# Timeline-Based Planning for Engaging Training Experiences

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### Abstract

This paper reports on a novel use of timeline-based planning as the core element of a dynamic training environment specifically designed for crisis managers. It describes an effort to build a complete application that helps the trainer to create and deliver engaging and personalized training lessons for decision making skills in crisis management domains. The paper emphasis is given to (a) the timeline-based representation as the core component for creating training sessions and a trainee's model; (b) the combination of planning and execution functionalities required to maintain and dynamically adapt a "lesson plan" on the basis of individual interactions, behaviors and performance; (c) the "mixed-initiative" approach pursued, that allows the trainer to keep control of the activity loop. The application has been fielded and evaluated through a psycho-physiological assessment within a real crisis training room involving 18 real strategic decision makers in a three-days of classes experience, overall demonstrating the ability of the system to fully support trainees engagement thanks to the flexibility injected by the planning technology.

## Introduction

This paper describes a new application based on the use of planning technology that offers support for continuous animation and adaptation of lesson content within the domain of *training* for crisis management. The specific target of this system is not the one usually considered by other training systems. In fact, when referring to planning connected to crisis management during emergency situations, we have in mind the intervention plans for those people who go directly to the operational level of response, see (Wilkins et al. 2008). In reality there are distinctly different levels of decision making that needs to be trained, all of which are relevant in any crisis situation.

At the **operational level** we have the operational or **bronze level commanders**, people operating within the detailed area of a crisis situation who perform practical activities and actions. At the **tactical or silver level** decision makers are located close to but not within affected areas of the crisis and are responsible for translating high level strategic decisions into actions by allocating tasks and resources down to the bronze level. At this level, the **strategic or gold level** commanders identify the key issues of a critical situation and prioritize required activity from a detached and sufficiently high level of abstraction.

In this light the success of crisis management at strategic level depends not only on the ability to apply well established procedures, but also on the effectiveness of high-level strategic choices. The ability of decision makers to anticipate the possible consequences of their actions (decisions) by means of flexible and forward-looking reasoning is also crucial to an effective response to a crisis. Within this context, an effective training plays a crucial role in preparing crisis managers.

Most of the state-of-the-art training support systems and simulators are aimed at the operational or tactical levels. The PANDORA system on the contrary is specifically targeted towards strategic level decision makers thus presenting difficult challenges at both modeling and computational levels. Additional challenges arise from the need to foster quick decision making in stressful conditions and the need to encourage creative thinking to devise workable strategies to deal with uncommon situations. As a consequence, strategic crisis managers can be required to assess information and making decisions under significant psychological stress and physical demands, often caused by the difficulty to operate in contexts where consistent losses as well as damages both to human lives and property are occurring.

Training for strategic decision making has to foster leaders' ability to look forward, conceive creative solutions as well as to learn how to assess the consequences of their decisions. The PANDORA project aims to simulate all the dynamic elements of an entire disaster environment by emulating a complete training room through an engaging, true-life environment able to create and present different evolving crisis scenarios customized to the particular training needs. Additionally, the idea underlying PANDORA is to take behavioral and psychological features into account in order to plan training sessions according to individual differences.

The technology chosen for addressing the problem, is the timeline-based planning, an approach to temporal planning which has been mostly applied to the solution of several space planning problems (e.g., (Muscettola 1994;

Jonsson et al. 2000; Cesta et al. 2009)) [1].This paper describes our effort to build and assess the PANDORA system, which is completely based on the planning technology. Specifically, we use planning to compute diversified evolutions of the crisis scenario which correspond to alternative training paths. In addition we use planning also to model and maintain trainees' behavioral patterns according to which aspects of the training can be personalized. Planning is finally instrumental to support mixed-initiative interaction between the trainer and the automated learning environment. In other words, the idea of using planning within PANDORA is connected to the synthesis of a "lesson plan", that is an organized set of lesson's items called *tokens*, which are presented to trainees over a span of time according to a given training strategy. In order to maintain an updated representation of the *user's psychological status* we rely on psychological self-assessment and physiological measurement, that take as input the values of specific psycho-physiological variables and represents them by means of similar temporal items. In this way, both the lesson content and the user model share the same uniform structure and use causal connections between different parts of such plan to foster the continuous update of the plan.

The remainder of this paper is organized as follow: a description of the PANDORA approach and the main building blocks of the learning environment are introduced. The role of the timeline-based representation as the core component for creating training sessions and representing trainee's model is then underscored. A combination of planning and execution functionalities that enables the maintenance and adaptation of a "lesson plan" is described. Finally the deployment into a real training crisis room and the evaluation with real crisis managers is illustrated.

## The PANDORA approach

The goal of the PANDORA project is to build an intelligent training environment able to deploy a spectrum of realistic simulations of crisis scenarios that: (1) reproduce the stressful factors of the real world crisis; (2) personalize the planned stimuli according to the assessed abilities and features of different trainees and (3) supports the dynamic adaptation of "lesson plans" during the training time-horizon.

The system design has followed a user-centered approach, based on a close cooperation with the training experts. Specifically, the Emergency Planning College[2] (EPC) in York, UK, shared its knowledge and expertise in delivering Cabinet Office-approved emergency planning and crisis management training and contributed to identify the main requirements specification of the innovative training environment, deeply influencing the design and implementation choices. The traditional EPC approach to training was based on table top exercises, that is a set of group discussions based mainly on paper and pen and pre-prepared material guided

[1] We here use the term "timeline-based planning" because recently it is more widely used, see for example (Chien et al. 2012), instead of "constraint-based interval planning" (Frank and Jonsson 2003) which could be however technically more accurate.

[2] http://www.epcollege.com/

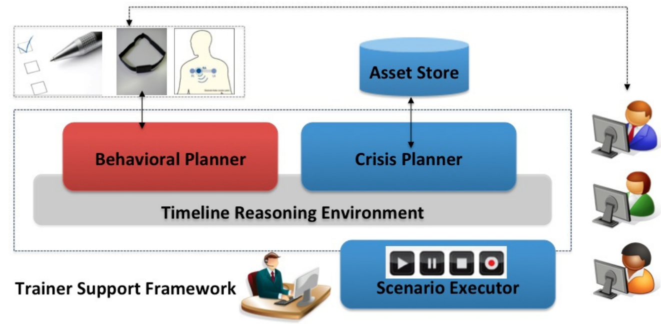


Figure 1: The PANDORA architecture. The Crisis Planner and the Behavioral Reasoner are the key components that share a common timeline-based reasoning structure.

by a simulated disaster); table top exercises are generally low cost and can be easily and frequently organized, but they cannot recreate the real atmosphere, in terms of stress, confusion and pressure of a real crisis. In this respect the PANDORA system had to overcome this limitation and recreate realistic, customizable and dynamic situations that the trainees could experience.

A number of general constraints have emerged during a first phase of user requirement analysis:

- *Support cooperative decision making*: it has become clear immediately how important it is to train gold commanders to take key decisions jointly in collaborative working conditions.
- *Training personalization*: the role of personalized teaching has been underscored even within a group decision making context.
- *What-if Analysis*: the possibility to rapidly present different courses of the crisis evolution and to observe the consequences of bad decisions has been expressed as a clear advantage of the system.
- *Mixed-initiative interaction*: the need for a tool that empowers the trainer to adapt and adjust the training session became apparent rather than relying upon a video-game type of immersive experience, hence the need to create a mixed-initiative environment in which the trainer is fully integrated in the "lesson loop".

Figure 1 sketches the PANDORA architecture. It is composed of the following four software components:

**Crisis Planner.** This module is responsible for the generation of the "lesson plan" selecting and combining different media from an asset store. The module continuously adapts the scenario in an engaging way taking into account both the evolution of the specific group of people under training and their individual performance/status.

**Behavioral Reasoner**. This module is responsible for creating an initial user model for the trainees, using the information taken from psychological questionnaires and physiological feedback. Additionally it performs periodic psychological assessments and continuous physiological analysis of trainees decisions through data monitoring by a holter during the lesson in order to update the user model.

**Trainer Support Framework**. This is the module that enables the mixed-initiative interaction. Specifically it offers different functionalities to the trainer to setup, configure the system and dynamically adapt the scenario. Through it the trainer can set up a "class" ensuring that all the roles in the scenario are filled by asking the PANDORA system to role-play any missing players. The trainer keeps control of the training session by adapting the learning content throughout the execution of the *Scenario*, dynamically adjusting the stimuli based on both his/her experience and observation of the different trainees' actions (both at the individual and group level). Finally, through simple commands, the plan can be executed, paused, resumed and re-wound.

**Trainee Clients**. Following a Client-Server architecture, trainees can join a class and participate. They dynamically receive scheduled information, both collectively and individually, in the form of videos, maps, decision points, etc. This information is displayed on a main communication window that also allows to input their strategy decisions which needs to be collective joint decisions taken after a period of discussions and exchange of opinions.

Overall the PANDORA system supports the loop *trainer* $\rightarrow$ *training environment* $\rightarrow$ *trainees* $\rightarrow$ *training environment* $\rightarrow$ *trainer*, encouraging the customization and adaptation based on the users feedback (in terms of decisions and psychological status) as well as the inclusion of training goals and other inputs by the trainer.

We now turn to the use of timeline-based planning technology within the PANDORA system and describe how the planning technology has become the unifying element of the system.

## Planning a Lesson

The basic goal for our learning environment is to create and dynamically adapt a four hours lesson. The pursued idea is to represent lesson's content as a *plan* composed of different "messages" to be sent to trainees (both at individual and group level) which have temporal features and causal relations among them. In PANDORA a lesson plan is first synthesized starting from an abstract specification given by the trainer, then it is animated, expanded and updated during its execution, in relations to new information gathered form trainees and their decisions. Specifically, the lesson plan contains time-tagged activities that trigger multimedia events presented to the trainees. A key point is represented by the reaction of trainees to lesson stimuli (e.g., the answer to a request to produce both individual and joint decision on a specific critical point). "User reactions" are internally represented in the plan and trigger different evolutions of the current plan thus supporting dynamic adaptation.

The use of AI planning is quite natural for creating such a master plan. Previous work has explored the use of constraint reasoning for synthesizing multi-media presentations (e.g., (Jourdan, Layaida, and Roisin 1998)), the use of planning and scheduling in story-telling (e.g., (Young 1999)), the use of planning and scheduling in e-learning environments (e.g., (Castillo et al. 2010; Garrido, Morales, and Serina 2012)), etc. The main "technological idea" we have pursued in PANDORA is to use timeline-based technology to represent and manage heterogeneous information. In particular two aspects are worth to be mentioned: (a) the use of timeline-based technology to plan and execute a long lesson, having the possibility to dynamically adapt its content by reasoning on time intervals; (b) the application of timeline-based technology to a challenge that directly emerged from the training domains (i.e., the need for complex trainee models to support personalization).

In timeline-based planning, the main data structure is the *timeline* which, in generic terms, is a function of time over a finite domain. Events on timelines are called *tokens* and are represented through a predicate extended with extra arguments belonging to the Time domain $\mathbb{T}$ (real or discrete). For example, a predicate $At\,(l)$, denoting the fact that an agent is at a certain location $l$, can be extended with two temporal arguments $s \in \mathbb{T}$ and $e \in \mathbb{T}$, with $s < e$, representing its starting and ending times, respectively; the $At\,(l, s, e)$ formula would be true only if the agent is at location $l$ from time $s$ to time $e$. Tokens can be linked to each other through *relations* in order to reduce allowed values for their constituting parameters and thus decreasing allowed system behaviors.

In order to express planning domain/causal rules in the current internal representation we make use of the concept of *compatibility* (see an example in figure 2). We describe compatibilities through logic implications $reference \rightarrow requirement$ and, in some cases, we will give tokens a specific name and will address their arguments using a Java style *dot* notation (i.e., given a token $t$ having proposition $P\,(s, e)$ its starting point will be expressed as $t.s$).

Within this context, the task of the planner is to find a legal sequence of tokens that bring the timelines into a final configuration that verifies both the *domain theory*[3] and a determined set of desired conditions called *goals*. Starting from an initial state, the planner moves in the search space performing a complete refinement search by adding or removing tokens and/or relations (i.e., changing the current state) until all goals are satisfied.

In our case, goal conditions are characterized by high level scenario events representing the abstract blueprint for the master plan while the initial state is, trivially, an empty plan. The scenario represents an abstract plan sketch that works as a sequence of "lesson goals" and as a skeleton plan for the ground planner. It is described through a particular timeline that generates sub-goaling by interacting with the set of compatibilities.

The initial driving role is given to the trainer who loads a specific "Scenario" through his Trainer Support Framework. The planner works on the ground timeline representation to create the training storyboards, i.e., the set of connected "events" that are communicated to the trainees (e.g., a video news from the crisis setting, a phone call or e-mail from a field manager, and a set of temporal distances among events). Once the planner has achieved a fix-point given

[3]The set of compatibilities that model the domain's dynamic behavior

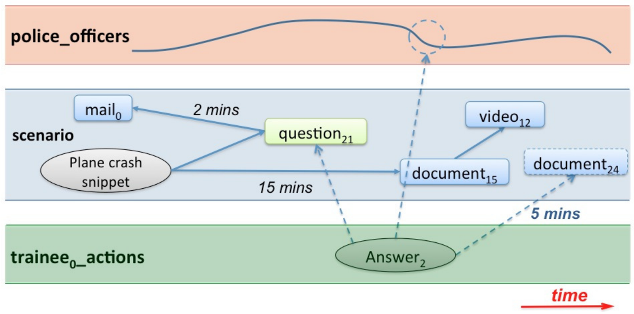


Figure 2: The timeline-based plan data structure.

the abstract scenario goals from the trainer and the domain compatibilities, the responsibility is left to the plan executor that step-by-step executes the plan by sending tokens to the rendering environment according to their progressive start times. Some of the tokens are requests for individual trainees or to the entire class to make decisions or self assess their status with respect to a given psychological variable (see Figure 1), the result of which is fed back to the timeline representation as additional information for plan adaptation. In fact the system is able to react to trainees' strategic decisions and also behavioral dynamics, triggering consequent events to continue the training session.

Scenarios have the double role of enabling the trainer to reason on a high level of abstraction thus avoiding the details of the planning technology and to continuously influence the plan that actually implements the detailed lesson at ground level. Furthermore the trainer is endowed with commands to introduce single steps in a scenario hence triggering dynamic plan adaptation. It is worth highlighting how the overall system aims to empower the trainer with a more effective means to train people. Indeed the suggested crisis stimuli as well as the behavioral analysis is offered to the trainer who can influence at any moment the training session in perfect line with a *mixed-initiative* style.

Figure 2 shows an example of crisis plan distributed over three timelines representing (a) the number of available police officers, (b) the scenario timeline and (c) actions taken by a trainee. Arrows represent causal links. This means that $mail_0$, $video_{12}$, $question_{21}$ and $document_{15}$ are there *because of* high level goal "Plane crash snippet". It is worth underscoring how taking dynamically into consideration the answers received by the trainee can cause a dynamic adaptation of the scenario plan with the insertion of the sub-goal $document_{24}$ and an update on the "police officers" resource (the example is quite trivial for the sake of space) that may change the perception of the current crisis scenario either of a single trainee or to the whole class. This is also a way for increasing the workload to a single person or to the whole class.

The disjunctions of requirements produce branches on the search tree guaranteeing varieties of presented scenarios. In particular, it may happen that some compatibility cannot be applied since it imposes too strict constraints resulting in an inconsistent partial plan. In such cases, a backtracking procedure allows to return to the highest safe decision level.

Since not all courses of action in a crisis can be predicted at scenario design time, we have also endowed the trainer with a service that allows to incrementally modify the ongoing scenario in order to adapt the simulation to unpredicted trainees' decisions. Alternatively, the trainer can manipulate ongoing crisis to bring back the execution to a desired behavior having already predicted courses. This kind of scenario modifications are stored in a knowledge base providing the ability to expand and evolve the system training capabilities during its use.

## The Trainee Model

The same timeline-based technology has been also used to represent the trainee model, that is a set of relevant human factors that influence the decision making and can be used to personalize the training paths. The selection of the factors relevant to build the trainee model has been inspired by different sources among which the analysis of the state-of-the-art, frequent interviews to our expert trainers as well as participation in real lessons as both trainees and observers. Specifically the analysis of the state-of-the-art has been particularly useful to identify the main "affective factors" that play a crucial role in the decision making under crisis, while the last two sources have contributed to ground the choice on a solid and concrete basis. The variables taken into account are *personality traits*, *leadership style*, *background experience*, *self-efficacy*, *performance*, *perceived stress* and *anxiety*.

Finally, by means of an holter monitoring system, *heart rate* and *beat-to beat variability* of trainees are also taken into account as a measure to assess the perceived stress/engagement.

These variables are subdivided between (a) *static* features that do not change during lessons, being mainly related to individual personality and (b) *dynamic*, which can be on the contrary related to both the context and the time, so they may vary during the training. Both dynamic and static variables are used to create the initial trainee profile, while the dynamic ones are also used to update the model.

The trainee model has also been enriched by additional information that regards the interaction with the system in terms of actions, decisions, inactivity time, amount of information shared with the other members of the group and so on. These additional info contribute to gather useful feedback on the trainee's interaction with the system that can be presented to the trainer both during the exercise, as an immediate feedback, and at the end of the session to support the debriefing phase.

### Static parameters

– *Personality Traits*. Personality refers to an "individuals characteristic patterns of thought, emotion, and behavior, together with the psychological mechanisms, hidden or not, behind those patterns" (Funder 2010). There are several inventories that investigate the personality traits. Among them we consider the Revised NEO Personality Inventory, or NEO-FFI (Five Factors Inventory), a psychological personality inventory measuring five main personality factors: *neuroticism*, *extraversion*, *openness to* *experience*, *agreeableness* and *conscientiousness* (Costa and McCrae 1985). NEO-FFI has been widely used to correlate behavior and internal personality traits and each of the "big five" has been associated to specific behaviors and/or predicted significantly various job performances, as well as the ability to cope with stress. Within PANDORA we used this measure to investigate the relationship between the personality traits and the performance of crisis decision makers, which is however not reported in this paper.

- *Leadership Style*. In (Northouse 2009) leadership is defined as a "process whereby an individual influences a group of individuals to achieve a common goal". Different classifications exist related to the leadership style. In particular (Bales 1958) distinguish between socio-emotional and task oriented. The "socio-emotional leader" takes into account feelings and moods of individuals, pays attention to the emotional aspects of interpersonal relationships. A leader focused on the task has as his constant concern the attainment by the group of its purposes. In order for a group to be "successful", both a socio-emotional leadership and a "task leadership centered style" is necessary. The leadership style can obviously not change with a short term training, but the training can be personalized in order to let the trainee understand the consequences of their leadership style on certain decisions and to encourage them to learn accordingly. Within PANDORA the trainer acts on this variable by modulating the lesson also to foster group decision making.
- *Background experience*. Another relevant variable for a crisis leader is obviously his/her past experience in managing crisis situations. We refer to this as background experience. A very short questionnaire has been used to assess leaders socio-demographic information, their previous experiences with leading public health and safety crises and their level of success in doing it. This variable is used also for tuning the right level of difficulty during the training exercise.

## Dynamic parameters

- *Self-efficacy*. Individuals belief in their capabilities to perform a certain task successfully has been defined by (Bandura 1986) as Self-Efficacy. It has been shown that this variable has influence on different aspects like managing stressful situation, increase the performance as well as receive benefits from training programs.
- *Stress and Anxiety*. In (Salas, Driskell, and Hughs 1996) stress is defined as "a process by which certain work demands evoke an appraisal process in which perceived demands exceed resources and result in undesirable physiological, emotional, cognitive and social changes". This definition is considered particularly relevant, since in an emergency situation a key factor is that demand often exceeds resources, both in the management of an emergency and in response options. As for the anxiety we distinguish between State Anxiety, which reflects a "transitory emotional state or condition of the human organism that is characterized by subjective, consciously perceived feelings of tension and apprehension, and heightened autonomic nervous system activity" and Trait Anxiety that denotes "relatively stable individual differences in anxiety proneness and refers to a general tendency to respond with anxiety to perceived threats in the environment". These two variables are assessed both before and during the training with psychological and physiological measures.
- *Performance*. An additional variable representing the individual and group performance is also used to adjust the training stimuli. We have added to some pre-canned actions a delta value. An estimate of the performance is automatically computed by the system by analyzing actions taken by trainees searching for this delta value. However, the system provides the trainer a graphical representation of the performance allowing the trainer to adapt the pre-computed performance of a trainee. It is worth saying that scenarios are designed for giving customized stimuli to trainees who need to collaborate. Trainees have to take joint decision that often update performance values and the trainer can still adapt the lesson so as to stimulate different collaborative skills.

## Physiological parameters

In order to enrich the trainee model within PANDORA as well as to adopt an orthogonal approach for the assessment of trainee's variables, we also use neurophysiological measures.

The physiological monitoring during the study was performed through Heart Rate (HR) and Heart Rate Variability (HRV), both directly associated with levels of stress and arousal (Dirican and Göktürk 2011; Mandryk, Inkepn, and Calvert 2006; Park 2009). An Holter monitor is part of the PANDORA system being responsible for recording these variables. HR and HRV are the parameters associated with the activity of the Autonomic Nervous System which consists of two major sub-branches: the sympathetic and the parasympathetic systems. The Sympathetic system is usually activated in stress generating emergency situations (states that generically require either "fight" or "flight") and are usually associated also to a level of engagement. In particular, the sympathetic nervous system, when activated, produces a series of effects such as rapid heartbeat, increased blood pressure, and increased sweating. In contrast, the parasympathetic nervous system is the normal response to a situation of calm, relaxation and absence of danger and/or stress. The parasympathetic system, when activated, usually induces a slower heart rate, increased bronchial muscle tone, decreased blood pressure, slower breathing, and muscle relaxation. Sympathetic signals increase HR while parasympathetic activity lowers HR, causing shorter and longer interbeat intervals, respectively (Acharya et al. 2006). The human body can be considered at any moment in a status that is determined either by the equilibrium or by the predominance of one of these two nervous systems. HRV is a measure of the continuous antagonism between sympathetic and parasympathetic effects on HR yielding also information about the capability to regulate emotional response. The most frequently used HRV parameters are spectral parameters such as low-frequency (LF) band and high-frequency (HF) band percentual powers. These values are related to the heart's sympathetic and parasympathetic activity. The LF band is mainly driven by the activity of the sympathetic nervous system while the HF band is considered an expression of the Parasympathetic Nervous System.

In this frame, within PANDORA we integrate the users psychological characteristics and measurements with the physiological parameters during the training sessions and crisis situations. The integration of these assessments is used along the whole training experience to both dynamically update the trainee model and to assess the level of engagement of the trainees (see later in the Evaluation Section).

## A Continuous Plan Adaptation

As described in previous section, starting from the scenario goals and from the set of domain compatibilities, the planning process generates a plan that is consistent with the given goals, ordering tokens in time through scheduling features and producing proper event consequences. Additionally new goals can be added during crisis simulation to represent (a) decisions taken by trainees, (b) inferences made by the behavioral reasoner, (c) new scenario steps added by the trainer. The PANDORA planner is therefore able to replan in order to make its current partial plan to remain consistent with respect to the new dynamic input and with its consequences, namely, changing the current course of the simulated crisis.

The trainee's profile is built by considering the relevant variables mentioned above and described in more detail in (Cortellessa et al. 2011). An initial assessment is made through standardized psychological tests and physiological measurements made off-line (through pre-created questionnaires), immediately before the training session begins and updated during the training session (through specific questions during the lesson).

The wide variety of possible combinations of behavioral parameters[4] together with the difficulty of making an accurate assessment have suggested the use of machine learning techniques to classify trainees. Given the discrete nature of the input data and a small amount of training data, we have chosen to use a C4.5 (see (Quinlan 1993)) algorithm to perform trainee classification. Machine learning techniques enabled us to customize the classification to the trainers specific style. Different trainers could use over time different rules and the machine learning techniques could consequently allow learning a "particular trainer style", so that it could be automatically adopted during the lesson.

[4]Although we could be more detailed in the scales or add additional variables to the profiles, we chose to use three values (Low, Medium and High) for each of the five parameters of the NEO-FFI questionnaire, two values for self-efficacy and two for anxiety. We ask trainees for perceived self-efficacy and perceived anxiety (dynamic measurements) using a ten value scale, we relay on a fifteen values for performance, three values for background experience and ten values for physiological stress resulting in 43740000 possible combinations.

Similarly to the storyboard, we chose to model trainees variables through timelines in order to maintain a homogeneous representation of information. We clarify this with a simplified example. To this purpose we consider two among the trainee features: (a) the *background experience*, represented through a state-variable assuming values 0 for low experience, 1 for medium experience and 2 for high experience; (b) the *perceived-stress*, represented through a state-variable assuming values ranging from 0 to 10.

Let us suppose that the heart beat rate of a trainee $t$ exceeds some threshold during a training session and that, consequently, his perceived-stress state-variable is updated. The compatibility that is applied by solving procedure will have a structure similar to the following:

$$t.perceived\text{-}stress \rightarrow \begin{cases} cat : x.category \\ during\,(this, cat, [0, +\infty], [0, +\infty]) \end{cases}$$

This compatibility assures that every time we have a perceived-stress update, a token, named $cat$ locally to the rule, is added to $category$ timeline of trainee $t$, new perceived-stress value must appear "during" $cat$ (triggering token's starting point is constrained to be $[0, +\infty]$ after $cat$'s starting point while $cat$'s ending point is constrained to be $[0, +\infty]$ after triggering token's ending point).

Let's assume now that the following rules, representing trainee categorizations, are defined inside the Behavioral Reasoner (notice that the real system considers all the parameters):

$$r_0 : (ps.value = 0 \wedge be.value = 0 \wedge cat.value = 0)$$

$$r_1 : (ps.value = 1 \wedge be.value = 0 \wedge cat.value = 1)$$

$$\dots$$

These rules basically state that, if perceived-stress value is equal to 0 and background-experience is equal to 0 then the $value$ parameter of $cat$ must be equal to 0, if perceived-stress value is equal to 1 and background-experience is equal to 0 than the $value$ parameter of $cat$ must be equal to 1. We use this set of rules as a learning set to the C4.5 algorithm that will retrieve us the category value when asked. The Behavioural Reasoner adapts the current plan generating consequences to the category value in terms, for example, of induced stress (e.g., in terms of difficulty presented to the trainee) and feedback for the trainee $t$. Finally, the Crisis Planner solves induced stress and feedback compatibility by selecting proper tokens from the domain knowledge and proposing them to the trainee $t$ (for example giving some encouragement words) in order to decrease the stress level with the aim of maximizing the learning process.

Token $cat$ is added to the current plan once the solving procedure is called and requires itself a compatibility application. The compatibility associated to the $category$ predicate is:

$$t.category \rightarrow \begin{cases} ps : (?)\, x.perceived\text{-}stress \\ be : (?)\, x.backgroung\text{-}experience \\ contains\,(this, ps, [0, +\infty], [0, +\infty]) \\ contains\,(this, be, [0, +\infty], [0, +\infty]) \\ value = C4.5\,(ps.value, be.value) \end{cases}$$

where the $(?)$ symbol forces target values $ps$ and $be$ to "unify" with an already solved event in order to close the loop and interrupt the pattern application process for the event. It is worth saying that the trainer can see at any moment the results of the trainee classification process and customize it, even in the middle of a lesson, to his/her strategy by adding his/her own specific classification rules enhancing the *mixed-initiative* approach.

## Executing the Lesson

Last crucial aspect of the PANDORA system is represented by the crisis scenario execution. Training process requires ease of temporal navigation through storyboard allowing execution speed adjustments as well as rewinding features. The simulation time $t$ is maintained by the execution module and increased of execution speed $dt$ at each execution step. Each timeline transition that appears inside interval $[t, t + dt]$ is then dispatched to the PANDORA rendering modules for creating the best effect for the target trainees.

Maintaining information about current simulation time, the executor module is responsible for placing in time tokens that represent trainees' actions, adding proper relations, thus fostering replanning features in order to integrate actions' consequences inside the current partial plan. Plan adaptation times are normally below few seconds. As trainees receive around one hundred and fifty stimuli during about a four hours span, the lesson results to be quite slow making replanning delays sufficiently transparent to the users.

Finally, going back in time, in order to revert to a crucial decision point at time $t'$, entails that actions taken after time $t'$ along with their consequences need to be deleted in order to allow a different simulation course.

Information related to execution is mainly shown to the trainer in a tabular form with a series of important information such as the execution time of each token and who is the main recipient of information. It is worth highlighting how this representation reproduces the current way of working of the trainers and has been instrumental in establishing a dialogue with them, before proposing any kind of completely new solutions. Having represented all the information given to the class, trainee's psycho-physiological state and their taken actions, through the common concept of timeline, the final plan represents a picture of the whole simulation and can be used by the trainer for debriefing purposes to possibly improve future training sessions.

## System Deployment and Evaluation

The PANDORA system has been deployed in a real training crisis room at the EPC premises and assessed in a three-days evaluation session.

Participants in the study have been recruited among the group of Gold Commanders who participate in training courses organized by EPC. Specifically 18 gold commanders were recruited and subdivided into three groups, one for each day, according to their level of expertise (basic, intermediate, high). Figure 3 shows a picture of one of the evaluation days. Evaluation covered different aspects like usability of the system, learning climate, influence of the psychological variables on the performance, perceived level of engagement , etc. For the sake of space, among these aspects we here concentrate on the ability of the PANDORA to reproduce engaging situations, which has been assessed, in addition to the self-reported assessment, through the use of the more objective physiological data analysis. To this purpose, trainees wore the portable Holter device during the whole training day. Each day was organized according to two different phases which we call respectively *Tutorial* and *Training*. During the Tutorial session, which lasted around 1 hour, participants were given a part of general typical traditional lesson by a trainer also receiving instruction on how to use the PANDORA. During the Training session, which lasted for the remaining part of the day, they were given a lesson through the PANDORA. The heart activity was monitored during the entire day in addition to the administration of the above mentioned questionnaires. Whenever any (or all) of the trainees overcame a certain HR threshold (individually set in order to recognize a possible increase in stress level), the working station automatically warned the trainer about such an increase that occurred in any of the experimental subjects.


Figure 3: PANDORA evaluation session with crisis managers

In particular the system is made so that starting from a baseline (different from one individual to another), whenever the subjects increase the heart rate by a certain percentage as compared to the baseline there is an alarm signal to the control computer. The software automatically saved the ECG trace and HRV analyses have been done off-line.

The analysis we report here is the difference between the HRV during the Tutorial and Training session. Figures 4 and Figure 5 show the difference of the HRV of trainees between the Tutorial and Training phases.

During the Training phase a predominance of the sympathetic tone has been detected again confirming the increased level of stress and engagement during the training phase based on PANDORA, with respect to the tutorial session. These findings supports the hypothesis that the system is able to reproduce engaging situations. It is worth underscoring that also the analyses of the questionnaires, not shown in this paper for the sake of space, confirm the per-

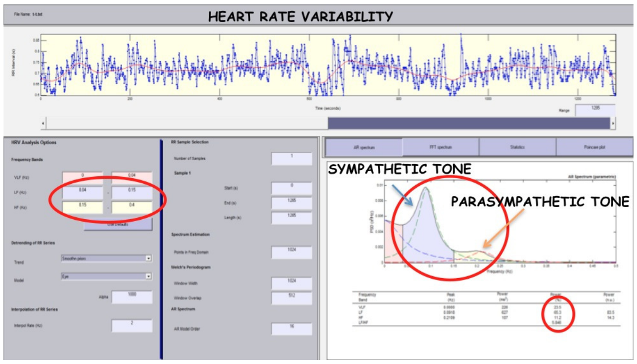


Figure 4: HRV during the Tutorial session

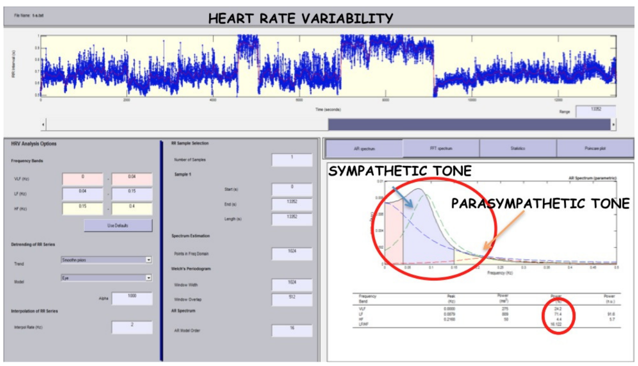


Figure 5: HRV during the Training session with PANDORA

ceived level of involvement of crisis managers during the training session with the PANDORA system.

In addition to the physiological analysis we also performed an interview to both trainers and trainees during the debriefing phase. The feedback obtained has been extremely positive especially with respect to the flexibility offered by the planning technology to create different courses of actions and *what-if* analysis situation. Indeed, the experiential learning is crucial for strategic crisis managers and the possibility to easily create different courses of actions and directly experience the consequences of their choices was particularly appreciated by both the trainers and the trainees to make learning points. The trainers also appreciated the possibility to easily and dynamically inject new events in the scenario having an updated situation of the lesson plan.

## Final Remarks

An application based on the use of planning technology can be, in our opinion, considered a success if it is able to support the problem in a comprehensive manner providing a system able to serve the whole cycle of usage.

In our case, the use of planning is at the basis of the back-end reasoning module, but it has been also shown to be functional to reproduce a situation which was perceived as realistic and immersive. This shows that the PANDORA has hidden the underlying technology so as to favor the realization of an engaging learning experience, thus achieving the pursued objective and serving the users requirements. The physiological results, also supported by the statements of the trainees during the debriefing, in fact, show that the crisis managers during the lesson felt immersed in a real situation and have almost forgotten to be in a simulated experience.

In this respect it is worth mentioning some of the comments from trainees: *[“... Really good, definitely as true to life as you can get in a training environment]”*; *[“... I like the flexibility of the system, it enables real decision making]”*; *[“... Real potential to understand your own ability and potentiality]”*; *[“... Flexible system, and truly dynamic]”*; *[“... I can deliver training to Senior Directors across the country simultaneously using this system]”*; *[“... Emotional learning to put you under stress is good, often we assume people can cope with the job we give them, when we find out they can’t, it’s too late!]”*;

These comments provide and indication of the positive feedback of trainees on the application and its potentiality in the long term, thanks also to the use of planning technology.

Finally, it is worth emphasizing the importance and usefulness of *plan adaptation*. This feature is supported by the flexibility of the timeline-based technology. For example, during the evaluation session crisis managers did not perceived any disruption in the course of events, reflecting the fact that the causal representation of the plan was able to satisfactorily capture the specificity of the domain.

## Conclusions

The main goal of the paper is to give the reader a comprehensive idea of the use of planning technology in PANDORA and how it has served to build a complete end-to-end application. In the design phase we have taken into account a number of cognitive features to support the analysis of the user involvement as well as the level of training personalization. Psychobiological features, indeed, are dynamically extracted from both trainees’ self assessment and physiological analysis and are used to enrich the training personalization. We have seen how the representation with timelines is the core component of both the crisis simulation and the user modeling, and that a continuous loop of planning, execution, plan adaptation is created to support personalized training still maintaining the Trainer in the loop. In order to prove the generality of the approach, we aim at enlarging the use of personalization strategies and their interrelationship with the timeline-based planning. In doing this, we have chosen not to use standard tools adopted in current learning management systems mostly because, as far as we know, they have limited support to interaction reducing the possibility for personalization and for physiological adaptation. The PANDORA system has been deployed in a real training facility and used continuously during a three-days evaluation session with real crisis managers who particularly appreciated the system capability of creating different courses of actions and showing the consequences of their strategic choices. The physiological assessment also confirmed the ability of the system to reproduce realistic and engaging crisis situations.

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