Individual Decision Making in a Learning Organization

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ABSTRACT
Individual decision making in the context of a human organization is a complex process, which involves individual reasoning about own needs, capabilities and experiences, about the surrounding formal organization and (informal) social structures and processes. The context of individual decision making changes constantly due to organizational learning and change. Organizations learn via their individuals, however also individual behavior and decision making are influenced by organizational learning. This paper contributes a formal approach, which can be used for inspecting and predicting individual decision making in the context of a learning organization. The approach is based on a number of well-established sociological and psychological theories. The paper illustrates the approach by a simulation case from the air traffic control domain. Furthermore, the paper addresses the issue of model validation.

Categories and Subject Descriptors
I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence – *intelligent agents.*

General Terms
Design, Experimentation, Human Factors.

Keywords
Individual decision making, learning organization, organization modeling, agent-based social simulation

1. INTRODUCTION
Many modern human organizations are characterized by complex structures, variety of processes, and highly dynamic internal interaction and interaction with the environment. Structural and behavioral complexities of the organizational and environmental context, in which an individual is situated, are reflected in the behavior and decision making mechanisms of the individual [1]. Individual decision making in a complex context is always an act of compromising among the different selves. For example, an organizational individual while making a decision often considers his/her current needs, own capabilities, own beliefs about the formal organization, his/her social context and the environment. The prosperity of an organization depends greatly on the behavior of its individuals. Thus, an organization should arrange work and provide incentives to its individuals in such a way that they are constantly motivated to make decisions that ensure the satisfaction of the essential organizational goals. To this end, a closer investigation is required of (interrelated) dynamic and static aspects that influence individual decision making in the organizational context. Such investigation is also useful for understanding motives of unproductive or even destructive behavior of an organizational individual.

The organizational context in which an individual makes decisions comprises aspects of both formal (prescriptive) and informal (not predefined, deviant) organization. Furthermore, the organizational context changes constantly, since every organization learns over time. Some organizations choose learning deliberately, and align their objectives, structures and processes constantly, so a fit with the environment is achieved. Other organizations make no focused effort on learning, however are forced to learn in order to survive. Organizations learn via their individuals. Moreover, organizations can learn independent of any specific individual, but not independent of all individuals. In its turn, organizational learning influences also the behavior of organizational individuals [7]. Reciprocal relations between individual decision making and organization learning are in the focus of this paper. The paper contributes a formal modeling approach, which can be used for inspecting and predicting decision making of a learning individual in a dynamic organizational context. This approach is in particular useful for understanding the reasons of unproductive behavior of individuals and determining conditions for efficient and effective work of individuals of different types. The proposed approach is operational, which allows performing automated analysis (e.g., by simulation). Organizational individuals are modeled as agents, as in many other organization modeling approaches [8]. Although much research has been done on (multi-)agent decision making and coordination [10, 14], the obtained results cannot be applied directly for the human organizational context. Human organizations are characterized by diverse structures, relations and processes, which are not considered in decision making of software agents. These organizational peculiarities call for a dedicated decision making modeling approach. Such an approach is proposed in this paper. It relies strongly on a well-established sociological and psychological background, described in Section 2. An organization model comprises the prescriptive part (formal organization) addressed in Section 4, and the varying part due to autonomous behavior of agents considered in Section 5. The approach is exemplified by a case study from the air traffic domain, which simulation results are presented in Section 6. A procedure for model validation is considered in Section 7. Section 8 concludes the paper.

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2. PSYCHOLOGICAL AND SOCIOLOGICAL BACKGROUND

Traditionally, rational choice theory has been the dominant framework in economics and social science for modeling of individual decision making. Based on this theory, three degrees of behavioral approximation of individual decision making can be distinguished [1]:

- The first-cut approximation models, often used in economics, posit utility maximization behavior on the parts of agents. An agent seeks to maximize its own utility given some rational expectations about the behavior of other agents. Usually agents demonstrate a largely egoistic behavior in such models.
- The second-cut approximation models include learning and adaptation of agents through feedbacks on their behavior and observation of other agents.
- The third-cut approximation models provide more profound insights into human needs, capabilities and motivations so that the individual behavior might be more fully explicated. Such models are often built based on the assumptions of *willful-choice behavior* [1, 5], which include the abilities of an individual:
  - to assess probabilities for the states of the world;
  - to assign a utility value to each (complex) consequence;
  - to calculate the expected utility value of each possible action;
  - to compare actions by their expected utility values.

Although, it has been argued by many that work-related behavior of individuals is largely rational [1], many empirical evidences showed violation of the assumptions of the rational choice theory. To address this issue theories have been proposed (e.g., Prospect Theory [5]) to integrate rationality with diverse reasoning imperfections, and moods and emotions.

The individual learning considered in the second-cut approximation models can be reduced to three main classical learning types from psychology [7]: (i) by pairing conditioned and unconditioned stimuli (classical conditioning); (ii) by pairing behavior with specific consequences (instrumentalist conditioning); (iii) learning from the behavior and experience of others (social learning). Classical conditioning learning does not occur often in organizations and will not be considered.

In the context of organizations a number of studies have been performed, which investigated the link between individual and organizational learning [7], viewed in particular from *the adaptation* and *knowledge* perspectives.

From the *adaptation perspective* organizational learning is defined as the process of organizational adaptation to internal/external changes based on individual learning. Within this perspective the model of organizational learning by March and Olsen [6] (see Figure 1) deserved much attention. In this model an individual action is based on certain individual beliefs. This action, in turn, may lead to an organizational action, which may produce some environmental response. The learning cycle is completed when the environmental response affects individual beliefs. In such a way an individual learns through instrumentalist conditioning by observing the effects of own actions.

The model also addresses the issue of incomplete learning cycles, when learning is impaired because of the weakening or breakage of one or more links. For example, link 3 in Figure 1 is broken, when the individual affects organizational action in an ambiguous way; link 4 is broken when no real basis for the connection between organizational action and environmental response can be identified.

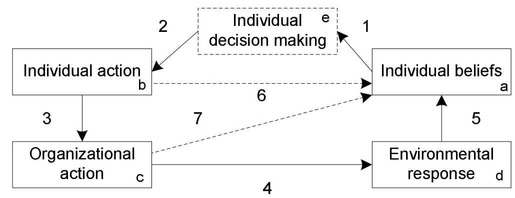

Figure 1. Model of organizational learning adapted from [6] with the modifications indicated by dotted lines.

Many studies [7] have shown that information about incomplete learning cycles is also remembered by individuals and used in their decision making, thus influencing the organizational learning. In such a way organizational learning does not always lead to the organizational improvement. To capture such effects, the March and Olsen's model is extended in this paper as shown in Figure 1 by dotted lines. Also, the individual decision making process, implicit in the original model, is made explicit.

From the *knowledge perspective* organizational learning is defined as accumulation of organizational knowledge [3]. From this perspective a significant part of the organizational knowledge is captured in the organizational routines (e.g., procedures, regulations, guidelines). Furthermore, much of not formalized organizational knowledge can be learned through informal social interaction within the organization (individual social learning).

An interaction between the adaptation and knowledge perspectives can be established through individual beliefs. More specifically, an individual forms beliefs about formally and informally provided organizational knowledge. A relevant subset of these beliefs can be used further in the individual decision making about the action choice as shown in Figure 1.

3. MODELING DECISION MAKING IN A LEARNING ORGANIZATION

In this section first the desiderata for the modeling approach are introduced (Section 3.1). Then, an overview of the proposed modeling approach is provided (Section 3.2). Finally, a case study is introduced used for the illustration of the approach.

3.1 Modeling desiderata

Based on the background from the previous section, the following list of desiderata for an approach for modeling of individual decision making in a learning organization have been identified:

(1) Modeling power of the second-cut approximation models for the context of a learning organization, which includes the means to specify:
  (a) diverse aspects of a formal organization, among which: performance-related, process-related, authority- and interaction-related aspects (for blocks b and c; links 3 and 4 from Figure 1; for specification and provision of routines);
  (b) interaction between the environment and organizational individuals (for block d; links 4 and 5);
  (c) generation, maintenance and update of the beliefs of organizational individuals (for block a; links 5, 6, 7);
  (d) informal structures and informal interaction (for blocks b and c; link 3; for individual social learning).

(2) Modeling power of the third-cut approximation models, which additionally to (1) includes means to specify cognitive states of organizational individuals and their dynamics:
(a) willful choice behavior of individuals (for blocks b and e; links 1, 2);
(b) intentional and motivational states of individuals (e.g., goals, desires and needs; organizational commitment);
(c) skills, knowledge and psychological traits of individuals;
(d) informal normative states of individuals and of groups of individuals (e.g., informal norms and values of a group).

(3) Possibility to include individual biases and errors in decision making.

(4) Possibility to include emotional states and moods of individuals in decision making.

(5) The modeling language should have formal semantics and be executable to enable automated analysis.

3.2 Overview of the proposed modeling approach

According to the modeling desiderata from Section 3.1, both prescriptive aspects of the formal organization, as well as autonomous behavior of organizational individuals need to be considered. For modeling of a formal organization the approach from [12] is used, described briefly in Section 4, which satisfies desideratum 1a and partially 1b. For modeling autonomous behavior of individuals, the agent modeling approach from [12] has been extended to incorporate individual and organizational learning, satisfying the desiderata 1b, 1c, 2b, and 2c. The desiderata 1d and 2d cover a large variety of informal aspects, each of which requires a detailed elaboration. In this paper informal interaction of agents in formal structures, which occurs in all types of organizations, is considered more specifically. Modeling of organizational agents is considered in Section 5.

To model willful choice behavior of agents (desideratum 2a) a refined version of the expectancy theory by Vroom [9] is used. Some advantages of the expectancy theory are: (a) it can be formalized; (b) it allows incorporating the organizational context; (c) it has received good empirical support. According to this theory, when a human evaluates alternative possibilities to act, s/he explicitly or implicitly makes estimations for the following factors: *expectancy*, *instrumentality*, and *valence* (see Figure 2).

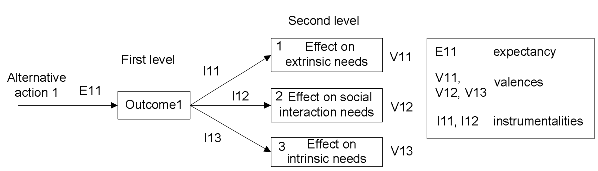

Figure 2. A refined expectancy model.

Expectancy refers to the individual's belief about the likelihood that a particular act will be followed by a particular outcome (called a first-level outcome). For example, if an individual chooses to execute a task, then expectancy may refer to the belief about the likelihood of the successful accomplishment of the task.

Instrumentality is a belief concerning the likelihood of a first level outcome resulting into a particular second level outcome; its value varies between -1 and +1. Instrumentality takes negative values when a second-level outcome does not follow a first-level outcome. A second level outcome represents a desired (or avoided) by an agent state of affairs that is reflected in the agent's goals and needs. For example, instrumentality may refer to the belief that the successful task accomplishment results in a reward. In the proposed approach the original expectancy model is refined by considering specific types of individual needs, distinguished in social science [9]: (1) *extrinsic needs* associated with biological comfort and material rewards; (2) *social interaction* needs that refer to the desire for social approval and affiliation; (3) *intrinsic needs* that concern the desires for self-development and self-actualization. Intrinsic needs are satisfied by intrinsic rewards that are a natural consequence of the individual behavior related to the task execution. Externally provided rewards (e.g., salary, bonuses, group acceptance) serve to the satisfaction of extrinsic and social interaction needs.

Valence refers to the strength of the individual's desire for an outcome or state of affairs. While second level outcomes are directly related to the agent's needs, the valence values associated with these outcomes refer to priorities of these needs.

In the Vroom's model the force on an individual to perform an act is defined as:

$$F_i = \sum_{j=1}^{n} E_{ij} \cdot \sum_{k=1}^{m} V_{ik} \times I_{jk} \qquad (1)$$

Here E_{ij} is the strength of the expectancy that act i will be followed by outcome j; V_{ik} is the valence of the second level outcome k; I_{jk} is perceived instrumentality of outcome j for the attainment of outcome k.

As the result of decision making an alternative with the highest force value is chosen for execution.

Values of expectancies, instrumentalities and valences change over time, in particular due to individual and organizational learning. As has been discussed in Section 2, an individual in an organization learns both by observing the consequences of his/her actions and through social interaction. Social interaction may be formal and informal. Formal interaction occurs according to organizational routines. Through informal interaction agents acquire information about informal norms, behaviour and experience of other agents. By learning, agents improve their skills and create beliefs about formal and informal aspects of the organization. Essentially these beliefs and skills determine the values of expectancies and instrumentalities. More specifically modeling of individual and organizational learning will be considered in Section 5.

In [5] a number of different biases and errors in human decision making are described. To satisfy the desideratum 3, many of them can be modeled by attributing to agents faulty beliefs and/or under-/overestimated expectancies and instrumentalities. The implementation of some typical biases is considered in the context of the case study in Section 6. The desideratum 4 is not currently covered by the approach.

The approach is formally grounded in order-sorted predicate logic with finite sorts. More specifically, the static properties of a model are expressed using the traditional sorted first-order predicate logic, whereas dynamic aspects are specified using the Temporal Trace Language (TTL) [12, 13], a variant of the order-sorted predicate logic. In TTL, the dynamics of a system are represented by a temporally ordered sequence of states. Each state is characterized by a unique time point and a set of state properties that hold, specified using the predicate at: STATE_PROPERTY x

TIME. Dynamic properties are defined in TTL as transition relations between state properties. For example, the property that for all time points if an agent ag believes that action a is rewarded with r, then ag will eventually perform a, is formalized in TTL as:

$\forall$t:TIME [at(internal(ag, belief(reward_for_action(r, a))), t)
$\rightarrow$ $\exists$t1 > t at(output(i, performed_action(a)), t1)]

For a formal description of the syntax and semantics of TTL we refer to [12]. As shown in [13], TTL specifications can be automatically translated in an executable format (desideratum 5).

3.3 Case study

One of the safety problems, which air navigation service providers (ANSPs) face, is that not all safety occurrences happened during air and ground operations are reported by air traffic controllers. An example of a ground safety occurrence is 'taxiing aircraft initiates to cross due to misunderstanding in communication'. In particular, knowledge about occurrences is useful for proactive safety analysis (e.g., identification of safety trends). Although reporting is obligatory in most ANSPs, still the amount of not reported occurrences is estimated as significant (around 50%) even in ANSPs, which are highly committed to safety. To understand the reasons for such behavior, decision making of an air traffic controller whether to report a safety occurrence is investigated in this study in the context of an ANSP.

Controllers work in shifts, within each shift a pair of controllers is allocated to each sector of an airport. A controller supervisor manages work in a shift. The composition of shifts may be stable (allocation of the same controllers to the same sectors every day) or variable. Some ANSPs reprimand controllers for occurrences. Sometimes also rewards are provided for reporting (not serious) occurrences. After a controller decides to report an observed occurrence, s/he creates a notification report, which is provided to the Safety Investigation Unit (SIU) of the ANSP. Depending on the occurrence severity and the collected information about (similar) occurrences, SIU makes the decision whether to initiate a detailed investigation. During the investigation accumulated organizational knowledge about safety related issues (in particular, learned from notification reports) is used. As the investigation result, a final occurrence assessment report is produced, which is provided (in reality not always) to the controller-reporter as a feedback. Furthermore, often final reports contain recommendations for safety improvement, which are required to be implemented by ANSP (e.g., provision of training, improvement of formal procedures, extension of staff).

4. MODELING FORMAL ORGANIZATION

For modeling the formal organization the approach from [12] is used, which has been applied for the case study following a sequence of design steps. Due to the space limitations only an informal description is provided.

Step 1. The identification of the organizational roles. A *role* is a (sub-)set of functionalities of an organization, which are abstracted from specific agents who fulfill them. Each role can be composed by several other roles, until the necessary detailed level of aggregation is achieved, where a role that is composed of (interacting) subroles, is called a composite role. Each role has an input and an output interface, which facilitate in the interaction with other roles. The environment represents a special component of a model, which also has input and output interfaces. In the case study roles are identified at three aggregation levels; the ANSP's roles of the aggregation level 2 are presented in Figure 3.

Step 2. The specification of the interactions between the roles. Relations between roles are represented by interaction and interlevel links. An *interaction link* is an information channel between two roles at the same aggregation level. An *interlevel link* connects a composite role with one of its subroles. The interaction relations at the ANSP's aggregation level 2 are shown in Figure 3.

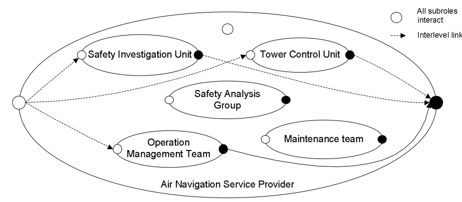

Figure 3. ANSP considered at the aggregation level 2.

Step 3. The identification of the requirements for the roles. In this step the requirements on knowledge, skills and personal traits of the agent implementing a role at the lowest aggregation level are identified. A prerequisite for the allocation of an agent to a role is the existence of a mapping between the capabilities and traits of the agent and the role requirements. For example, among the requirements for the air traffic controller role are: passed a rigid medical examination; thorough knowledge of the flight regulations; air traffic control training; excellent listening and communication skills; quick decision-making skills. Organizations implement very diverse allocation principles (e.g., based on equality, seniority or stimulation of novices).

Step 4. The identification of the organizational performance indicators and goals. A performance indicator (PI) is a quantitative or qualitative indicator that reflects the state/progress of the company, unit or individual. PIs can be hard (e.g., occurrence investigation time) or soft, i.e., not directly measurable, qualitative (e.g., level of collaboration between controllers). *Goals* are objectives that describe a desired state or development and are defined as expressions over PIs. The characteristics of a goal include, among others: *priority*; *horizon* – for which time point/interval the goal should be satisfied; *hardness* – hard or soft. A goal can be refined into subgoals forming a hierarchy. For example, goal G18 'It is required to maintain timeliness and a high quality of occurrence investigation' is based on two PIs 'timeliness of occurrence investigation' and 'quality of occurrence investigation'. This goal is refined in several subgoals: G18.1 'It is required to maintain a high proficiency level of incident investigators', G18.2 'It is required to maintain a sufficient level of details of notification reports', G18.3 'It is required to maintain the timely investigation of an occurrence' and G18.4 'It is required to maintain a high level of thoroughness of occurrence investigation'. To ensure the satisfaction of G18, the (sufficient degree of) satisfaction of its subroles is required. Goals are related to roles. E.g., G18 is attributed to Safety Investigation Unit and Regulator roles of the ANSP.

Step 5. The specification of the resources. Resource types are characterized by: *name*, *category*: discrete or continuous, *measurement unit*, *expiration duration*: the time interval during which a resource type can be used; *location*; *sharing*: some processes may share resources. Examples of resource types are: aircraft, incident classification database, a notification report.

Step 6. The identification of the tasks and relations between the tasks, the resources and the goals. A task represents a function performed in the organization and is characterized by *name*, *maximal* and *minimal duration*. Tasks can be decomposed into more specific ones using AND- and OR-relations. Each task performed in an organization should contribute to the satisfaction of one or more organizational goals. For example, task T4 'Safety occurrence reporting and the report handling' is refined into more specific tasks, among which T4.1 'Create a notification report', T4.3 'Making decision about the investigation necessity', T4.4 'Investigation of an occurrence'. Task T4.4 is related to resources as follows: it uses a notification report and produces a final occurrence assessment report. Furthermore, T4.1 contributes to goal G18.2, and T4.4 contributes to goals G18.3 and G18.4.

Step 7. The specification of the authority relations. The following types of authority relations are distinguished: superior-subordinate relations on roles with respect to tasks, responsibility relations, control for resources, authorization relations. Roles may have different rights and responsibilities with respect to different aspects of task execution, such as execution, passive monitoring, consulting, making technological and managerial decisions. For example, Safety Investigator role is assigned responsible for execution of and making technological decisions with respect to task T4.4, Safety Manager is responsible for monitoring, consulting and making managerial decisions related to T4.4.

Step 8. The specification of the workflows. Workflows describe temporal ordering of processes of an organization in particular scenarios.

Step 9. The identification of the generic and domain-specific constraints. Generic constraints ensure internal consistency of an organizational specification. Domain specific constraints restrain behavior of individuals in a particular organization. In particular, organizational reward/sanction policies can be formalized as domain-specific constraints. For example, if a controller has been involved in more than 2 occurrences of type B during the evaluation period, s/he will be fined. The approach provides means for automated checking of constraints both on an organizational specification and on the actual execution of organizational scenarios (see Part III of [12]).

5. MODELING ORGANIZATIONAL AGENTS

In this Section first the agent modeling framework from Part III.7, 8 of [12] is briefly described (Section 5.1) and illustrated for the case. Then, an extension of this framework for individual and organizational learning is considered in Section 5.2.

5.1 Agents

Similarly to roles, internal, input and output states of agents are distinguished. First, internal agent states are considered.

For an agent a set of *capabilities* (i.e., knowledge and skills) and *personal traits* is defined, relevant in the organizational context. Knowledge defines organizational facts and procedures, and is modeled by a set of time-labeled beliefs. Skills describe developed abilities of agents to use effectively and readily their knowledge. In the literature [9] four types of skills relevant in the organizational context are distinguished: technical, interpersonal (e.g., communication), problem-solving/decision-making and managerial skills. The personal traits are divided into five broad categories discovered in psychology [9]: openness to experience, conscientiousness, extroversion, agreeableness, and neuroticism.

In modern social science behavior of individuals is considered as goal-driven. It is recognized that high level goals of individuals are largely dependant on their extrinsic, social interaction and extrinsic needs. For example, for a controller agent based on its social interaction needs two goals have been specified: 'it is desired to maintain acceptable own group approval' and 'it is desired to maintain acceptable management approval'. By defining the acceptable degrees of needs satisfaction, it is possible to establish at any time whether the agent's goals are satisfied. As shown in Section 3.2 individual needs are used also in the evaluation of desired and unwanted consequences of decision making.

Empirical evidences showed that importance of different types of needs (and the associated goals) changes over time. Furthermore, when long-term goals are satisfied, their priority decreases over time.

Agent goals may be in line with or contradict organizational goals. An agent has a high *organizational commitment* when it accepts the organizational goals and is willing to exert effort on behalf of the organization [7]. In the ANSP model, the commitment of a controller agent to organizational safety goals is modeled through the prism of the agent's own needs. Thus, the commitment to safety is determined: (1) through extrinsic needs – by safety reprimands and rewards; (2) through management approval needs – by the priority of the organizational safety goals and the agent's perception of the management commitment to safety; (2) through own group approval needs - by the perception of the group's commitment to safety; (3) through intrinsic needs - by the perceived own influence degree on safety and the possibility of self-actualization.

Now input and output states of agents are considered. An organizational agent communicates (i.e., receives information at its input and generates information at its output) with other agents through formal and informal communication channels. Communications are formalized as speech acts using the function communicated_from_to(ag1:AGENT, ag2:AGENT, s_act:SPEECH_ACT, message:STRING), here agent ag1 communicates speech act s_act to agent ag2 with the content message.

An agent observes the behavior of other agents and of the environment. Passive and active observations are distinguished. In contrast to a passive observation, an active observation is always concerned with the agent's initiative. An active observation of a state property p by an agent is formalized using the function to_be_observed(p: STATE_PROPERTY). Observation results are provided to the agent's input using the function observation_result(p: STATE_PROPERTY, sign: BOOL), which indicates whether p holds in the environment or for another agent. Actions of an agent generated at its output are specified by performed(act:ACTION).

It is assumed that agents create time-labeled internal representations (beliefs) about their input and output states:

∀ag:AGENT ∀p:STATE_PROPERTY ∀t:TIME at(input(ag, p), t)
→ at(internal(ag, belief(p, t), t+1) (similarly for output states)

In such a way agents collect histories of belief states over time. Depending on the agent type such histories may persist forever or decay over time (i.e., be forgotten by agents) [5].

5.2 Learning of agents and organizational learning

In this paper by agent learning a change of agent's skills and/or knowledge is understood. No assumption about the necessity of a performance improvement due to learning is made. In particular, forgetting is also seen as a special kind of learning. Organizational agents vary in the abilities and desires to learn. In particular, the agent's learning behavior depends on the agent's traits and needs. Some traits mediate the attainment of skills [9]. For example, extroversion and agreeableness are important for building interpersonal skills. High priority agent's needs that cannot be satisfied due to the agent's skill and/or knowledge limitations result into generation of goals to learn the required capabilities.

Two types of individual learning were identified in Section 2 as particularly relevant for organizational learning: instrumentalist conditioning and social learning. By instrumentalist conditioning an agent is able to form beliefs about dependencies between its own states, observed states of the environment, and observed states of other agents (such as expectancies and instrumentalities from Section 3.2). Since often agents do not have complete confidence in such dependences, the likelihood measure with the range [0, 1] is used for the beliefs of this type:

```
has_likelihood(occurs_after(p1:STATE_PROPERTY,
p2:STATE_PROPERTY, t1:TIME, t2:TIME), v:VALUE),
```

which expresses that state property p2 holds t' (t1 < t' < t2) time points after p1 holds with the likelihood v.

Initial likelihood values may be based on the provided formal information (e.g., routines) and/or agent's previous experience. Then, by instrumentalist conditioning the agent increases (decreases) the likelihood of a dependency, when it is actually (not) observed.

From the adaptation perspective on organizational learning, an agent ag creates for an action or a communication ag_act beliefs about the following dependencies (from Figure 1):

```
has_likelihood(occurs_after(output(ag, ag_act),
                            output(org_role1, org_act), t1, t2), v1)
has_likelihood(occurs_after(output(org_role1,org_act),
                            output(env, p1), t3, t4), v2),
```

here org_role1 is an organizational role responsible for an organizational action or communication org_act and p1 is an observed output state of the environment.

In the considered case each controller agent creates the belief about the dependency between providing of a notification report on an occurrence of some type to his/her supervisor and receiving a final assessment report on the occurrence (i.e., feedback) from a safety investigator agent. Moreover, often final assessment reports include recommendations for organizational and environmental improvement, which when implemented may be observed by the controller-reporter. These dependencies are formalized as:

```
has_likelihood(occurs_after(output(ag_controller,
          communicated_from_to(ag_controller, ag_supervisor, inform,
                                   notification_report_for_B)),
  output(ag_investigator,communicated_from_to(ag_investigator,
    ag_controller,  inform, final_assessment_report_for_B))), 24h, 1440h, v1)
has_likelihood(occurs_after(output(ag_investigator,
          communicated_from_to(ag_investigator, ag_controller, inform,
                                   final_assessment_report_for_B)),
  output(env, observation_result(recommendations_implemented_for_B))),
    360h,8640h), v2)
```

An agent may have beliefs about faulty dependencies and/or make incorrect estimation of likelihoods (e.g., some controllers may believe that reporting of insignificant occurrences is punishable, whereas in reality it is not). This type of human error is called illusory correlation [5].

The second learning type - social learning – occurs by observation of and communication with other agents. Communication may be formal (i.e., as prescribed by a formal interaction specification (Section 4)) and informal. To model informal communication of agents the Burt's social contagion theory has been used [2]. According to this theory, the intensity of informal communication between agents is dependent directly on: (1) similarity of the formal communication patterns of the agents' roles; (2) equality of the formal power statuses of the agents in the organization; (3) physical possibilities to communicate; (4) degree of acquaintance of the agents with each other. For a shift of controllers the factors (1)-(3) have a high degree of evidence, whereas the factor (4) depends on the shift composition (stable versus variable). Thus, generally a shift of controllers should have intensive informal communication relations, which was also confirmed by interviews. Such relations enhance the knowledge of controllers about safety issues and observed occurrences, and may contribute to the proactive identification of issues by the controllers.

Agents learn also by observing the behavior of other agents. From such observations (implicit) informal group norms and values can be inferred. In the case study a controller agent observes occurrence reporting of other agents from his/her shift, and based on that forms the beliefs about the shift's averaged attitude to reporting of different types of occurrences. More precisely generic informal normative aspects will be elaborated elsewhere.

6. SIMULATION RESULTS

In the simulation an ANSP regulating the aircraft flow in 6 airport sectors with 48 controllers agents has been considered. The controllers work in 4 shifts, 12 hours per day (12 controllers per shift; 2 per sector). A shift consists of three sessions. The duration of each session is 1h. After each session a 1h break follows. During a break the controllers are physically located in the same space, which enables their informal discussions of occurrences observed. Each shift is managed by a supervisor agent (1 supervisor for 2 shifts). The formal ANSP's specification described partially in Section 4 has been used in the simulation. Although the simulated ANSP is formally highly committed to safety (reflected in high priority of safety goals), its actual commitment is lower (not sufficient investments in personnel, low quality of management of safety activities). ANSP performs average control over the activities of controllers and reprimands them for (series of) occurrences.

Different types of occurrences happen randomly in the environment with the frequencies provided by a real ANSP. After a controller agent observed an occurrence, it makes the decision whether to report the occurrence. The agent's decision making consists in the evaluation of the forces for two alternatives (by the equation (1)) – to report and to not report – using the refined expectancy models (see Figures 4). The agent chooses to perform the alternative with a greater force.

The following common human biases, identified also in the air traffic domain were incorporated in the expectancy models:

- representiveness: occurrences of the same type are evaluated in the same manner;
- availability: the evaluation of the forces is performed based only on the knowledge possessed by a controller agent;
- retrievability of instances: the salience of a belief determines its lifespan and the effect on reasoning (e.g., after an occurrence reporting that caused dissatisfaction of the priority extrinsic needs the agent will decrease the instrumentality I21 significantly).

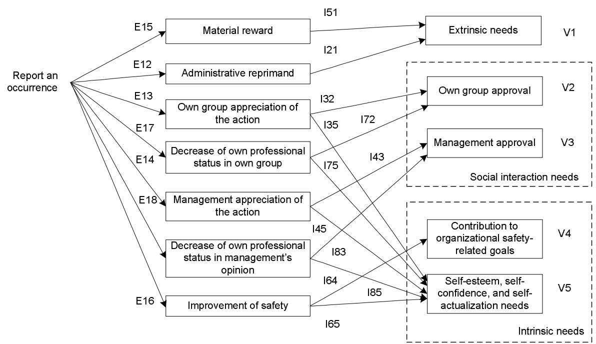

Figure 4. Expectancy model for reporting an occurrence.

Expectancies and instrumentalities of the expectancy models vary due to individual and organizational learning. In particular, the agent's expectancies E15, E12 and E26 change depending on the received (observed) reprimands and rewards for occurrences reported by the agent (or by another agent from the shift) (instrumentalist (social) learning). E13 and E22 are adjusted by the agent based on the observed shift's averaged attitude to reporting of different types of occurrences (social learning). E16 and E25 are adjusted based on the feedbacks from the safety investigator agent on the previously reported occurrences and the observed implementation of safety recommendations for previous reports (instrumentalist learning), and safety information informally provided by other controllers during breaks (social learning). Organizational learning leads to safety improvement, when the agent chooses to report occurrences. In this case from the knowledge perspective organizational learning leads to the accumulation of information about observed safety occurrences. From the adaptation perspective, safety improvement is supported by complete learning cycles.

Table 1. Some of the characteristics of the controllers agents

Controller	ATC skills	Basic valences of the needs				
		$v1_b$	$v2_b$	$v3_b$	$v4_b$	$v5_b$
from Eastern culture	0.7 + 0.3·a*	1	0.8 - 0.2·b	0.8 + 0.2·c	0.8 + 0.2·d	0.5 + 0.1·e
from Western culture			0.3 - 0.2·f	0.3 + 0.2·g	0.4+ 0.2·h	0.7+ 0.3·k

* a, b, c, d, e, f, g, h, k are random variable uniformly distributed in the interval (0, 1)

Many evidences exist that due to a strict selection procedure and similarity of training, controllers have a high degree of homogeneity of the skills and traits. At the same time, studies have shown [4] that the national culture determines to some degree the behavior of controllers agents. According to [4], individuals in the Eastern European culture in comparison with Western European individuals are more collectivity-oriented, follow stricter prescribed norms and rules, have a more strongly pronounced power distance. The cultural aspects influence the valences of the controller's needs. In the simulation ANSP is considered in the contexts of the Western and Eastern European cultures. Some of the controller's characteristics from both these cultures, used in the simulation are given in Table 1 (based on the numerical cultural indexes from [4]).

According to interviews, controllers supervisors differ in the realization of organizational goals and policies. In the simulation the supervisor agent 1 for shifts 1 and 2 performs a stricter control over the activities of controllers and initiates reprimands for both serious occurrences and for series of insignificant occurrences, whereas the supervisor 2 for shifts 3 and 4 is less strict in control and initiates reprimands for serious occurrences only. For each cultural context 100 simulation trials have been performed. In each trial the agents initially do not have previous beliefs about ANSP. During the first month (first 500 hours) the agents gain a substantial experience with the formal and informal processes and structures. Then, their learning becomes less intensive. The force to report insignificant safety occurrences deserves a special attention, since such occurrences often neglected in reality. As can be seen from Figures 5 and 6, the reporting force fluctuates less after the first month in the Eastern ANSP. To some degree this can be seen as an effect of the strongly pronounced collectivity of this culture. Further, in both cultures with stable shifts a stricter control and reprimands (shift 1) result in a better reporting (see Table 2), although the force is more negative than in the less strict case (shift 4) (see Figures 5 and 6). Note that the difference in the quality of reporting is greater for the Eastern culture (13%).

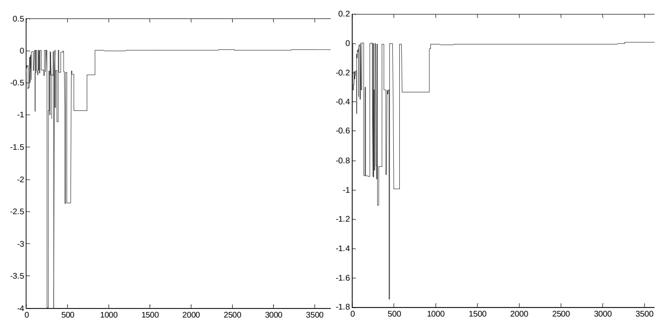

Figure 5. Force to report insignificant occurrence in the shift 1 (left) and shift 4 (right) of an Eastern European ANSP.

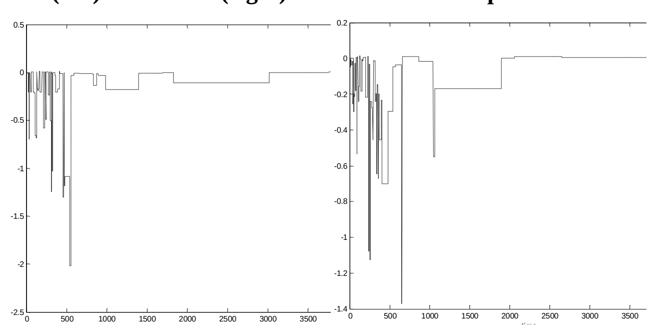

Figure 6. Force to report insignificant occurrence in the shift 1 (left) and shift 4 (right) of a Western European ANSP.

In the setting with variable shifts (new agent allocation every day) no significant difference of the reporting quality among the shifts has been identified. However, the overall reporting quality in the Eastern European ANSP drops by 5% compared to the stable shifts situation (1.5% decrease in the Western European ANSP).

From this a high sensitivity of the reporting quality in Eastern European ANSPs to the shift composition can be presumed.

Table 2. Percentages of the reported insignificant occurrences

ANSP's context	Stable shifts		Varying shifts	
	Shift 1	Shift 4	Shift 1	Shift 4
Eastern culture	56	43	46	45
Western culture	61	56	58	56

7. VALIDATION PROCEDURE

An important issue that needs to be addressed for any organization modeling approach is model validation. For the proposed approach the validation procedure consists of the following steps:

Step 1. A set of indicators (performance measures) and their satisfactory values are identified that describe the desired organizational behavior. These indicators constitute the output generated by the model. For the case study the percentage of reported safety occurrences is such an indicator.

Step 2. Key input factors in producing the desired behavior of the organizational model are determined:

2a. A large number of (stochastic) simulations is performed. For each input factor x_i two sets of values are determined: $x_i|B$ contains all values of x_i from the simulations that produced the desired organizational behavior, and $x_i|\underline{B}$ contains all x_i values that did not produce the desired behavior.

2b. The Smirnov two sample test is performed for each input factor independently [11]. The test statistics is defined by

$$d(x_i)= \sup_Y \| F_B(x_i|B) - F_{\underline{B}}(x_i|\underline{B}) \|,$$

here F_B and $F_{\underline{B}}$ are marginal cumulative probability functions calculated on the sets $x_i|B$ and $x_i|\underline{B}$ respectively; Y is the output. A low level of $d(x_i)$ supports null-hypothesis H_0: $f_B(x_i|B) = f_{\underline{B}}(x_i|\underline{B})$, i.e., the input factor x_i is not important, whereas a high level of $d(x_i)$ implies the rejection of H_0, i.e., x_i is a key factor.

2c. Input factors that gained significance due to interaction (correlation) with other input factors are determined by calculating total effect terms for each factor x_i identified as insignificant at step 2b, using the formula: $TE = \frac{E(V(Y \mid X_{-i}))}{V(Y)}$

Here $E(V(Y|X_{-i}))$ is the expected variance of the output Y obtained when all input factors (set X) but x_i are fixed; $V(Y)$ is the variance of the output Y.

To perform automated statistical analysis, the software package SIMLAB has been used.

Among the key factors identified for the case study are: priority of organizational safety goals; sufficiency of the amount of safety investigators; support for confidentiality of reporting; quality of the communication channel between controllers and investigators.

Step 3. Empirical data are collected in the organization (using interviews, questionnaires and formal documents) to determine the values for the key input factors as precise as possible. Then, simulation is performed with the identified values of the input factors. The obtained simulation results are compared with the observed organizational behavior, known indicators and issues.

8. CONCLUSIONS

In this paper a descriptive approach for modeling of individual decision making in a learning organization has been proposed and illustrated. The approach can be used for analysis of causes and consequences of individual behavior of organizations. In comparison with the existing multi-agent decision making modeling approaches, the organizational context in the proposed approach requires a more significant modeling effort.

It is recognized that human emotions and moods influence decision making. Currently the integration of these aspects in the proposed approach is considered.

9. REFERENCES

[1] Bell, D.E., Raiffa, H., Tversky, A. *Decision Making*. Cambridge University Press, 1989.

[2] Burt R.S. Social Contagion and Innovation: Cohesion Versus Structural Equivalence. *The American Journal of Sociology*, 92 (6), 1987, 1287-1335.

[3] Duncan, R.B., Weiss, A. Organizational learning: implications for organizational design, in Straw, B. (ed.), *Research in Organizational Behavior*, JAI Press, 1979, 75-124.

[4] Hofstede, G. *Cultures and Organizations*. McGraw-Hil, 2005.

[5] Kahneman, D., Slovic, P., Tversky, A. *Judgment under Uncertainty*. Cambridge University Press, 1982.

[6] March, J. G., Olsen, J., P. The Uncertainty of the Past: Organizational Learning Under Ambiguity, *European Journal of Political Research*, 3, 1975, 147-171.

[7] Meinolf, D., Berthoin Anthal, A., Child J., Nonaka, I. *Handbook of Organizational Learning and Knowledge*, 2001, Oxford University Press.

[8] *Multi-Agent Systems - Semantics and Dynamics of Organizational Models*. V. Dignum (ed.), IGI Press, 2008.

[9] Pinder, C.C. *Work motivation in organizational behavior*. Upper Saddle River, NJ: Prentice-Hall, 1998.

[10] Pynadath, D., Tambe, M. The communicative multiagent team decision problem: Analyzing teamwork theories and models. *Journal of Artificial Intelligence Research*, 16, 389-423, 2002.

[11] Ross, S.M. *Simulation*. Academic Press, Boston, 1997.

[12] Sharpanskykh, A. *On Computer-Aided Methods for Modeling and Analysis of Organizations*, PhD thesis, Vrije Universiteit Amsterdam, 2008. http://www.few.vu.nl/~sharp/thesis.pdf

[13] Sharpanskykh, A., Treur, J. Verifying Interlevel Relations within Multi-Agent Systems. In *Proceedings of the 17th European Conf.on Art. Intelligence*, IOS Press, 2006, 247-254.

[14] Trigo, P., Coelho, H. A hybrid approach to multi-agent decision-making. In *Proceedings of the 18th European Conference on Artificial Intelligence*, IOS Press, 2008.