

Situation Analysis and Performance Measurement: Application to Personnel Recovery

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Abstract – *In this paper we present a review Search and Rescue (SAR) performance measurement basic concepts. We also propose a formal framework for representing and measurement in a coalition setting, while proposing precise definitions for the following concepts: situation, situation awareness, context, mission and ability to perform an action. A prototype software, QUALIPSO, is also briefly presented. Further work includes the publication of formal definitions for the main SAR measures of performance as well as results based on simulations.*

Keywords: Personnel Recovery, Search and Rescue, Coalition, Modeling, Performance Assessment, XML transformation.

1 Introduction

In the following section we introduce the basic definitions and terminology relative to Personnel Recovery (PR) in general and Combat Search and Rescue (CSAR). Basic definitions related to performance criteria, measures and factors are also given.

Not all countries are equipped with specialized PR resources. For instance Canada has no Special Operations resources dedicated to this task and shall in theatre rely on allied nations. Since the UK and USA have well documented practices, techniques and doctrine for PR and CSAR the present document will often refer to this material. According to [1], “Joint Personnel Recovery (JPR) is the aggregation of military, civil and political efforts to obtain the release or recovery of personnel from uncertain or hostile environments and denied areas whether they are captured, missing or isolated. JPR includes Search and Rescue (SAR), Deployed Search & Rescue (DSAR), Combat Recovery (CR), Combat Search and Rescue (CSAR), Special Forces operations such as Unconventional Assisted Recovery (*i.e.* hostage rescue) and associated

Survival, Evasion, Resistance and Extraction (SERE) training, and Care After Recovery (CAR). This represents a broad span of different types of operation covering a disparate group of missions, roles and tasks but consolidated into a single and coherent spectrum covering a number of parameters, the principal ones being location and threat”.

Of particular interest here is the effect of threat and by consequence its effect on the type of operation to conduct. As it will be seen below in all Personnel Recovery Operations (PRO) the influence of the environment is a major factor to consider. Reading Figure 1 one can see that from left to right the environment becomes less and less neutral, ultimately actively attempting to disrupt the recovery mission.

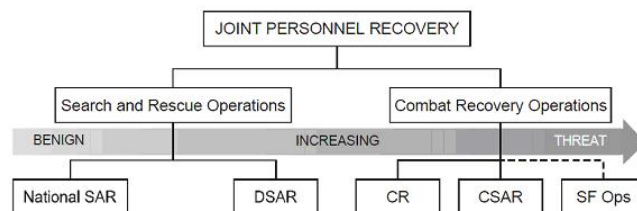


Figure 1: Spectrum of Joint Personnel Recovery [1].

According to [2], CSAR is a specific task performed by rescue forces aimed at the recovery of distressed personnel during war or Military Operations Other Than War (MOOTW). Each service and United States Special Operations Command (USSOCOM) is responsible for conducting CSAR in support of their own operations while Joint CSAR operations are requiring the involvement of two or more Joint forces components. According to several US publications the five essential tasks in PR operations are to report, locate, support, recover and reintegrate the isolated or missing personnel. For the US Air Force CSAR is the preferred mean of intervention in uncertain, denied or hostile environments. In

[3] the five essential tasks are defined as follow:

Report- Awareness and notification initiate the PRO process. Rapid and accurate notification is essential for a successful recovery.

Locate- Some of the methods used to locate IP include: theatre electronic surveillance, reconnaissance, command and control (C2) aircraft, global satellites, wingman reports, and visual search by PRO forces. Even with precise coordinates that can pinpoint the isolated person’s location, PRO forces still have to authenticate the isolated person’s identity prior to facilitating successful support and recovery operations.

Support- Support is the planned effort necessary to ensure the physical and psychological sustainment of IP. Support may also encompass the suppression of enemy threats to the IP.

Recover- This task reflects activities by commanders, staff, recovery force, and IP to physically recover the IP. This includes the planning as well as execution phases. By their very nature, PROs are time-sensitive undertakings. Ideally, PRO will be able to bring the isolated personnel under the control of the recovery force in less than two hours; this is a goal, not a strict requirement.

Reintegrate- The reintegration task begins when the recovery force relinquishes physical control of previously isolated personnel to a designated team member or organization in the theatre reintegration process.

It is interesting to note that PR operations include in the Reintegrate task, elements of post-operations knowledge management, whereas typically this is not part of the typical time line of Search and Rescue (SAR) operations. This is the reason why we have added a debriefing time interval to the classical time line used by Christopher [4] in Figure 3.

2 The CSAR mission in a coalition context

We describe below a coalition based CSAR scenario that has been chosen to discuss team related performance criteria and measures.

2.1 A typical CSAR mission

Figure 2 illustrates a CSAR mission where the communication links between the key actors appear: The Isolated Personnel (IP), here called the survivor, the Joint Search and Rescue Director (JSRD) in charge of planning the mission and assigning the resources, the Airborne Mission Commander (AMC) directing in this example the mission from an AWACS. To make this communication network more complete, diplomats (including high ranking state officials) and civilian organizations could be included. Physically these actors can

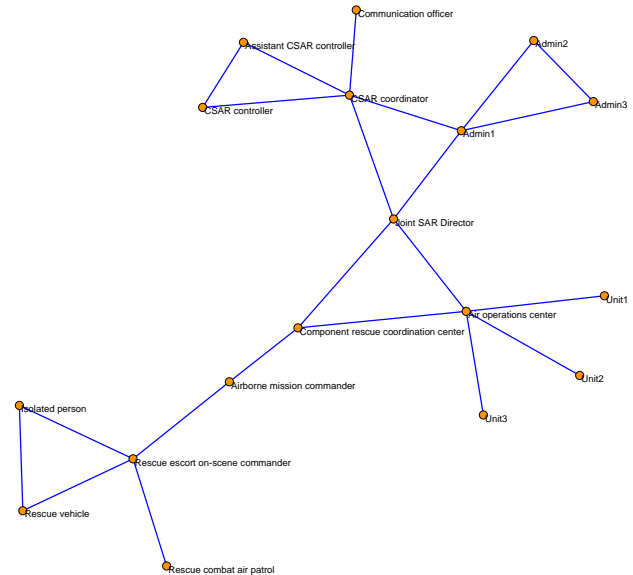


Figure 2: Communication links between the main actors for a typical CSAR mission.

be co-located or not, fixed or mobile depending on the case.

2.2 Coalition context

As described in [5], following the notification of the incident the situation is evaluated according to the associated IP recovery risk (position and lethality of enemy troops with respect to location of the incident, for example). In a first step the unit concerned with the incident evaluates its own ability to accomplish successfully the mission. If the evaluation is positive, the mission is conducted at the unit level, if negative the case is transferred at the unit’s component Rescue Coordination Center (RCC), Joint Rescue Coordination Center (JRCC) or coalition level for further assistance.

At the coalition level a Multinational Search and Rescue Center (MSRC) can be established formally. Risk and ability evaluation appears thus to be at the heart of preoccupations in operations handled in joint and coalition PR operations. Related work as been presented in [6, 7].

3 Performance assessment in JPR operations

Joint Personnel Recovery is very complex type of operation for which performance shall be assessed in order to help establish and define standards. More formally according to [2] a **standard** for a task “provides a way of expressing the acceptable proficiency that a joint organization or force must perform under a specified set

of conditions. A standard consists of one or more measures for a task and a criterion for each measure”. A **measure** provides the basis for describing varying levels of joint task performance. A measure is directly related to a task. A **criterion** defines acceptable the minimum acceptable level of performance associated with a particular measure of task performance. It is often expressed as hours, days, percent, occurrences, minutes, miles, or some other command stated measure. According to [2] the development of measures and criteria should obey the principles of Table 1.

Table 1: Principles for criteria and measures development [2].

Simple
Reflect an understanding of a task
Reflect how a task contributes to mission success
Sensitive to the impact of conditions on task performance
Reflect the key dimensions of task performance
Distinguish among multiple levels of performance
Focus on the outputs, results of performance, or on the process to achieve the task
Take advantage of the strengths of both absolute and relative measurement scales

More specifically, according to Christopher [4] the performance indicators for SAR shall (i) allow to identify current level of performance (ii) support comparison with past performance (iii) permit analysis for early warning of changes and trends (iv) support specification of/comparison with SAR goals and standards (v) provide support for SAR planning and decision-making.

3.1 Typical time line of SAR operations

Figure 3 depicts the typical time line of a SAR incident¹. The following time points identify specific ac-

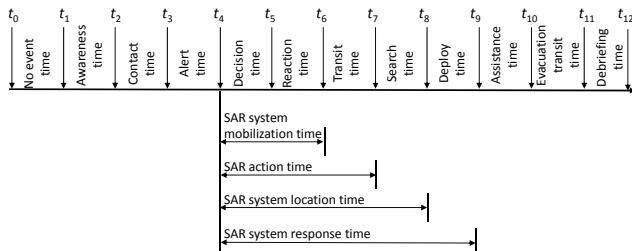


Figure 3: Typical search and rescue operations time line. Modified from [4].

tions of events taking place: (t_0) Last known position (LKP); (t_1) Incident occurs, start of SAR operation;

¹In the following the performance measures will only be presented for the time intervals for which DND has jurisdiction and responsibility, *i.e.* once a Rescue Coordination Center (RCC) is notified. This time line is consistent with the one identified in the Cross Commission Report (Canada), the only difference being what we call here Debriefing time, explained below.

(t_2) Responsible agency notified; (t_3) Alerting post notified; (t_4) RCC notified; (t_5) SAR resource tasking; (t_6) SAR resources departs; (t_7) SAR resource arrives on-scene; (t_8) Location of SAR object; (t_9) Commencement of aid; (t_{10}) On-scene assistance completed; (t_{11}) SAR resources released; (t_{12}) Participants debriefed and post-mission information logged.

3.2 Performance indicators for SAR

Following Christopher’s survey [4] it is possible to draw a taxonomy of the main performance indicators shown in Figure 4 and described below. It is important to note that this taxonomy can be extended principally in three different ways:

- By detailing furthermore the time line or similarly the operations taking place in a given interval of time.
- By singling out specific components of the SAR system, such as the knowledge management capability.
- By taking into account the fact that groups of agents are in fact interacting to accomplish a SAR mission. Thus the SAR performance indicators shall also include the team or coalition dimension.

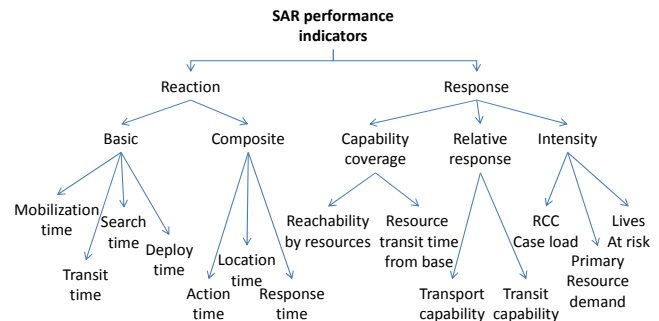


Figure 4: Taxonomy of performance indicators (drawn from [4]).

3.2.1 Reaction capability

Basic Measures - Mobilization Time: It is the time between Alerting post notified at t_4 and the time at which the first SAR resource is launched to reach the incident site, *i.e.* t_6 . Factors influencing this measure are: Incident validation procedure, resource readiness, preparation and launch time, resource availability. **Resource Transit Time:** This is the time between the launch of the first SAR at t_6 and the time of its arrival on-scene at t_7 . Factors influencing this measure are: Resource speed and endurance, case geographic

distribution, base location, refueling locations, weather capability. *Search Time*: This is the the time from the arrival of the first resource on-scene at t_7 until the SAR object is located at t_8 . Factors influencing this measure are: Resource search capability, environmental characteristics, search procedures, ELT assistance, fleet size and availability. *Rescue Deploy Time*: This is the time interval between the location of the SAR object at t_8 to the start of assistance being provided at t_9 . It is an indicator of the adequacy of resource capacity to deploy SAR technicians and equipment. Factors influencing this measure are: a/c deployment capability and system response capability.

According to [8] search effectiveness must take into account the following factors: (i) Search area covering time, (ii) Target confirmation time, (iii) Target confirmation time, (iv) Call-around time, (v) Time lost due to missed target, (vi) Time lost due to reduced visibility, (vii) Data processing time.

Composite Measures - For these composite measures, the same factors influencing the basic measures will have an effect. *System Action Time*: This is the time from RCC notification at t_4 until the first resource arrives on-scene at t_7 . It serves as an indicator of the time required to arrive on-scene upon RCC notification. *System Location Time*: This is the time from RCC notification at t_4 to the SAR object being located at t_8 . It is an indicator of the time required to locate the search object upon RCC notification. *System Response Time*: This is the from RCC notification at t_4 to the start of assistance being provided at t_9 . It is an indicator of the time required to provide medical assistance upon RCC notification.

3.2.2 Response capability

This capability is important for the identification and elimination of gaps and weak areas in the rescue system and the demands placed upon it.

Coverage - *Coverage Overlay Maps*: This is a map showing the total area of DND responsibility with an overlay displaying the total area that can be searched by DND resources considering factors such as platforms limitations, flight regulations, and refuelling location availability. Factors influencing this measure: resource endurance, base locations, refuelling locations. *Time Contour Maps*: This a map related to the coverage map showing time contours indicating that ideal transit time to arrive at the contour locations considering factors such as platforms limitations, flight regulations, and refuelling location availability. Factors influencing this measure: resource speed and endurance, base locations, refuelling locations.

Relative Response Capability - These indicators are derived from past incident occurrences. *Transit capability*: This is the proportion of SAR incidents that are within resource rescue range from the nearest refuelling. Factors influencing this measure: case geographic distribution, resource endurance, base refuelling locations. *Transport Capability*: This denotes the proportion of incidents where all the lives at risk could be transported in a single sortie. Factors influencing this measure: case lives-at-risk distribution, resource transport capacity.

Intensity - *RCC Case Load*: The total number of SAR incidents that the Rescue Coordination Center (RCC) dealt with during the course of the year. Factors influencing this measure are the number of SAR incident by category and the demand on RCC operation. *Primary Resource demand*: The number of SAR incidents during the year which involved DND primary SAR resources. Factors influencing this measure: demand on primary DND SAR resources. *Lives at risk*: The total number of lives that were at risk in the SAR incidents where DND primary SAR resources were involved. Factors influencing this measure are the demands on DND SAR response and the importance of DND SAR response.

3.2.3 Selection criteria

According to [4] the reaction time is a critical in the SAR process to save lives and accordingly the latter shall guide the choice of performance indicators. The same author also notes that the selected performance criteria shall allow to identify gaps and weak areas in SAR coverage and limits of resource response capability. The performance indicators shall also allow to identify when changes are beginning to occur in the SAR system.

4 Situation analysis and performance measurement

Basically, our standpoint is that any formal framework for the measurement of performance shall include precise definitions for and distinguish between the notion of situation and context. The notion of a *mission* is central if one aims to assess measures of effectiveness. A clear formal notion of *situation awareness* is necessary in the CSAR context, due to the importance of risk assessment in the decision cascade discussed in Section 2.2, as well as a precise definition of *ability* since this notion is used to assess the expected capacity of a team to successfully accomplish a mission or simply to request assistance from other teams of agents or organizations.

4.1 Situation analysis

In [9], we provided formal definitions of situation, situation analysis and situation awareness in the framework of the interpreted systems semantics, introduced by Fagin *et al.* in [10]. We recall here the main components.

\mathcal{A} is a set of $n + 1$ agents including the environment. To each agent i is associated a set ACT_i of actions for which this agent is competent. Each agent i is supposed to perform actions through a predefined protocol P_i which is a mapping from local states L_i to ACT_i . L_i is a set of possible local states. l_i is a particular local state for i encoding all the information the agent has access to. The execution of the joint protocol $P = (P_1, \dots, P_n)$ by the n agents into a *context* $\gamma = (P_e, S_0, \tau, \Psi)$ which includes the protocol of the environment P_e , a nonempty subset of initial states S_0 , a transition function between states τ , and an admissibility condition on runs Ψ , defines what we called a *situation* [9].

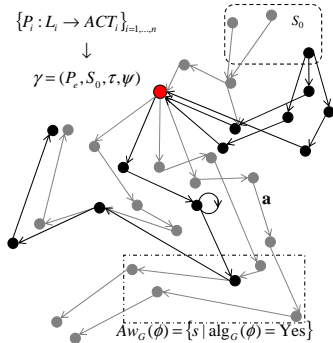


Figure 5: The execution of a joint protocol $\{P_i\}$ by the agents of the coalition in a context γ defines a transition state system, that we call a *situation*.

A situation is thus defined in terms of a transition state system whose nodes are global states and arcs are labeled by joint actions (see Fig. 5). *Situation analysis* is then the process by which the decision maker (or analyst) reaches a state of situation awareness which will then allow her (or him) to make decisions.

Finally, *situation awareness* is defined in terms of computational capability, such that an agent is aware of a given formula ϕ if she (or he) can compute its truth value before time t . Situation awareness is provided by test evaluations on observations about the environment (the objective state of the world). To perform such computation (truthfulness evaluation), each agent is assumed to have a local algorithm alg_i in its local state, which answers “Yes” if it finds that ϕ is true, “No” if it finds that ϕ is false and “?” if it is unable to answer. Situation awareness is thus defined in terms of states, *i.e.* the larger is the set of states in which the

agent has evaluated ϕ as true or false, the more aware it is.

Additionally, some notions of group knowledge (or equivalently of belief or awareness) can be formally defined (see [9] for details) for a group $G \subseteq \mathcal{A}$ of agents: Someone knows, everybody knows, distributed knowledge, common knowledge. These notions will be used for coalition assessment (see Section 5.4).

4.2 Coalition and ability

A *coalition* is defined as a tuple $\mathcal{C} = (\mathcal{K}, \mathcal{M})$ where \mathcal{K} is an institutional agent to which is assigned the mission \mathcal{M} [7]. The roles played by institutional agents in \mathcal{K} are those of *member* denoted $member(\mathcal{K})$, *organiser* denoted $organizer(\mathcal{K})$, or simply *actor* denoted $actor(\mathcal{K})$. In this last case actors can be institutional or not. The mission \mathcal{M} assigned to a group of agents \mathcal{A} (a coalition) is described as a complex action together with of a set of possible actions *Actions*, a set of temporal relations \mathcal{T} allowing to order actions, a set \mathcal{D} describing the world dynamic in terms of actions and states, under the form of $\langle preconditions \rangle action \langle postconditions \rangle$ [7].

From the primitive notion of *competence*, we used in [7] the notions of *theoretical ability* and *ability* for a non-empty set of agents $G \subset \mathcal{A}$ (possibly a singleton) and a primitive action \mathbf{a} [11], stating that the group of agents G is *theoretically able* to perform \mathbf{a} if G is competent to perform \mathbf{a} and some conditions related to the agents of G are true. And, G is *able* to perform \mathbf{a} if G is theoretically able to perform \mathbf{a} and \mathbf{a} is possible.

4.3 CSAR mission performance assessment

The performance indicators (Section 3) involving time can be computed as path lengths in the state transition graph (the situation), the arcs being weighted by the action times.

5 QUALIPSO prototype

As part of a bilateral research agreement between the Defense Departments of Canada and France, DRDC-Valcartier (Canada) and the Département de Traitement de l’Information et Modélisation (DTIM) ONERA-Toulouse (France) teamed on the development of a software prototype (QUALIPSO) aimed at the study of SAR performance measurement in coalitions. The ONERA-Toulouse was in charge of its actual development.

5.1 Principles

To meet some interoperability concerns and to match an open approach, the whole prototype has been developed using XML technologies with the aim of being integrated with some existing tools (*e.g.* a mission

simulator). QUALIPSO’s data model relies on a XML schema definition [12], its scenario description relies on XML schema instances [12], measures are performed as computations on XML transformations [13] and finally even visualisation is guided by XML stylesheets [13].

5.2 Data Schema

The scenario description schema has been generated from a UML modeler diagram to a XML schema definition file. All the needed concepts have been first

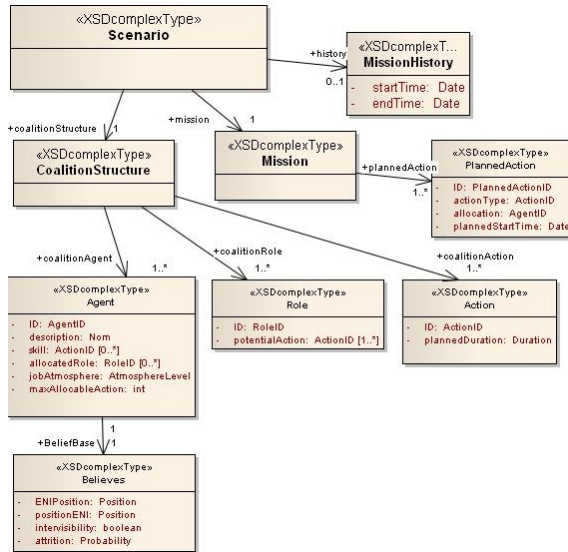


Figure 6: Scenario Data Model (UML).

identified, then most of their attributes have been created or modified when the measure definition emphasized this need. The result is a Scenario snapshot definition as three main sub-concepts: the **Coalition-Structure**, the **Mission**, and a **MissionLogs**. These sub-concepts are further recursively detailed (for instance the **CoalitionStructure** contains the **CoalitionAgents**, the **CoalitionRoles** and the **Coalition-Actions**) until sufficient level of detail is reached (see Figure 6).

5.3 Scenario description

A scenario describes a team of agents involved in a SAR mission. This team is structured with roles which are affected to agents (a leader, a pilot, 2 soldiers, a medic). Roles are characterized with the actions in their scope (*e.g.*, for the “soldier” role, to rescue and to neutralize). Actions are specified with their scheduled duration in relation with Figure 3. Agents are described with the actions they are skillful for, their role, and their set of beliefs. The mission is defined as

a plan composed of high level actions, each of them being affected to one agent of the team, with a scheduled temporal window to perform it.

5.4 Performance measures for coalitions

Table 2 provides the measures that have been implemented. They are restricted to the measures that may be used for a coalition assessment overview by ag-

Table 2: Measure definitions

Situation Assessment homogeneity	
Informal	Distance between agent believes about the situation, evaluated among all agents
Formal	100× the average of distance between believes of pairs of Agents involved in the StructureDeCoalition (see Listing 1)
Leader skill level	
Informal	Ratio of actions which are mandatory to play the role of leader for which the agent playing this role is identified as skilled.
Formal	let RA be set of actionPotentielle defining the leader Role let AC be the set of actions for which the Agent has Competences Value: 100× the cardinal of the intersection between RA and CA divided by the cardinal of RA
Mission efficiency	
Informal	Ratio of the sum of planned action durations divided by the real mission duration (mission end date – mission start date)
Formal	100× the sum of dureePrevue of ActionPlanifiee of the Mission divided by (dateDeFin – dateDeDebut)
Agent functional load optimality	
Informal	Percentage of agents whose individual functional load value lies between 70% and 90%. Individual functional load being the ratio of the number of actions allocated to an agent during the mission divided by the maximum number of actions that can potentially be allocated to him.
Formal	let IAFL be the ratio of the number of ActionPlanifiee for which the Agent has been given an affectation in the context of the Mission divided by maximum number of actions which can be allocated to her (nombreMaximumActionsAffectables) Value: Percentage of Agent for whom IAFL has a value lying between 0.7 and 0.9.
Agent temporal load optimality	
Informal	Percentage of agents whose individual temporal load value lies between 70% and 90% Individual temporal load being the ratio of time during which the agent has something to do divided by the whole mission time
Formal	let IATL be the ratio of the sum of dureePrevue of Action for which the Agent has been given affectation divided by the real mission duration. Value: percentage of agents for whom IATL has a value lying between 0.7 and 0.9.

gregation. For each of these measures, two definitions are mentioned. The second one, referred to as formal, uses the concepts from the scenario data schema to define the measure computation. Elements taken from the data model are emphasized using bold face in the definition.

The measure of Situation Assessment Homogeneity is a measure of distributed knowledge (or belief) as men-

tioned in Section 4.1. Measures of Mission Efficiency and Agent Temporal Load Optimality are concerned with time ratios between the Transit and Debriefing phase (t_6 and above in Fig. 3).

To produce a valuable synthetic result, all integrated measures must be: **numerical**, *i.e.* the measure values must be (or at least must be matchable with) numerical values ; **uniformly sized**, *i.e.* the units of the measures have to be the same ; **uniformly directed**, *i.e.* the higher the measure value is, the better the coalition is.

Based upon the previous single measures definitions, two kinds of global performance measures have been defined following either numerical or graphical approaches. Global measures are useful to give users global images of coalition performances and to compare coalitions performances. However they only make sense if the aggregated measures verify the three “aggregability” constraints mentioned above ; more precisely the three constraints are mandatory for numerical approach to make sense and are strongly recommended for the graphical approach for usability concerns.

On a graphical spider view (Fig. 5.4), it is usually expected that a very good result is a large circle, while having a measure based on a lower-is-better meaning will lead to a very good result looking like a “Pacman”. Comparison between two coalitions also becomes far less intuitive by having to observe parts of the area representing the result including the other candidate area while other parts should be included in it. This gives means for users to visually get and understand comparisons of coalitions performances.

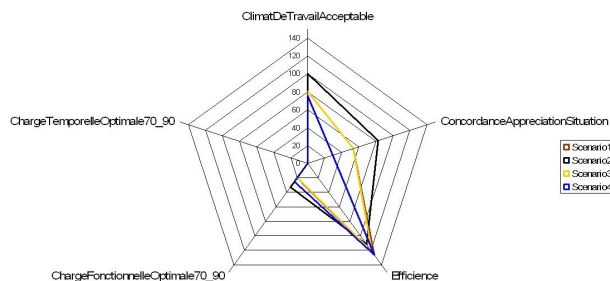


Figure 7: Graphical global measures of performances.

Numerical performance global measures may be defined with weighted average of single measures results, weights values reflecting users’ choices about measures relative importance in the aggregation process. The result is then a number which enables users to quickly compare coalitions global performances, but which “forgets” information coming from single measures, hence eliminating the opportunity to explain or understand finely the result.

On the other side, graphical global measures may be defined supported by classical statistical tools; their results keep trace of single measures results, so they are more suitable to adjust coalitions parameters in order to improve performance, even if they do not directly produce a total performance order between compared coalitions. Weights can be reflected on the axis scales to emphasize variations on the most weighted measures.

As already stated, measures are seen as a target meta-model (the scenario snapshot description being the source one) and consequently the XML Transformation language has been used to implement the measure computation. SaxonB is then used as the computation engine.

From the formal definition of a measure, a rather direct translation is made to XML transformation, as shown for example of the *situation assessment homogeneity* measure in Listing 1. A similar principle is then

```

\scriptsize
/*
  agentCount: the number of agents
  beliefCount: the number of agents' believes
  agent      : the vector of agents
  belief     : the vector of belief (by agent)
*/
nbMatch:= 0
for a:= 1 to agentCount
  for b:= a+1 to agentCount
    for i:= 1 to beliefCount
      believes by agent
      if agent[a].belief[i] = agent[b].belief[i]
        then nbMatch:= nbMatch+1
      endif
    endfor
  endfor
endfor
MatchRatio:=  $\frac{nbMatch}{beliefCount \times C_{agentCount}^2}$ 

```

Listing 1: Situation Assessment Homogeneity computation

used to implement numerical global aggregation measures. Two data sets are then used as entry: single measures results and users’ weights on her selection of measures.

5.5 Scenario analysis results

In order to try and adjust a coalition parameters and improve its performance, users may create an initial coalition scenario. One idea is then to slightly modify values for some data of this initial scenario, to get variants for it: For example, by adding or removing some agents in the coalition structure or modify their functional capacity, or by modifying some characteristics of the mission the analysed coalition has to cope with (actions durations, precedences order between actions, etc). One can use single performance measures and global measures for all variants of the initial scenario,

SituationAwareness
SituationAssessmentHomogeneity = 53 %
SkilledLeader
LeaderSkills = 100 %
MissionDuration
RealDuration = PT3H50M
SequentialPlannedDuration = PT4H50M
RealPlannedDurationRatio = 79.310344827586206897 %
Efficiency = 126.086956521739130435 %
AgentLoad
GlobalFunctionalLoad = 52.333333333333336 %
AllocatedAgentFunctionalLoad = 65.41666666666667 %
RealGlobalTemporalLoad = 25.217391304347828 %
PlannedGlobalTemporalLoad = 20 %
RealAllocatedAgentLoad = 31.52173913043478 %
PlannedAllocatedAgentLoad = 25 %
FunctionalOptimalLoadRatio = 20 %
TemporalOptimalLoadRatio = 0 %

Figure 8: Scenario analysis results

and then manually analyse results of comparisons. Figure 8 shows such a graphical global comparison for a scenario and its 3 variants; this diagram is here based upon the five single measures of Table 2.

6 Conclusions

We presented in this paper a review Search and Rescue performance measurement basic concepts. We have also proposed a formal framework for specification and measurement in a coalition setting, while proposing precise definitions for the following concepts: situation, situation awareness, context, mission and ability to perform an action. A prototype software, QUALIPSO, has also been briefly presented. Further work include the publication of formal definitions for the main SAR measures of performance as well as results based on simulations. Such an approach could also be used to enable users to evaluate the advantage for coalitions of using some new designed tools - such as Common Operational Picture tools - or to help to suggest trends of improvement for them.

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