomy which can be identified as *ConflictEntrants* and interaction providers in asymmetric *Environment*. One of the elements of the taxonomy is *MilitaryUnit* serving as main concept for representing an entity of accumulated military force in *Environment* and interacting with it through *Activities* which can be perceived as military *Tasks* for which we define abstract *Objectives*.

Concepts definitions provided in UBOM ontology contains mainly axioms which are used in classification process designed to support current scenario representation. Process of scenario classification assumes that:

- gathered from battlespace information about specific military unit or object is fused and represents consistent, deconflicted information about such entity;
- recorded information produces a graph of connected instances coupled around specific scenario with spatial description of terrain and reconnaissance information gaps declaring uncertain or unreliable information.

Instances of given scenario related entities expressed in UBOM ontology in the process of inference can change type (concept) membership. This is possible due to ontology axiom definitions and specific semantic formulas used by those definitions forming chain of classification rules applied by the DL reasoner. The inferred concept taxonomy graph structure and instance membership assignment is understood as building new knowledge in the given operational KB and is mainly concerned with reasoning about current scenario.

6. Identification of decision situations

Having formulated semantics of the scenario we can apply those elements for the decision situation vector definition, which contains knowledge about the terrain, military potential distribution in a combat formation and assigned tasks formulating a template for recognition process described further in the following chapter. We define a decision situations space as follows:

$$DSS = \{SD: \ SD = (\ SD_r)_{r=1,..,8}\} \tag{2}$$

Vector *SD* represents the decision situation, which is described by the following eight elements: SD_1 - command level of opposite forces, SD_2 - type of task of opposite forces (e.g. attack, defence), SD_3 - command level of own forces, SD_4 - type of task of own forces (e.g. attack, defence), SD_5 - net of squares as a model of activities (terrain) area $SD_5 = \left[SD^5_{ij}\right]_{\substack{i=1,..,SD_7\\ j=1,..,SD_8}}$, $SD^5_{ij} = (SD^{5,k}_{ij})_{k=1,..,7}$. The terrain square with the indices (*i,j*) each of the elements denotes: $SD^{5,1}_{ij}$ - the degree of the terrain passability, $SD^{5,2}_{ij}$ - the degree of forest covering, $SD^{5,3}_{ij}$ - the degree of water covering, $SD^{5,4}_{ij}$ - the degree of terrain undulating, $SD^{5,5}_{ij}$ - armoured power (potential) of opposite units deployed in the square, $SD^{5,6}_{ij}$ - infantry power (potential) of opposite units deployed in the square, $SD^{5,7}_{ij}$ - artillery power (potential) of opposite units deployed in the square, $SD^{5,7}_{ij}$ - coordinates of the square (*i,j*), SD_6 - the description of own forces: $SD_6 = \left(SD^6_i\right)_{i=1,..,4}$, SD^6_1 - total armoured power (potential) of own units, SD^6_2 - total infantry power (potential) of own units, SD^6_3 - total artillery power (potential) of own units, SD^6_4 - total air fire support power (potential); SD_7 - the width of activities (interest) in an area (number of squares), SD_8- the depth of activities (interest) in an area (number of squares).

The set of decision situations patterns are: $PDSS = \{PS : PS \in DSS\}$. For the current decision situation *CS*, we have to find the most similar situation *PS* from the set of patterns. Using the similarity measure function (6) we can evaluate distances between two different decision situations, especially the current and the pattern. We have determined the subset of decision situation patterns $PDSS_{CS}$, which are generally similar to the current situation *CS*, considering such elements like: task type, command level of own and opposite units and own units potential:

$$\begin{aligned} PDSS_{CS} = \{PS = (PS_i)_{i=1,..,6} \in PDSS : PS_i = CS_i\,, \\ i = 1,..,4, dist_{potwl}(CS, PS) \le \Delta Pot\} \end{aligned} \tag{3}$$

where:

$$dist_{potwl}(CS, PS) = \max\{\left|CS^6_k - PS^6_k\right|, k = 1,..4\} \tag{4}$$

ΔPot - the maximum difference of own forces potential.

Afterwards, we formulated and solved the multicriteria optimization problem (5), which allows us to determine the most matched pattern situation (*PS*) to the current one (*CS*) from the point of view of terrain and military power characteristics:

$$Z = \left(PDSS_{CS}, F_{CS}, R_D\right) \tag{5}$$

where:

$$F_{CS} : PDSS_{CS} \to R^2 \tag{6}$$

$$F_{CS}\left(PS\right) = (dist_{ter}(CS,PS),\, dist_{pot}(CS,PS)) \tag{7}$$

$$dist_{ter}(CS,PS) = \sum_{k=1}^{4} \lambda_k \cdot \left(\sum_{i=1}^{I} \sum_{j=1}^{J} \left(CS_{ij}^{5,k} - PS_{ij}^{5,k} \right)^p \right)^{\frac{1}{p}} \tag{8}$$

$$\sum_{k=1}^{4} \lambda_k = 1,\, \lambda_k > 0,\, k = 1,..,4 \tag{9}$$

$$dist_{pot}(CS,PS) = \sum_{k=5}^{7} \mu_k \cdot \left(\sum_{i=1}^{I} \sum_{j=1}^{J} \left(CS_{ij}^{5,k} - PS_{ij}^{5,k} \right)^p \right)^{\frac{1}{p}} \tag{10}$$

$$\sum_{k=5}^{7} \mu_k = 1,\, \mu_k > 0,\, k = 5,..,7 \tag{11}$$

$$I = \min\{CS_7, PS_7\}\ ,\ J = \min\{CS_8, PS_8\} \tag{12}$$

$$R_D = \begin{Bmatrix} (Y,Z) \in PDSS_{CS} \times PDSS_{CS} : \\ dist_{ter}(CS,Y) \le dist_{ter}(CS,Z) \wedge \\ dist_{pot}(CS,Y) \le dist_{pot}(CS,Z) \end{Bmatrix} \tag{13}$$

Parameters μ_k and λ_k describe the weights for components calculating the value of functions $dist_{ter}$ and $dist_{pot}$. The domination relation defined by (13) allows us to choose such PS from $PDSS_{CS}$, which has the best value of $dist_{ter}$ and $dist_{pot}$, that is the most similar to CS (non-dominated PS from the R_D point of view). The idea of the identification of a decision situation and CoA selection is presented in Fig. 6.

There are several methods of finding the most matched pattern situation to the current one, which can be used. For example, in the paper (Tarapata, 2007) a concept of multicriteria weighted graphs similarity and its application for pattern matching of decision situations is considered. The approach extends known pattern recognition approaches based on graph similarity with two features: (1) the similarity is calculated as structural and non-structural (quantitative) in weighted graph, (2) choice of the most similar graph to graph representing pattern is based on a multicriteria decision. Application of the presented approach to pattern recognition of decision situations has been described in (Tarapata 2008; Tarapata et al., 2010).

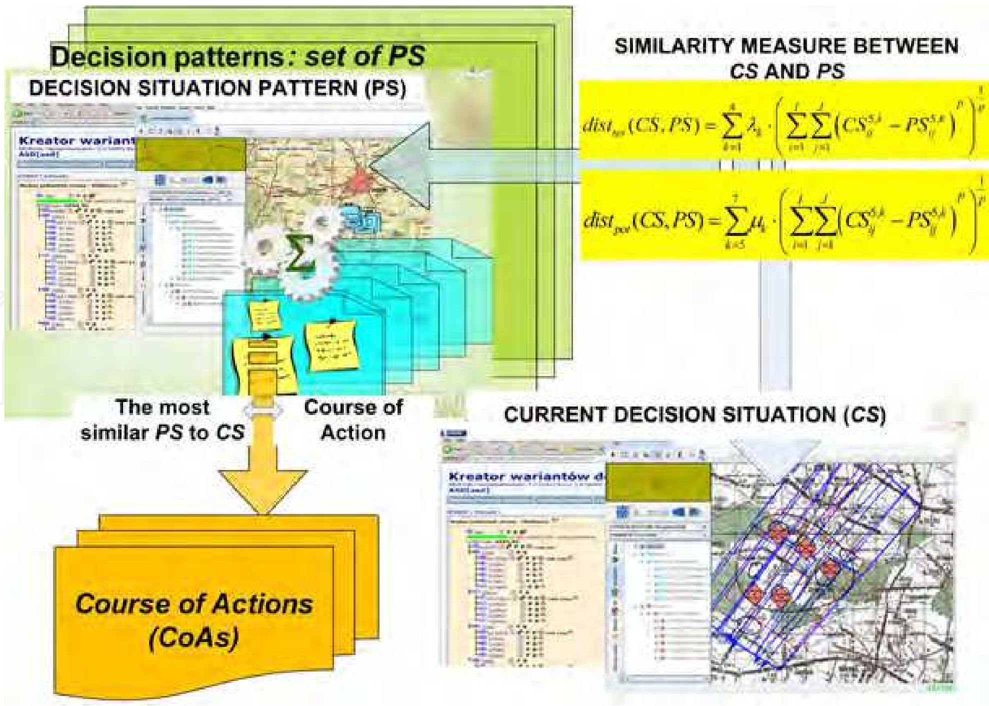

Fig. 6. The idea of identification of the decision situation and CoA selection

7. A practical example of using tool

The tool (called CAVaRS: Course of Action Verification and Recommendation Simulator) allows preparing knowledge base of decision situations patterns with values of characteristic parameters (Antkiewicz et al., 2011b). It also allows to fix the best (nearest) decision situation located in the knowledge base, choose (or create) the best CoA and simulate selected CoAs. The tool CAVaRS has been built at the Cybernetics Faculty of the Military University of Technology in Warsaw (Poland) and authors of this chapter are members of the team, which has created it. The CAVaRS may be used as a part of a Decision Support System (DSS) which supports C4ISR systems or it may work as standalone one. It models two-face land conflict of military units on the company/battalion level. The simulator is implemented in JAVA language as an integrated part of some system for CAXes. The model concerns a couple of processes of firing interaction and movement executed by a single military unit. These two complementary models use a terrain model, described by a network of square areas, which aggregates movement characteristics with 200m×200m granularity.

The example shows elements of knowledge base and the algorithm of the nearest pattern situation searching. The main element of the system is knowledge base which consists of Decision Situations Patterns (DSP). Each DSP is connected to the set of Course of Actions (CoA). The example of two DSPs and their CoAs are presented below.

The first DSP (Fig.7) is connected with two CoAs (Fig.9 and Fig. 10). The second DSP is shown in the Fig. 11. Parameters have been fixed for each DSP. Fig. 8 shows the analyzed area of the opposite forces. Parameters of each DSP are stored in the knowledge base. Finally, Table 2 and Table 3 show values of DSP parameters.

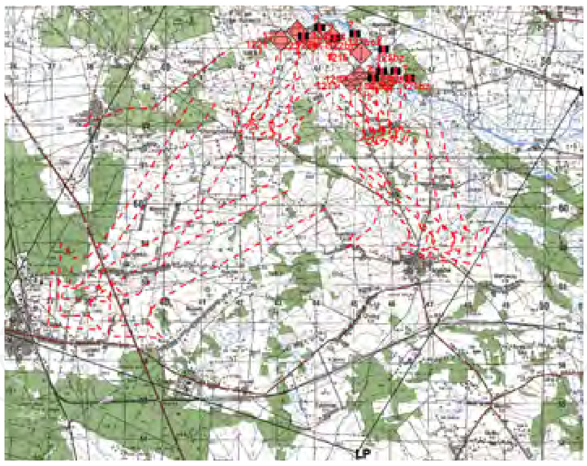

Fig. 7. Graphical representation of DSP 1

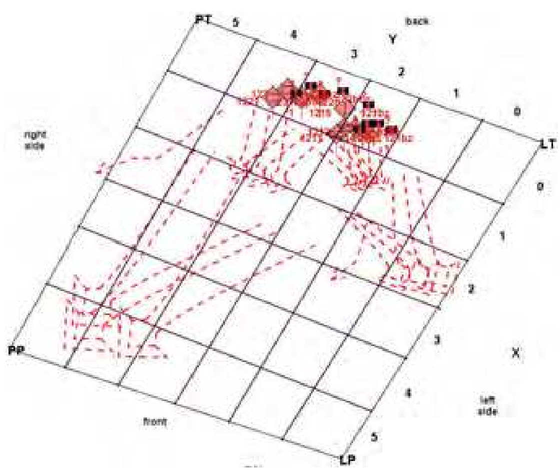

Fig. 8. DSP 1 – area of opposite forces

Coordinates of a terrain area for DSP 1 (NW: north-west corner, NE: north-east corner, SW: south-west corner, SE: south-east corner): NW (LP)=515556N 0213922E, NE (PP)=515740N 0213053E, SW (LT)=520056N 0214431E SE (PT)=520254N 0213541E.

Potential of own forces: mechanized 444; armoured 61.2; artillery 30; antiaircraft 0; other 0.

i	j	$SD_{ij}^{5,1}$	$SD_{ij}^{5,2}$	$SD_{ij}^{5,3}$	$SD_{ij}^{5,4}$	$SD_{ij}^{5,5}$	$SD_{ij}^{5,6}$	$SD_{ij}^{5,7}$
0	0	54%	1%	1%	0.069	0	0	0
0	1	44%	4%	1%	0.116	0	0	0
0	2	42%	15%	2%	0.186	0	17.46	94.13
0	3	45%	9%	4%	0.21	190	16.32	23.75
0	4	41%	8%	2%	0.252	80	5.2	0
0	5	42%	24%	1%	0.176	0	0	0
1	0	46%	23%	2%	0.12	0	0	0
1	1	54%	5%	1%	0.162	0	0	0
1	2	37%	15%	0%	0.231	0	26.98	140.8
1	3	47%	13%	0%	0.158	25	5.71	21.35

i	j	$SD_{ij}^{5,1}$	$SD_{ij}^{5,2}$	$SD_{ij}^{5,3}$	$SD_{ij}^{5,4}$	$SD_{ij}^{5,5}$	$SD_{ij}^{5,6}$	$SD_{ij}^{5,7}$
1	4	45%	10%	0%	0.177	25	1.62	0
1	5	35%	0%	34%	0.168	0	0	0
2	0	2%	0%	58%	0.096	0	0	0
2	1	7%	0%	54%	0.135	0	0	0
2	2	17%	0%	50%	0.183	0	0	0
2	3	11%	0%	38%	0.138	0	0	0
2	4	23%	0%	34%	0.162	0	0	0
2	5	51%	0%	29%	0.179	0	0	0
3	0	2%	0%	46%	0.168	0	0	0
...	...	...	...	...	...	...	...	...
5	5	25%	20%	0%	0.013	0	0	0

Table 2. Detailed values of DSP 1 parameters using notations from (2)

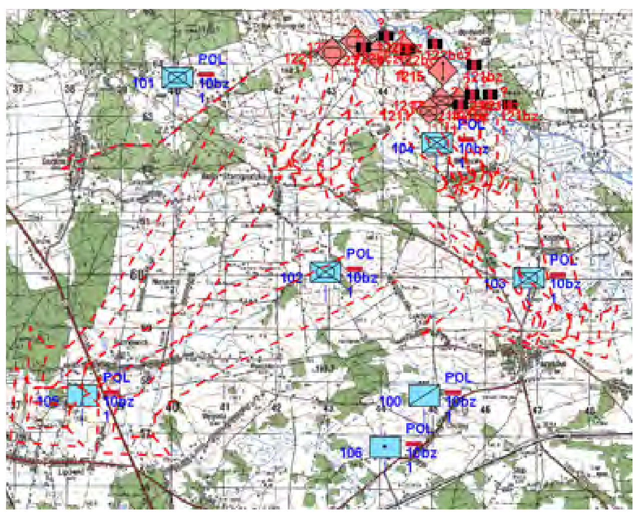

Fig. 9. Graphical representation of DSP 1, CoA 1

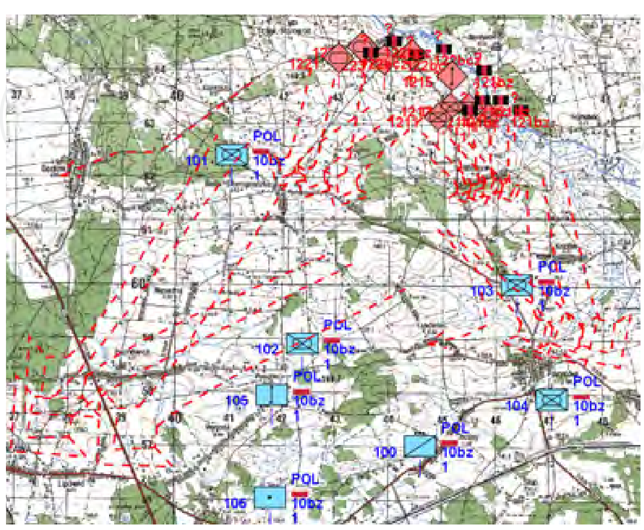

Fig. 10. Graphical representation of DSP 1, CoA 2

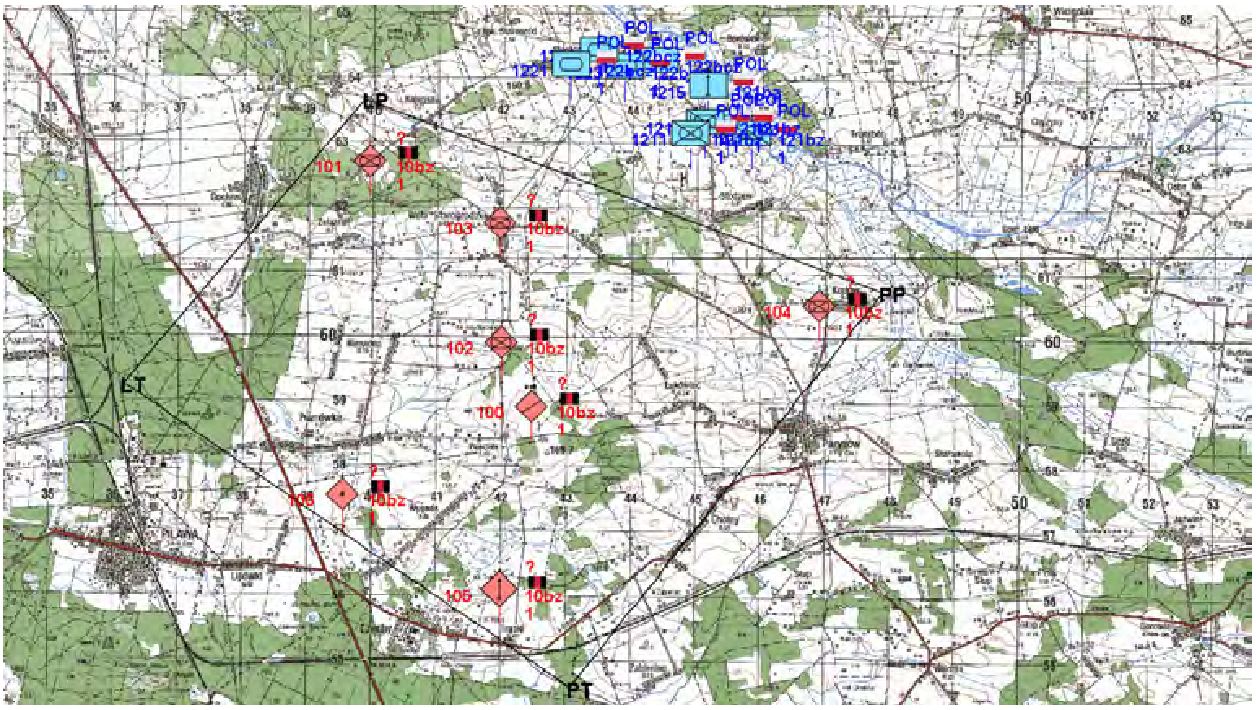

Fig. 11. Graphical representation of DSP 2

Coordinates of a terrain area for DSP 2 (NW: north-west corner, NE: north-east corner, SW: south-west corner, SE: south-east corner): NW (LP)=520120N 0213451E,

NE (PP)=515943N 0214150E, SW (LT)=515858N 0213135E, SE (PT)=515625N 0213736E.

Potential of own forces: mechanized 320; armoured 73.3; artillery 280; antiaircraft 0; other 0.

Each DSP parameter of the current situation (see Fig.12) were calculated. The algorithm for finding the most similar pattern situation compares current situation parameters with each DSP from knowledge base using the method described in section 3. As a result the DSP1 has been fixed according to the *dist* values (equation (8) and (10)) presented in Table 4 because: $dist_{pot}(CS,DSP1) < dist_{pot}(CS,DSP2)$ and $dist_{ter}(CS,DSP1) < dist_{ter}(CS,DSP2)$, hence DSP1 dominates DSP2 from the R_D (formula (13)) point of view.

i	j	$SD_{ij}^{5,1}$	$SD_{ij}^{5,2}$	$SD_{ij}^{5,3}$	$SD_{ij}^{5,4}$	$SD_{ij}^{5,5}$	$SD_{ij}^{5,6}$	$SD_{ij}^{5,7}$
0	0	29%	93%	0%	0.01	0	0	0
0	1	55%	48%	0%	0.06	0	0	0
0	2	91%	1%	0%	0.04	8.62	4.49	0
0	3	84%	10%	0%	0.04	5.38	2.81	0
0	4	84%	11%	0%	0.03	0	5.85	27
0	5	76%	30%	0%	0.01	0	0.65	3
...	...	...	...	...	...	...	...	...
2	2	88%	0%	0%	0.03	13	1.44	0
2	3	84%	10%	0%	0.05	60	6.55	0

i	j	$SD_{ij}^{5,1}$	$SD_{ij}^{5,2}$	$SD_{ij}^{5,3}$	$SD_{ij}^{5,4}$	$SD_{ij}^{5,5}$	$SD_{ij}^{5,6}$	$SD_{ij}^{5,7}$
2	4	59%	44%	0%	0.07	6	0.6	0
2	5	77%	12%	0%	0.06	0	0	0
3	0	66%	33%	0%	0.09	0	0	0
3	1	83%	4%	0%	0.04	0	0	0
3	2	88%	3%	0%	0.02	6.5	0.72	0
3	3	80%	7%	0%	0.08	32.5	3.59	0
3	4	82%	1%	0%	0.1	0	0	0
3	5	81%	0%	0%	0.12	0	0	0
4	0	40%	74%	0%	0.08	66.9	7.39	0
4	1	62%	43%	0%	0.06	32.7	3.61	0
4	2	85%	1%	0%	0.05	93.6	10.4	0
4	3	70%	22%	0%	0.09	0	0	0
4	4	69%	9%	0%	0.15	0	0	0
4	5	87%	4%	0%	0.05	18.9	2.09	0
...	...	...	...	...	...	...	...	...
5	5	85%	6%	0%	0.05	85.1	9.41	0

Table 3. Detailed values of DSP 2 parameters using notations from (2)

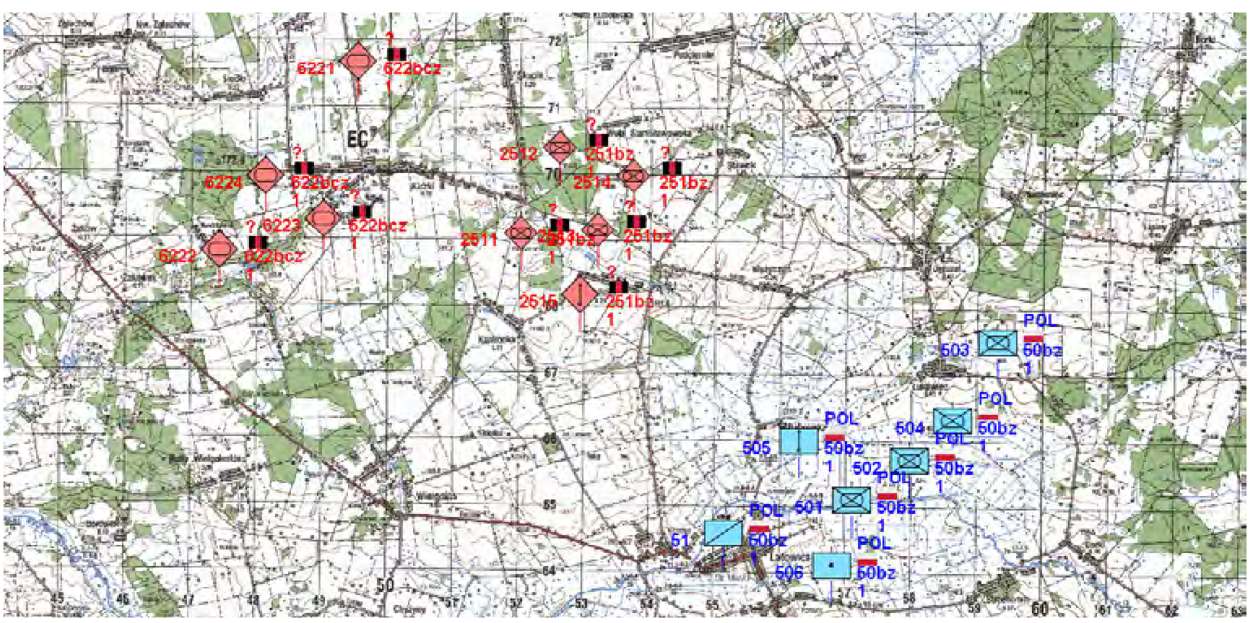

Fig. 12. Current situation (CS)

DSP	$dist_{pot}(CS, DSP)$	$dist_{ter}(CS, DSP)$
DSP1	203.61	1.22
DSP2	222.32	1.47

Table 4. Detailed values of dist parameters from (8) and (10)

8. Conclusions

In this chapter there was presented the problem of using the knowledge base tool for mission planning. The proposed tool (with knowledge base and pattern recognition method) was implemented and verified during the practical experiment. One of the most important problems is to prepare the knowledge base with decision situation patterns and CoAs for each decision situation pattern. The specialized tool for knowledge base management was created - it allows preparing decision situations patterns using GIS functions. The validation process of combat models is very complex, however it is possible to utilize such tools like simulation models calibrator and expert knowledge (Dockery & Woodcock, 1993; Hofmann & Hofmann, 2000; Przemieniecki, 1994). The construction of the simulation model enables testing of different courses of actions including concepts in the area of Network Enabled Capabilities (Moffat, 2003).

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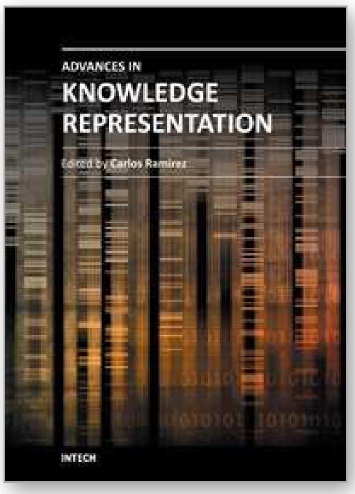

Advances in Knowledge Representation

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