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ESTIMATING PERFORMANCE OF A BUSINESS PROCESS MODEL

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ABSTRACT

In this paper we suggest a model for estimating performance of human organizations and business processes. This model is based on subjective assessment of the capabilities of the available human resources, the importance of these capabilities, and the influence of the peripheral factors on the resources. The model can be used to compare different resource allocation schemes in order to choose the most beneficial one. We suggest an extension to Business Process Modeling Notation (BPMN) by including performance measure of performers and the probability by which an outgoing Sequence Flow from a Gateway is chosen. We also propose an analytical method for estimating the overall performance of BPMN in simple cases and a simulation method, which can be used for more complicated scenarios. To illustrate how these methods work, we apply them to part of a military Operational Planning Process and discuss the results.

1 INTRODUCTION

Human organizations are complex and dynamic webs of humans and other resources that are composed to solve specific tasks according to defined rules and regulations and are subject to constraints such as number of personnel and financial resources. The task to measure performance of organizations is a challenging one and it is not possible to define a universal measure of performance, which is applicable to all organizations or even all processes in a single organization. For instance, while in a business enterprise the company's revenue or profit build the natural measure of performance, in a political party, number of members or votes in an election may be defined as the measure of performance for the party organization.

In a governmental organization like military staff the outputs of the system are decisions and plans. It is clear that a plan or a decision has not a measurable value and the ultimate measure of performance for any decision or plan is how it succeeds and to what degree the desired effects are achieved. A consequence of this observation is that any process improvement and optimization of organization should consider the influence of organization changes on the final outcome of the actions. However, measuring the success of a plan is an elusive task and it is difficult to relate this measure with changes in the organization. Despite this fact, decision makers try to improve the outcome of organizations by reasoning about the the characteristic and qualities of employees. They try to employ qualified personnel, improve the capabilities of the personnel by training and education, and optimize the business process by assigning tasks to employees who are best qualified to perform them. We consider the quality of the output of an organization as a measure of performance of the organization. It is reasonable to assume that given a set of human resources, different configurations of these resources yield varying quality of the outputs, depending on how these resources are utilized. A business process in which human resources perform tasks that best fit their capabilities can produce high-quality outputs. The aim of this paper is to present a decision support method for decision makers to efficiently organize human resources in a business process.

2 RELATED WORK

Measuring human performance is generally more difficult than measuring performance of non human systems because of the versatility of individual characteristics and unpredictable nature of human beings. Individual characteristics like cognitive ability, motivation, mental models, expertise, experience, creativity and mood all have critical impacts on the performance of individuals and thereby performance of the organization. Below, we consider three types of related work that have studied human performance from different contexts and disciplinary perspectives.

2.1 Human Performance Modeling

Human Performance Modeling (HPM), which is mainly concerned with developing models of human reliability and performance, e.g. in flight control systems and nuclear power industry is celebrating its 50 years anniversary. While there has been much progress in the field since the first known publication (Tustin 1947), there is still no generic model of human performance available. According to Pew (2008) models developed so far work well for the conditions under which they were initially developed but cannot manage even mild extensions of operating conditions.

Research in the HPM considers various aspects of human capabilities, sensing ability, perceptual information processing, cognitive information processing, and motor system, while our focus is mostly on processes in which problem solving, decision making, and planning is the primary task. Therefore, we found the field of organizational behavior and human decision processes to be a good source of knowledge.

2.2 Organizational Behavior and Human Decision Processes

A great amount of research work in this field has been focused on how people as individuals and groups process information, solve problems, and act in organizations. Problem solving is the act of finding a way to proceed from a given state to a desired goal state. Problem solving is considered to be one of the most complex human functions and consists of the five steps: (i) problem definition and formulation, (ii) generating alternative solutions (iii) decision-making and choosing one of the alternatives (iv) implementation of the solution (v) evaluation of the solution. In many cases these steps are iteratively repeated.

Problem solving ability is highly correlated with reasoning, which is part of human cognitive ability and is defined as the process of drawing conclusions from facts (Wos et al. 1984). The input of this process is the existing knowledge, facts, and premises and the output is prediction of an event or explanation of a phenomenon.

Problem solving in many organizations are explained by *commonsense reasoning*, the sort of reasoning people perform in daily life. The field of Artificial Intelligence has been trying to invent ways to automate this type of reasoning since John McCarthy coined the term, however this feature is still reserved for human beings. Commonsense reasoning is a process that involves taking information about certain aspects of a scenario in the world and making inferences about other aspects of the scenario based on commonsense knowledge (Mueller 2006).

A characteristic related to the reasoning that governs the performance in problem solving is *creativity*. Creativity is a process that involves bringing something into being that is original (new, unusual, novel, unexpected) and also valuable (useful, good, adaptive, appropriate) (Howard-Jones 2002). Experiments show that creativity-enhancing process employed either manually or delivered via computer software affect the level of creativity in response to problem-solving tasks (Marakas and Elam 1997). However, creativity is not an isolated individual characteristic and is highly correlated with other aspects of a process.

The relationship between mood and creativity is discussed by Davis (2009) and a contextual perspective of mood-creativity relations is supported. While the research is not conclusive it is mainly believed that positive moods in an organization facilitate creativity and negative moods can inhibit it.

Due to stimulating effects, membership change in groups enhances the creativity of groups (Choi and Thompson 2005). This beneficial effect is believed to depend on the fact that the groups that experience membership change on a regular basis are typically more focused on their task than those that do not experience such a change. Secondly, membership change can diversify a group's knowledge-base via the infusion of new ideas, perspectives, and information. Experiments conducted by Choi and Thompson (2005) show that "open groups" in which group members are randomly replaced by newcomers enjoy a higher performance.

Even though collectivistic values in current research in organizational behavior are generally recommended since they promote cooperation and productivity, Goncalo and Staw (2006) highlight the impact of individualistic values and suggest that individualistic values may be beneficial, especially when creativity is the most important goal.

Risky decision is defined as a decision situation where the probability distribution of the outcomes are available, while ambiguity situation is when this distribution is unknown, i.e. there is an "uncertainty about the uncertainty" (Ellsberg 1961). A model to explain when human decision makers prefer risky decision and ambiguous decision is provided by Lauriola, Levin, and Hart (2007). According to this model there are two types of decision makers. Risk-averse decision makers prefer a certain option to any risky prospect whose expected value is equal to or greater than the certain consequence. On the other side, decision makers with risk-seeking attitude prefer the risky prospect over its certainly equivalent. In the same manner there is an intrinsic individual factor that makes decision maker ambiguity-avoiding or ambiguity-seeking. It is shown by Lauriola, Levin, and Hart (2007) that there is a positive correlation between these two preferences, i.e. risk-seeking people are more ambiguity-seeking and vice versa. The same applies to risk-averse and ambiguity-avoiding people.

Intuition suggests that having more information can increase prediction accuracy of uncertain outcomes. However, in a series of experiments Hall, Ariss, and Todorov (2007) show that contrary to this belief, in some circumstances more information leads to the illusion of knowledge and decreases the decision makers' accuracy by reducing their reliance on statistical cues. This decrease in accuracy is simultaneously combined with increased confidence in prediction. The effects of amount of (relevant) information on judgment accuracy and confidence is discussed also by Tsai, Klayman, and Hastie (2008). They show that by increasing information to decision makers, their confidence in their decision increases more than their accuracy, i.e. we have an increase in the confidence, which is not grounded in the accuracy of the decision. This phenomenon is due to the fact that judges do not adjust for the cognitive limitations that reduce their ability to process additional information effectively.

2.3 Organizational Simulation

One valuable source of knowledge about individual, group, and team behavior and performance is an approach that tries to model and simulate people, groups, teams and organizations using a rich set of modeling methods and tools. A frequently employed method in the field is *agent-based* simulation, which is a bottom up approach for modeling a system. In an agent-based simulation model the decision process of simulated actors is explicitly described at the micro level. Structures emerge at the macro level as a result of the actions of the agents and their interactions with other agents and the environment (Siebers and Aickelin 2007). There is a large number of published literature about organizational simulation, however the collection (Prietula, Carley, and Gasser 1998) edited by the pioneers of the computational study of organizations and (Rouse and Boff 2005) containing works of the leading experts in organizational simulation cover many aspects of emerging problems in the field. We have been especially inspired by (Kang, Waisel, and Wallace 1998) and (Salas et al. 2005).

3 A MODEL FOR MEASURING PERFORMANCE OF HUMAN AGENTS

In a business process model such as a military planning, we suggest the weighted sum of the accumulated contributions of agents as an indicator of the quality of the output. Obviously a high amount of work does not assure whether a plan is valid and the desired effect will be achieved. However, our assumption is that a higher amount of qualified planning work yields a plan that is more thoroughly worked out and minimizes the risk to end up in an unexpected state. The military planning staff is modeled as a collection of agents. Each agent has a *role*, which defines the set of permissible positions in the organization and several *attributes*, which define the characteristics of the agent and its behavior. Some of these attributes may evolve during the simulation. Based on the literature presented in Section 2, we find the following attributes particularly relevant in modeling human performance in this context.

- Knowledge or expertise (competency and technical skills)
- Experience
- Cognitive ability (the ability to solve a problem)
- Creativity (the ability to find new and original problem solutions)
- Communication (the ability to expresses knowledge)
- Mood (the psychological mood)
- Motivation or willingness

It is possible that some of these attributes are broken down into sub-categories, e.g. communication may be divided in writing and oral communication.

The effect of these characteristics on the performance depends obviously on the nature of the work, e.g. physical strength may have no impact on a problem solving task, while it is most important when discussing the performance of a fireman. In other words, the performance of an agent or its contribution is task-specific and can be expressed, as follows

$$v_{il} = f(c_1, \ldots, c_n, w_1, \ldots, w_n),$$

where v_{il} is the value created by agent i when performing task l. Parameters c_1 to c_n are the capabilities of the agent, and w_1 to w_n are the weight or importance of each of these capabilities for the task at hand. The function $f(c_1,\ldots,c_n,w_1,\ldots,w_n)$ is generally an unknown function, however we approximate this value as a linear combination of agent attributes weighted by the importance of these attributes for the task, i.e. the value added by agent i to task l is estimated by

$$v_{il} = \sum_{j=1}^{n} w_j c_j = w_1 c_1 + w_2 c_2 + \cdots + w_n c_n. \tag{1}$$

The numerical values of attributes c_j and weights w_j are (subjective) values assigned by decision makers and domain experts to individuals and tasks. For the values of attributes we suggest a scale between $[0,2]$, where 1 indicates a normal (average) skill, 0 is the worst case, i.e. lack of any skills and 2 is extra ordinary skills. The weights of these capabilities should sum up to the number of capabilities, i.e. $\sum_{j=1}^{n} w_j = n$. If all capabilities are believed to be equally important, then all w_j should be equal to 1.

There are other factors that influence the performance of the agent. We designate these factors by the common name *peripheral factors*, since they impact the performance indirectly by strengthening or weakening one or more specific capabilities. Examples of peripheral factors are the following:

- *Environmental factors:* Different environmental factors may have impact on the individual performance. Task load, time pressure, and noise are examples of environmental factors generally having negative effects on the performance.
- *Technical aids:* Tools and technical aids impact clearly the individual performance, e.g. a worker equipped with a bulldozer can dig the ground much more efficiently.
- *Information:* Depending on the type of the task the individual performance may be affected by the available information. The role of information in some category of tasks is more crucial. For instance, the quality of decisions in decision making clearly depends on the available information. In a dynamic environment, there is a threshold that if the information falls short of it, it is not possible to make any decisions without taking the risk of changing the situation to the worse. However, as discussed in Section 2.2 all information is not good, e.g. disinformation or irrelevant information. Even overload of relevant information is not desirable. Overload of information, when it is over the processing capacity of the individual has the same effect as noise.

The impact of a peripheral factor on the capability c_j can be expressed by multiplying this value by a number $p_j \geq 0$, where 0 indicates that the capability is completely destroyed, and 1 indicates no effect on the the capability. The maximum value of p_j depends on the nature of the capability and the corresponding peripheral factor. A peripheral factor may impact different attributes in different ways. As an example consider the impact of playing loud heavy metal music on three attributes of individuals working in an office environment: (1) communication capability, (2) creativity, and (3) knowledge capability. If we assume that it completely eliminates the first attribute, increases the second attribute by 20 percent, and has no effect on the third attribute, then $p_1 = 0$, $p_2 = 1.2$, and $p_3 = 1$. In general, if r peripheral factors are considered and agents have n capabilities, we have a $r \times n$ matrix $\mathbb{P} = [p_{kj}]_{r\times n}$, where the element p_{kj} is the effect of the peripheral factor k on the capability j of agents. These values are derived from experiments or assigned by domain experts. The elements p_{kj} are set to 1, whenever the peripheral factor k has no effect on the capability j. By incorporating the peripheral factors, equation (1) is modified to

$$v_{il} = \sum_{j=1}^{n} p_j w_j c_j = p_1 w_1 c_1 + p_2 w_2 c_2 + \cdots + p_n w_n c_n, \tag{2}$$

where $p_j = \prod_{k=1}^{r} p_{kj}$ is the coefficient defined by multiplying all peripheral factors that affect attribute c_j.

We summarize the statements above in matrix form. Assume we have m agents each having n capabilities, s tasks and r peripheral factors that affect the capabilities. We define the following matrices:

- A *capability* matrix $\mathbb{C} = [c_{ij}]_{m\times n}$, where c_{ij} is the attribute j of agent i.
- A *peripheral factor* matrix $\mathbb{P} = [p_{kj}]_{r\times n}$, where p_{kj} is the effect of peripheral factor k on attribute j of agents.
- A *weight* matrix $\mathbb{W} = [w_{jl}]_{n\times s}$, where w_{jl} is the weight assigned to attribute j in task l.

Then the *value-added* matrix $\mathbb{V} = [v_{il}]_{m\times s}$, where v_{il} is the value added by agent i to the task l is calculated by

$$\mathbb{V} = \mathbb{G}\mathbb{W}, \tag{3}$$

where $\mathbb{W}$ is defined as above and $\mathbb{G} = [g_{ij}]_{m\times n}$ is the *modified capability* matrix with $g_{ij} = \prod_{k=1}^{r} p_{kj} c_{ij}$. If peripheral factors have no effects on the capabilities, i.e. $p_{kj} = 1, \forall p_{kj} \in \mathbb{P}$, then $\mathbb{G} = \mathbb{C}$.

4 AN EXTENSION TO BPMN

A business process model, expressed in BPMN is a network of graphical objects, which are activities (i.e., work) and the flow controls that define their order of performance. BPMN consists of a small set of recognizable notation categories for basic types of elements. Within the basic categories of elements, additional variation and information is added to support the requirements for complexity without dramatically changing the basic look-and-feel of the diagram (White 2004). The four basic categories of elements are:

- Flow Objects (Event, Activity, Gateway)
- Connecting Objects (Sequence Flow, Message Flow, Association)
- Swimlanes (Pool, Lane)
- Artifacts (Data Object, Group, Annotation)

Since the introduction of BPMN in 2004 and its adoption as an Object Management Group (OMG) standard in 2006, it has received a widespread attention and acceptance in both industry and academia (Recker 2008). BPMN v1.2 was released in early 2009, and request for proposals for version 2.0, which would be a major revision is issued.

There has been a lot of research on BPMN in recent years. The *Business Process Technology* research group of the Germany based *Hasso Plattner Institute* has studied the strengths and weaknesses of BPMN and suggested extensions to it. In (Decker and Puhlmann 2007) the failure of BPMN to capture advanced cross-organizational collaboration scenarios, like auctions is shown and an extension that removes the problem and broadens its applicability is proposed. Grosskopf (2007) is looking from an execution perspective and identifies capabilities and shortcomings of BPMN in order to make it unambiguously executable. The work introduces a framework to measure the control flow capabilities and proposes a formal semantics named *xBPMN* aligned with the current BPMN semantics, which meets these requirements. Further work to extend xBPMN and define a mapping of *Business Process Execution Language (BPEL)* to xBPMN is conducted by Weidlich (2008).

In BPMN, the association of a particular action or set of actions with a specific resource is illustrated through the use of the *Pool* and *Lane* constructs, commonly called *Swimlanes*. However, Wohed et al. (2006) show that the BPMN's support for the resource perspective is not sufficient. To overcome these limitations an extension using *Unified Modeling Language (UML)* constructs is introduced by Siegeris and Grasl (2008). This work provides an example of process modeling for a large-scale modeling effort using BPMN.

Usually simulating BPMN models is concerned with verifying correctness and accuracy of the sequence flow of diagrams. For this purpose a token is propagated from the *Start Event* of the diagram along *Sequence flows*, across *Activities* and *Gateways*, being duplicated and merged when necessary, until it is consumed by an *End Event*. By studying the path of the token one can verify if the modeled process flow behaves in the same manner that the decision maker wishes or what changes are required to obtain the desired flow. Changes in the process model of military activities and in general all activities require a holistic and long-term approach, considering all relevant business factors. In many cases there are various political and economic interests that influence the decision and the outcome is usually a compromise.

In this work we are mostly interested in managing human resources and studying the effect of peripheral factors on performance without introducing any major changes in the process model. The goal is to provide a decision making method that guides the decision maker in organizing human resources within the existing organizational structure, by evaluating various *what-if* queries.

To the best of our knowledge there are no published studies on the evaluation of the performance of BPMN diagrams. However, a related approach has been proposed by Magnani and Montesi (2007) to evaluate the (monetary) cost of BPMN diagrams. Two methods are suggested: *cost intervals*, in which the cost of a task is expressed by its lower and upper limits, and *average cost* in which, an average cost is assigned to each task together with the probability of alternative paths. In both methods costs are aggregated in an additive manner to the overall cost of the entire process.

We suggest extending the BPMN constructs with a performance metric by applying the model introduced in Section 3 for performance of agents. Tasks are weighted subjectively with a weighting coefficient between 0 and number of tasks, according to their importance in the process as a whole. These weights should sum up to the number of tasks. If the tasks are assessed to be equally important then all weights are set to 1. The total value added by agents in a process, denoted as

u, is calculated by

$$u = \sum_{l=1}^{s} x_l q_l \sum_{i=1}^{m} v_{il} z_{il}, \tag{4}$$

where x_l is the number of times task l is performed, q_l is the weight of the task in the process, v_{il} is the value added by agent i in task l, and z_{il} is the element of the *assignment* matrix $\mathbb{Z} = [z_{il}]_{m \times s}$. The il-entry of this matrix, z_{il} is set to 1 if task l is assigned to agent i and 0 otherwise. The inner sum $\sum_{i=1}^{m} v_{il} z_{il}$ gives the value added by all agents working on task l.

If the value of x_l is deterministic then u is easily calculated, otherwise $E[u]$, the expected value of u should be estimated. Although in simple cases there are analytical methods to calculate this average, there is no general method to estimate the performance of the diagram, hence simulation methods have to be employed.

It should be clarified that the value calculated here is a "gross" measure, since the costs associated with the business process are not deducted from it. Costs should usually be subtracted to obtain the net value-added and make any comparison consistent and meaningful. However, if the costs are equal for different assignment schemes it can be omitted without affecting the final result.

5 A CASE STUDY

A military staff, from here on interchangeably referred to as staff, is a group of officers in the headquarters that assists the commander in planning, coordinating and supervising operations. One of the main tasks of the staff is to acquire accurate and timely information and provide the commander with analyzed and processed information. It is not difficult to see that the quality of the commander's decision-making process mainly depends on how the staff works as an organization and the best way to augment decision-making is to optimize the activity of the staff i.e. utilize available human resources as efficiently as possible.

To demonstrate how the suggested approach works, we apply this method on a simplified part of the planning process in a military staff. The planning process in the military staff is a complicated and lengthy process that is executed in parallel in *political-military*, *strategic*, *operational*, and *tactical* levels. However, we focus here on a stage of this process in the operational level, namely *Operational Planning Concept Development*, which is modeled by BPMN as shown in Figure 1.

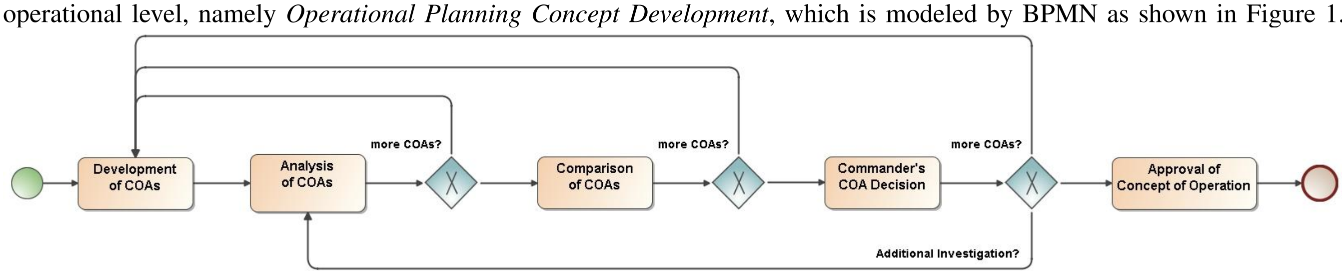

Figure 1: Operational Planning Concept Development expressed in BPMN.

The purpose of this stage, which is deliberately simplified to five tasks, is to determine *how* best to carry out operations using available resources to accomplish the mission effectively and efficiently. The input of this process is the *Commander's Planning Guidance*. Based on this document and further staff analysis *Courses of Actions (COAs)* are developed. COAs are tested for validity and refined through analysis and war gaming. The results of the staff analysis and comparison of various COAs are presented with a recommendation to the commander in the form of *Decision Briefing*. When the commander makes his decision, the staff refines the decision and the output is the *Concept of Operations (CONOPS)* and *Statement of Requirements (SOR)*. CONOPS is a verbal or graphical statement that clearly and concisely expresses what the commander intends to accomplish and how it will be done using available resources. It should give an overall picture of the operation.

As illustrated in Figure 1, the Operational Planning Concept Development starts with a task named *Development of Course of Actions (COAs)*, in which all alternative actions are developed. The developed COAs are analyzed in the next task, *Analysis of COAs* and it is decided whether more COAs are required to be investigated or not. If more COAs are not required the flow proceeds to the task named *Comparison of COAs*. In this step various COAs are compared with each other and a few COAs that are most promising are chosen. Once more it is controlled whether more COAs should be investigated and if necessary the flow returns to the first task. Otherwise, in the task *Commander's COA decision*, these candidates are briefed to the Commander who chooses the most appropriate COA. Finally, the flow proceeds to the task *Approval of*

Concept of Operation and the End Event. However, if the commander finds it necessary the flow may go back to one of the tasks Analysis of COAs or Development of COAs.

5.1 A Numerical Example

As an example, assume that besides the commander 4 other personnel or agents named *A, B, C* and D are involved in these processes, which for the sake of simplicity are denoted by *I, II, III, IV, V*. We want to assign each task to only one agent in the best possible way. The subjective capabilities of agents are summarized in Table 1. Value 1.0 corresponds to a normal

Table 1: A table containing 5 agents each having 4 attributes and the corresponding capability matrix.

	Creativity	Experience	Cognitive Ability	Knowledge
Commander	1.0	1.0	1.5	1.5
A	1.0	2.0	1.0	2.0
B	2.0	2.0	2.0	2.0
C	1.0	0.5	1.0	0.5
D	2.0	0.5	2.0	0.5

$$\mathbb{C} = \begin{pmatrix} 1.0 & 1.0 & 1.5 & 1.5 \\ 1.0 & 2.0 & 1.0 & 2.0 \\ 2.0 & 2.0 & 2.0 & 2.0 \\ 1.0 & 0.5 & 1.0 & 0.5 \\ 2.0 & 0.5 & 2.0 & 0.5 \end{pmatrix}$$

capability, 0.0 to the lack of the capability and 2.0 to the highest possible score. All values in between are allowed if it is reasonable to make such fine-grained distinctions.

According to the model suggested in Section 3, these capabilities are weighted differently, depending on the task. For instance it is reasonable to assume that creativity is more important when developing COAs, but experience has a higher value when analyzing COAs. Table 2 shows an example of the weights assigned to capabilities for various tasks and the corresponding weight matrix. The weights are scaled so that they sum up to the number of agent attributes. For instance in this example they sum up to 4, where value 0 indicates that the corresponding capability has no importance for the task. Value 4 is used when the capability is dominating, i.e. the performance is completely determined by it.

Table 2: Weight of each attribute in different tasks and the corresponding weight matrix.

	I	II	III	IV	V
Creativity	2.5	0.5	0.5	1.0	1.0
Experience	0.5	1.5	1.0	1.0	1.0
Cognitive Ability	0.5	1.0	1.5	1.0	1.0
Knowledge	0.5	1.0	1.0	1.0	1.0

$$\mathbb{W} = \begin{pmatrix} 2.5 & 0.5 & 0.5 & 1.0 & 1.0 \\ 0.5 & 1.5 & 1.0 & 1.0 & 1.0 \\ 0.5 & 1.0 & 1.5 & 1.0 & 1.0 \\ 0.5 & 1.0 & 1.0 & 1.0 & 1.0 \end{pmatrix}$$

According to (2) apart from task related weight, each capability is weighted by another factor p_j, which is peripheral factor. Here, for simplicity we ignore the impact of peripheral factors, i.e. $p_{kj} = 1, \forall p_{kj} \in \mathbb{P}$. This implies that $\mathbb{G} = \mathbb{C}$ and $\mathbb{V}$ can be easily calculated using (3). These values are calculated and shown in Table 3.

Table 3: Value added by agents to different tasks and the corresponding value-added matrix.

	I	II	III	IV	V
Commander	4.5	5.0	5.25	5.0	5.0
A	5.0	6.5	6.0	6.0	6.0
B	8.0	8.0	8.0	8.0	8.0
C	3.5	2.75	3.0	3.0	3.0
D	6.5	4.25	5.0	5.0	5.0

$$\mathbb{V} = \mathbb{G}\mathbb{W} = \begin{pmatrix} 4.5 & 5.0 & 5.25 & 5.0 & 5.0 \\ 5.0 & 6.5 & 6.0 & 6.0 & 6.0 \\ 8.0 & 8.0 & 8.0 & 8.0 & 8.0 \\ 3.5 & 2.75 & 3.0 & 3.0 & 3.0 \\ 6.5 & 4.25 & 5.0 & 5.0 & 5.0 \end{pmatrix}$$

Given the $m \times s$ matrix $\mathbb{V} = [v_{il}]_{m\times s}$ the goal is to maximize the objective function as defined by (4), i.e. $\sum_{l=1}^{s} x_l q_l \sum_{i=1}^{m} v_{il} z_{il}$ by choosing a feasible assignment matrix $\mathbb{Z} = [z_{il}]_{m\times s}$. We face a *task assignment problem* containing uncertainty, since the process is non-deterministic and x_l is a random variable. The probability that after completing task l the flow proceeds to task l' depends on several factors, among others: the agent that performs task l and the entire history of the process. The complexity of the probabilistic model of the process justifies that simulation methods should be used in order to estimate the expected value of x_l rather than any analytical method. However, in order to demonstrate the overall structure of the method we make some simplification and present an analytical solution to the problem.

5.2 Analytical Approach

The process is non-deterministic and can be considered as a stochastic process with 6 states. States $1,2,\ldots,5$ correspond to tasks $I,II,\ldots,V$. We let the only *absorbing* state 6 represent the *End Event*. Without any loss of accuracy the *Start Event* can be ignored, since after start the process proceeds unconditionally to state 1.

We assume the process has the *Markov property* meaning that future states depend only on the present sate and are independent of past states. In other words, the probability that after completing task l the flow proceeds to task l' is a value $\rho_{ll'}$ that can be estimated for example by using historical data. An updated version of the BPMN diagram in Figure 1 using this assumption is depicted in Figure 2. In this Figure some fictitious values are assigned to probabilities $\rho_{ll'}$.

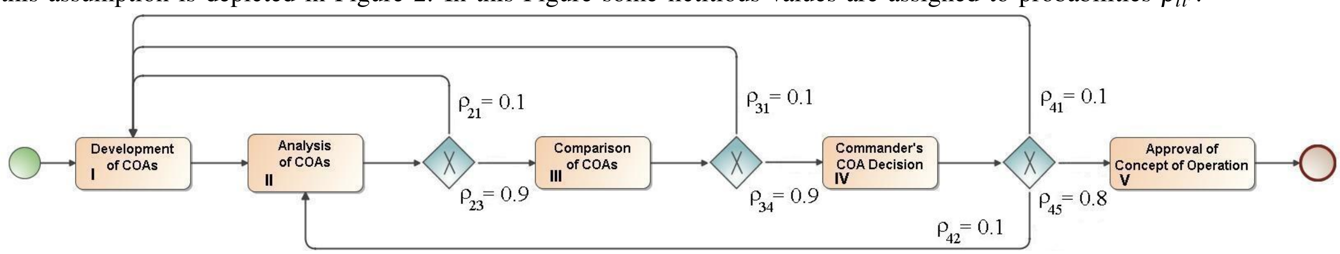

Figure 2: Operational Planning Concept Development expressed in BPMN extended by the probability of branches.

Assuming the Markov property the diagram can be considered as a *Markov chain* with the following *transition matrix*

$$\mathbb{M} = \begin{pmatrix} \rho_{11} & \rho_{12} & \rho_{13} & \rho_{14} & \rho_{15} & \rho_{16} \\ \rho_{21} & \rho_{22} & \rho_{23} & \rho_{24} & \rho_{25} & \rho_{26} \\ \rho_{31} & \rho_{32} & \rho_{33} & \rho_{34} & \rho_{35} & \rho_{36} \\ \rho_{41} & \rho_{42} & \rho_{43} & \rho_{44} & \rho_{45} & \rho_{46} \\ \rho_{51} & \rho_{52} & \rho_{53} & \rho_{54} & \rho_{55} & \rho_{56} \\ \rho_{61} & \rho_{62} & \rho_{63} & \rho_{64} & \rho_{65} & \rho_{66} \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0.1 & 0 & 0.9 & 0 & 0 & 0 \\ 0.1 & 0 & 0 & 0.9 & 0 & 0 \\ 0.1 & 0.1 & 0 & 0 & 0.8 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}.$$

We are interested in estimating the number of times each task is performed before the process is completed, i.e. the number of visits to *transient states* before absorption in state 6. Denoting the expected number of visits to state l by $E[x_l]$, $l \in \{1,2,\ldots 5\}$, one can intuitively reason that $E[x_l]$ is equal to the sum of expected values of being in all states $E[x_l']$, $l' \in \{1,\ldots,5\}$ weighted by the probability that the state changes to l, i.e. $\rho_{l'l}$. For state 1 this value must be increased by one, since we start from stat 1. That is, $E[x_l]$ is the solution of the linear system

$$\begin{cases} E[x_l] = 1 + \sum_{l'=1}^{5} E[x_{l'}]\rho_{l'l} & if l = 1 \\ E[x_l] = \sum_{l'=1}^{5} E[x_{l'}]\rho_{l'l} & if l = 2,3,4,5. \end{cases} \tag{5}$$

More formally, the same result is obtained by calculating the *fundamental matrix* of the Markov chain. For an absorbing Markov chain with transition matrix $\mathbb{M}$, we denote by $\mathbb{Q}$ the sub-matrix of $\mathbb{M}$ containing the transition probabilities from transient states to transient states. It can be shown that the matrix $(\mathbb{I}-\mathbb{Q})$, where $\mathbb{I}$ is the identity matrix with appropriate dimensions is invertible. Furthermore, the ij-entry of the inverse matrix $(\mathbb{I}-\mathbb{Q})^{-1}$ (the fundamental matrix of the Markov chain) is the expected number of times the chain is in state j, given it starts in state i. The initial state is counted if $i = j$ (Grinstead and Snell 1997). Since the chain starts in state 1, the expected value of visiting different states are elements of the first row of the matrix $(\mathbb{I}-\mathbb{Q})^{-1}$, i.e.

$$E[\mathbb{X}] = (1,0,0,0,0)(\mathbb{I}-\mathbb{Q})^{-1}. \tag{6}$$

Here, $\mathbb{I}$ is the 5×5 identity matrix and $\mathbb{Q}$ is the matrix obtained if we strike off row and column containing absorbing state, i.e. row and column 6 from the transition matrix $\mathbb{M}$. Either (5) or (6) yields $E[\mathbb{X}] = (1.42, 1.54, 1.39, 1.25, 1.00)$.

For simplicity we assume here that tasks are equally important, i.e. all $q_l = 1$ and multiply each column of the matrix $\mathbb{V}$ by corresponding element of $E[x_l]$ to obtain

$$\begin{pmatrix} 4.5 & 5.0 & 5.25 & 5.0 & 5.0 \\ 5.0 & 6.5 & 6.0 & 6.0 & 6.0 \\ 8.0 & 8.0 & 8.0 & 8.0 & 8.0 \\ 3.5 & 2.75 & 3.0 & 3.0 & 3.0 \\ 6.5 & 4.25 & 5.0 & 5.0 & 5.0 \end{pmatrix} \begin{pmatrix} 1.42 & 0 & 0 & 0 & 0 \\ 0 & 1.54 & 0 & 0 & 0 \\ 0 & 0 & 1.39 & 0 & 0 \\ 0 & 0 & 0 & 1.25 & 0 \\ 0 & 0 & 0 & 0 & 1.00 \end{pmatrix} = \begin{pmatrix} 6.39 & 7.70 & 7.30 & 6.25 & 5.00 \\ 7.10 & 10.01 & 8.34 & 7.50 & 6.00 \\ 11.36 & 12.32 & 11.12 & 10.00 & 8.00 \\ 4.97 & 4.24 & 4.17 & 3.75 & 3.00 \\ 9.23 & 6.55 & 6.95 & 6.25 & 5.00 \end{pmatrix}.$$

The il-entry of the resulting matrix is the value added by agent i to the process if it performs task l. The problem is now reduced to a standard assignment problem. The *Hungarian algorithm* (Kuhn 1955) provides an effective solution to this problem even for large number of tasks and agents. However, here we choose to calculate the objective function for all possible assignments. The commander is dedicated to the task *Commander's COA decision*, i.e. task IV. The remaining 4 tasks can be assigned to agents A to D in 24 different ways. By comparing the sum for different assignments the maximum value $39.61 = 9.23 + 10.01 + 11.12 + 6.25 + 3.00$ and the optimal assignment $D, A, B, Commander, C$ are respectively obtained as shown in Figure 3. These values can be compared with the minimum value $32.07 = 7.10 + 6.55 + 4.17 + 6.25 + 8.00$, which is obtained for the combination $A, D, C, Commander, B$.

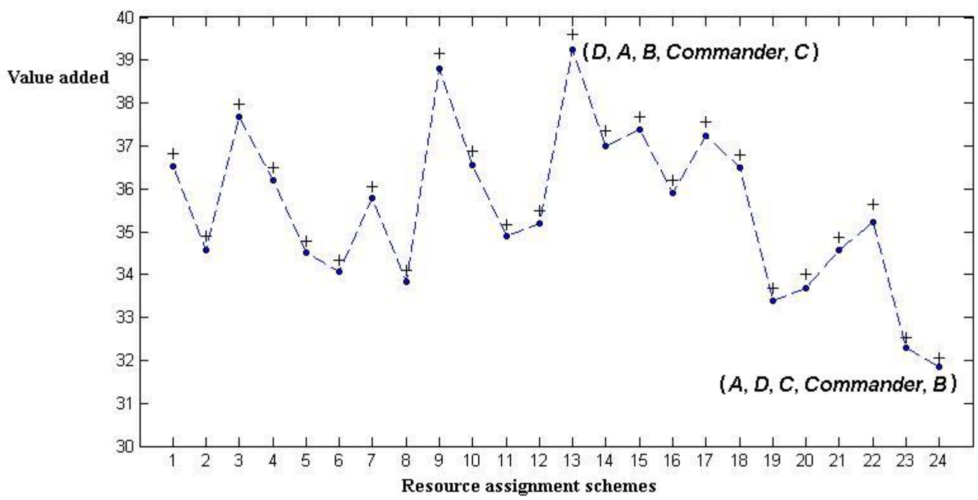

Figure 3: Simulation results for all possible task assignments. The corresponding analytical values are marked by plus signs.

5.3 Simulation Approach

Although the presented analytical method is appealing, it is not generally applicable. Therefore, alternative approaches such as simulation must be considered. Scenarios where analytical solutions are not available include cases in which the transition probabilities depend on how the tasks are performed and the agents are utilized. In many cases poor performance of a task l results in increasing the probabilities $\rho_{l'l}$ for some values of l'. It implies that the transition matrix of the Markov chain is not constant and varies depending on the assignment of tasks to agents. The analytical method is not applicable either when the process is not Markovian and the probabilities depend on the previous events. In both cases simulation provides a convenient means for comparing alternative assignment schemes. Another benefit of the simulation based method is its simplicity and flexibility. Without any mathematical expertise it is possible to change the diagram and the required resources and run *what-if* simulations to study the effect of various task assignments and the impact of peripheral factors on the performance of the business process model.

The simulation method is relatively straightforward and follows the intuitive structure of the BPMN diagram. Tokens are generated at Start Events and are propagated along Sequence flows, across Activities and Gateways, being duplicated and merged when necessary, until they are consumed by an End Event. A task holding a token is considered to be active, which may result in updating the values of some parameters. The simulation is repeated a sufficient number of times so that the average values of the desired parameters are calculated.

The simulation of the above model is implemented using the simulation software *Arena* and the total value-added for 24 different assignments of tasks to agents are estimated by averaging over 1000 runs of the simulation. As Figure 3 suggests values obtained by simulation method are rather close to the analytical results, and most importantly they follow exactly the same pattern. The maximum value obtained by simulation is 39.24 for the same assignment of tasks to agents as calculated by the analytical method. The minimum value obtained by simulation is 31.84, which is obtained for the same combination as the one obtained by the analytical method. Simulation results converge rather quickly to the analytical values. The convergence of simulation results and their corresponding analytical values for three task assignment schemes are shown in Figure 4. The x and the y axes show the number of simulations and the total value-added, respectively. The green curve corresponds to the optimal scheme, the red curve is the scheme yielding the minimum value, and the blue curve considers the arbitrarily chosen scheme $B, A, C, Commander, D$.

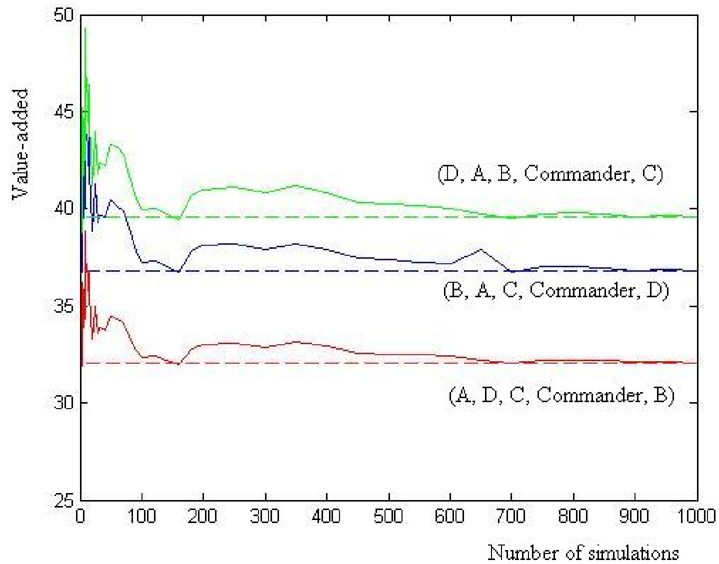

Figure 4: Convergence of values obtained by simulation for three different task assignments.

Obviously, with increasing the number of agents and tasks, we face a combinatorial explosion and it is not feasible to exhaustively search all possible solutions. However, other constraints usually narrow the search space to a tractable number of alternatives. For instance consider an operational planning process in military staff consisting of tens of tasks and personnel, where these tasks are assigned to personnel according to their expertise, capabilities and other constraints. Assume 4 tasks in this process require reinforcement and 4 unscheduled personnel whose expertise match these tasks are available. Our method can provide appropriate answer to various what-if questions such as how to best distribute these 4 agents between the 4 tasks.

6 CONCLUSION AND FUTURE WORK

In this paper we presented a model for estimating the value added by agents to a business process in human organizations. This value is estimated based on the agents capabilities, the weight (importance) of these capabilities for performing the tasks involved in the process, and the effect of peripheral factors on these capabilities. We suggested extending BPMN constructs by redefining performers of activities as agents with specific capabilities. An analytical method to evaluate the contribution of agents to tasks, when the BPMN diagram can be expressed as a Markov chain was presented. However, in general there is no analytical method to evaluate the value-added and hence a simulation method was proposed. To demonstrate how the analytical and the simulation method work, a simplified version of a part of planning process in military staff was studied and the results of these methods were compared. Even though by increasing the number of agents and tasks the combinatorial explosion prohibits this method to explore all possible task assignment schedules, nevertheless the method makes it possible to compare tractable number of alternatives.

One of the shortcomings of the simulation model suggested here is that the performance of a group is assumed to be the sum of the performances of agents involved in the task. However, it is not generally the case when agents cooperate and interact with each other. A team is usually much more effective than the same number of individuals with equal capabilities performing the same task without any cooperation. Superiority of team over individual performance is due to the higher information processing capacity of teams and the variety of individuals' skills and capabilities. Modeling and including different aspects of team working in estimating the performance of organizations is the natural next step of the work, which we have already initiated.

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