Complex Landscapes of Risk in Operations Systems
Aspects of Modelling and Processing

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***Abstract*— Large, dynamic landscapes of interdependent risks are potentially existential challenges to industry. Substantiated by an example out of a variety of concrete industrial cases, we discuss in this paper concepts of modelling and managing such landscapes in a new way. The starting-points of the concept are managerial responsibility, the propagation of risk along dependencies in complex operations' systems and resulting impacts, fundamental ambiguities of awareness, events' classification and mitigation of impacts. For solving these problems, we suggest semantic technologies and the programming paradigm of multi-agent systems that for this reason are to be leveraged by effective parallel computing.**

Keywords–Operations' Risk Management; Disambiguation; Semantic Technologies; High-End Computing.

I. INTRODUCTION: COMPLEX LANDSCAPES OF RISK

For the purpose of this paper we shall reduce the scope of *Risk Management* (RM) as it is described in ISO 31000 (2009) to is the task of managing the negative or positive impact of events under uncertainty [17]. The *Event Risk* (ER) is equal to a stochastically or statistically defined probability p, with $0 \leq p \leq 1$, where 1 and 0 represent certainty of occurrence or non-occurrence respectively.

In managerial contexts, the *relevance* of events is equal to its *Economic Expectation Value* (eEV), which is the product of event risk (p), impact (I, a monetary value) and awareness (A): eEV = p*I*A. Impacts may be positive or negative and will be experienced by at least one *victim* or *beneficiary*. We added the parameter of "awareness" to the model because it is an obvious prerequisite of managerial acting. So the awareness of a competitor's attack may be achieved too late. The factor of awareness again depends on factors like implicitness, ambiguity, ignorance, taboos, hubris or *unknown knowables and unknowables* [1] that may antagonize managerial effort. *Risk landscapes* (RL) develop from interacting risks and the value of p may be a function of other incidents: the risk of a denial of service attack depends on the probability to hijack a sufficiently large number of computers. That way, forward chaining of events is represented as risk of transit and negative impacts may be mitigated or eliminated by other events (consider noise cancellation) or meet a well prepared "victim". Accordingly, beneficiaries may not be that impressed by a price.

Time in Figure 1 passes from left to right with cones representing the universe of past and future events. Those to the left are causes and those to the right effects of the one in the centre. Given a maximum speed of propagation events outside delimitations can neither be causes nor effects of the event in the focus. In managerial contexts, except in computer trading [3], propagation is determined by physical or organisational parameters of the system, not at least by the factor of awareness. Further the cause of an event matters. But when the event has arrived immediate managerial action needs to focus on appropriate response. The causes are subject of back-office analysis.

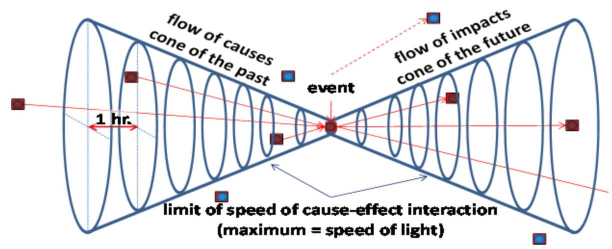

Figure 1. Cone of Cause-Effect Relations and Propagation.

Hence, landscapes of risk are (possibly very large) sets of interacting cause-effect cones with a system-specific behaviour. It is "the set of all (possible) events in the managerial universe" [4]. Complexity emerges from variety and resolution of object and time, the chance that more and more variant objects become source or target of more and more variant events. This reduces the control of a system's behaviour: due to Ashby's Law of Requisite Variety [5], controllers need to dispose of as much Discretion to Act (DTA) as the controlled system – but it should be the right ones.

This paper explains an industrial use-case (Section II), the need and aspects of computing the model (Section III), a semantic model of a risk landscape (Section IV) and concluded by a section on current and future work.

II. THE ARUM SCENARIO

The *ARUM project* [6], a project in the 7th European Research Framework Program, aims at improving ramp-ups of small series of complex products, chiefly in aviation industry. Delays and costs' explosions of the Airbus A380 or Boeing B787 exemplify the problem [7]. Nightmares may develop from a component (e.g., a bracket later used for harnessing) showing a failure that has slipped through previous tests. To avoid "*extrinsic hazards that can result in compromises in the quality of engineering*" [1], production management is obliged to report failures. But only engineering is entitled to ascertain the failure and to decide conditions to continue work. Thus production is interrupted and solutions may change technology needing to revise previous assemblies. So delays may sum up to weeks and costs to Millions of euros.

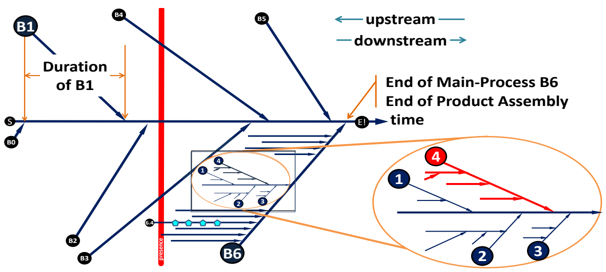

Figure 2. Diagram for Cause-Effect Analysis (fictitious example).

Landscapes of risk develop under such circumstances since at any time a variety of disruptions may occur at any node of operations. In short, the reasons are that competition pushes the technological envelops, that not all detail can be tested or that at some point in time capital intensity and small series enforce the start of production. After that immatureness of technology, resources, suppliers or processes are left to ramp-up management, now required to identify and clear up the nature of the problem, to assess impact, to select or in situ elaborate and to coordinate system-wide *policies* that mitigate impact. But although the defined technological and economical constraints may fail, they provide a reference that, as far as possible, is expected to be recovered. It also is an advantage that most aspects are transformed into monetary values.

The example of the faulty bracket mentioned above may lead to a formal declaration of '*non-conformity to design*' and by this withdraw many brackets of this type from production. If buffers are exhausted, the problem propagates along technical dependencies, the more the longer it takes to solve the problem. Figure 2 shows such dependencies in a *Fishbone Diagram* (a tool of Failure Effect and Mode Analysis [8]) matching the breakdown of work in a production system and relates to its *explosion of the bill of materials*. For this paper a time-line and a red line representing the present are added. The fictitious plant hosts lines B1 – B6, together delivering, e.g., an aircraft. Substructures are indicated for line B6 (bottom right). All assemblies finished in point B6 meet time constraints. The example of line B1 shows the duration of an assembly.

A station manager is expected to know "his" events' cones. So downstream, an NC-event that occurs in station 4 (marked in red) will disable the execution of subsequent work-orders in station 3 and following ones. Besides starting the NC-process, the station manager has only one obligation: mitigating negative impact by implementing a *policy* (pre-structured tactics). In in economic operations, this decision is driven by *economic relevance* (the eEV): Mitigating action is justified by exceeding a threshold of economic impact and policies need to provide adequate positive effect compared to the case of doing nothing.

In the case of the faulty brackets, a policy may be to implement an auxiliary solution, e.g. special cable ties, to be replaced later in time, but now applied in order to avoid far more expensive problems in station 3. However, further events may turn efficient policies into problems and so their effectiveness is to be tracked and changed: e.g., engineering needs more time and the problem propagates more than initially expected and planned. Alternatively, the policy may have to be suspended in order to save time and rework if station 3 is stopped for another reason, while the auxiliary solution is being implemented.

III. Efficient Handling of Landscapes of Risk

A. Managerial Concepts

A variety of use-cases from airports, airlines, inflight catering, large-scale technological ventures, or small series production show that even small operations systems can become very complex and not call for both, significantly improved planning capabilities and augmented awareness of system behaviour and the propagation of impact.

Effective policies are outcomes of operations' intelligence and deep knowledge about operations' behaviour like indicators of sensitivity or criticality. Policies may be an idea of proficient workers, step by step building a library of policies. Some are limited to a station or to a set of proceedings agreed between neighbour stations, others may refer to the main process or the whole factory. To ease rework policies may be considered in the design of the product. Some are documented or even certified, others may be used more informally.

In the simplest case an RL connects work-stations by sequential technical dependencies as indicated in Figure 2. But not all stations may be directly connected. A little more complicated model is shown in the Pert diagram [9] in Figure 3: a failure in station 6 may affect station 7 by stopping work in station 8 and shared resources may open another path of propagation.

Unplanned events with a serious impact switch the mode operations management from 'maintain standard operations' into 'manage an exception' with objectives different from standard proceedings. The background lies in the arguments of the formula eEV = p*I*A: If a substantial economic expectation value would have been identified already in planning, a proficient management would have planned for that contingency. If p or I are underestimated it arrives as unplanned event, and if A is (close to) 0 the event belongs to the class of *unknown knowables* [1].

While contingency buffers enable standard processes to breath, policies are temporarily implemented processes that exchange failing standard processes with the objective to recover (possibly improved) standard operations as soon as possible. Therefore the lifetime of policies is either limited to the time it needs to find and implement a solution recovering the initial or, if need be, a new standard or until a new event requires to change the policy.

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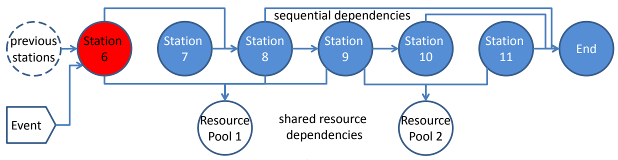

Figure 3. Pert-diagram of dependencies in Figure 2.

A policy has the planned impact to reduce a downside or to save an upside of the related unplanned event, both calculated from the eEV of the triggering event with p=1 and A=1 but still with an impact to be validated. As in real world the evaluation follows the way of propagation and, therefore, is calculated by the target stations until propagation is stopped. Considering first-level effects only, the impact of an unplanned event in station 6 in Figure 3 is equal to the sum of impacts in stations 7 to 11 and in the pools of resources (e.g., in terms of idleness).

As a process a policy employs resources and has costs. These resources may be (a) implemental ones like cable-ties that temporarily replace proper brackets for cables, or (b) contingency buffers that may even have been allocated to another purpose. The management of policies may use any discretion to act (DTA): In the cable-ties' example the chance to reduce rework was introduced as consequence of the actually negative event of failing operations in Station 3. In this way DTA belong to the 'fabric' of policies.

So the industrial cases have common demands: (a) to provide technology that supports back- and the front-office analysis and planning, and (b) to provide simulation-based training of managerial awareness of events.

With regard to the need for effective reasoning about the ambiguity of events, impacts and finally the value of policies, semantic technologies constitute the most promising approach and the integration of case-based, process-based and ontology-based reasoning. It should be noted that this concerns borders between conceptualisation strategies based on the (today most popular) root-concept of things on one side and on the root-concept of "process" (change) on the other side [13].

B. *Draft of a Multi-Agent Approach of Handling RLs*

Agent-based modelling and simulation (ABMS) provides means to handle RLs with thousands of geographically or organisationally distributed nodes. In the example, each node of the landscape, e.g., a work-station and its share in the work breakdown (fishbones in Figure 2 and resources assigned to it), pools of workers, inventories of resources etc. can be represented by one agent, or, if a deeper resolution of the network is required, further agents may represent elements of their substructures.

The choice of algorithms coding the behaviour of agents belongs to the core aspect of modelling. Examples are algorithms to check eligibility of resources to serve in a particular process (workers, tools or components need specified skills) or economic algorithms to minimize idle times. Methods will also control the behaviour of agents depending on constraints: e.g., agents of components of the product may be passive in a phase of transfer as one of many shipments (transport) or as one of many stock keeping units (storage) that temporarily are represented by one agent.

The impact of events and related activity is driven by communications between agents: affected by a statement of non-conformity (setting value of the attribute "eligible for" to zero) the withdrawal of respective resource(s) will cause a missing-resource event in the respective process, start evaluation of impact and activate mitigating action and respective implemental resources. The value of risk in this context may be defined by the responsible managers or calculated on the base of simulations and statistics.

But, also human factors and the variety or context sensitivity of latency times of organisations (slow decision procedures) or of IT-systems or material resources are to be modelled because each may substantially contribute to problems in synchronising activities and to disambiguate the character and control the impact of events.

The computational support of managing complex RLs calls for High-end or High-performance capacity, while however current multi-agent systems (MAS) are hardly designed for running under the conditions of present HPC/HEC environments and implementations, that again are less economic for applications imposing the burden of a high load of communication that is typical for MAS.

Technology arranging architecture and operations systems that provide high computational power and architectures of applications allowing high granularity and high adaptiveness to events are described in [14]: an example is the Repast HPC tool [16], offering both an editor for designing a multi-agent system and a platform organising and synchronizing interactions of agents in a way that is compatible to HEC/HPC environments.

To estimate the computational scale of simulating an RL, similarities to existing HEC applications deliver an idea: an architecture of a weather model with a number of interdependent geographic cells may compare to a network of interdependent cells of managerial responsibility (e.g., in a factory).

While the number of cells of the latter may be smaller, the variety of interactions is noticeably higher. And while weather models have clear inputs like temperature or humidity, managerial models may have to deal with the question "Is it the problem about humidity?". The phenomenon of immediate impact of human behaviour (awareness) implies that the disambiguation of events, of propagation, of building of patterns is not an input but an expected output of computing.

IV. A SEMANTIC MODEL OF EXCEPTION MANAGEMENT

A. *The Role of Ontologies in Operations' Risk Management*

Ontology is a formal specification of shared concepts within a domain and the relationships between those concepts and is used to improve communication between human beings and computers. With ontologies, a vocabulary capturing concepts that underlie knowledge of a specific domain can be defined [13]. For example, an ontology of a manufacturing domain would capture concepts describing seman-

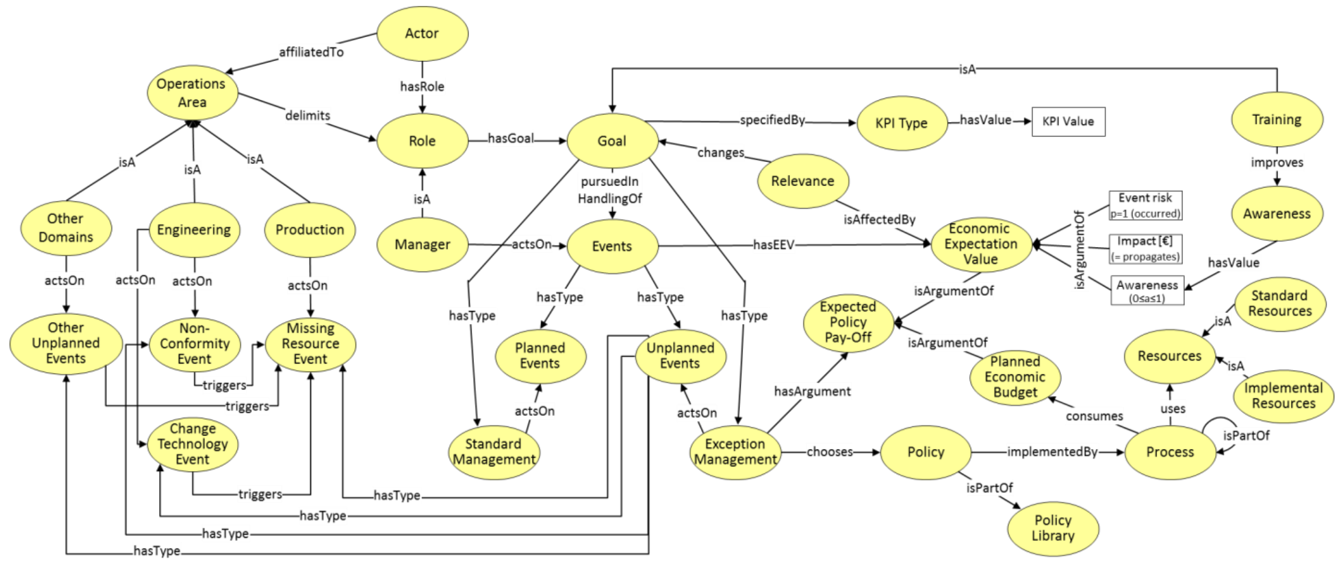

Figure 4. Ontology of Exception Management.

tically the existing production processes, the resources that are required for or the goals that need to be achieved by these processes. A risk exception management ontology, as the one presented in the lower section, should include the basic concepts of an unplanned event, the impact and risk values of this event, the management processes and policies applied in case of an exception, etc.

A major advantage offered by ontologies is the act of *Reasoning* or *Inference*. Reasoning is the process of deriving facts that are not explicitly stated in an ontology [14]. The process of inference can be achieved with a piece of software known as *Semantic Reasoner*. In the context of the RL of a factory, reasoning can be applied in order to identify the most appropriate policy to mitigate the impact of a negative unplanned event or to take advantage from the impact of a positive event that may follow a negative event. The reasoner should take into consideration the parameters of the context of the unplanned event, which include but are not limited to details of the work-order, the resources utilised during the process the event was raised, any other event that has preceded and the policies, if any, that were applied in order to mitigate the impact of this event.

Based on knowledge offered by the ontology, the need for the specification of a new policy, the application of an already existing one or even the re-evaluation of an already applied policy can be derived through the process of inference. In this manner, the semantic representation of policies in combination with the adoption of logic inference facilitates the control of a complex system, such as a manufacturing system, autonomously, thus, reducing human error.

Furthermore, a well-defined ontology can be used in combination with ontologies of different domains, providing the opportunity to build large-scale ontologies covering the concepts and the relations among them in a broader context. For example, in the semantic model presented in the lower section, the concept of time is planned to be expressed by means of a Time Ontology. Knowledge related to the engineering domain is planned to be modelled in an Engineering Ontology. Additionally, a unified ontology, providing a shared and reusable vocabulary, can be effectively used to govern the operational behaviour of multi-agent systems, where agents operate using knowledge from different domains. To sum up, the benefit of a unified semantic model is its flexibility, providing effective handling of heterogeneities, as well as its extensibility for additional semantic information, maintaining the Integrity of the Specifications

B. Ontological Model of Exception Management

In order to capture the aforementioned concepts, the ontological model shown in Figure 4 was created. When an event is raised, an instance of the *Event* class is created being either a *Planned Event* or an *Unplanned Event*. Each is associated with an *Economic Expectation Value*, which is formed by the *Event Risk* value, the *Impact* value and the *Awareness* value of the respective event. The latter may be improved by *Training*, which is a type of *Goal*. A *Goal* is assigned to a *Role* or a set of *Roles*, implemented by an *Actor*. Generally, a *Goal* is specified by a *KPI (Key Performance Indicator) Type*, which may be quantitative or qualitative, and is associated with a *KPI Value*. It is pursued within events handling by the responsible *Manager* and may be modified by *Relevance* of events due to the *Economic Expectation Value*.

Usually, a *Goal* may be either of type *Standard Management*, denoting an everyday production goal related to *Planned Events* handling, or *Exception Management*, representing the goal of dealing with an exception, referring to an *Unplanned Event*. Specifically, the *Exception Management* process, which may consist of one or more sub-processes, is responsible for choosing the appropriate *Policy*. A *Policy* may be explicitly elaborated and filed into a *Policy Library*. Implicit *Policies* are implemented during the exception handling process, in order to provide an intermediate solution by reducing the impact of the unplanned event's propagation and mitigating the impact of waiting time, during which it is necessary to find and implement an enduring solution.

Furthermore, each *Policy* is implemented by a *Process*, which uses *Resources* that may be either *Standard*, i.e., resources that are used by default according to the type of the production process, or *Implemental*, *i*.e., complementary resources that are not included in the work-order but it is known that they are able to substitute the resource in question. The aforementioned process consumes the *Planned Economic Budget*, which is an argument of the *Expected Policy Pay-Off*, taking also into account the *Economic Expectation Value* of the unplanned event. Note that the eEV now is determined by the value of expected propagation, only because the event has occurred so that p=1 and since the work on finding a policy implies that awareness has the value a=1.

Additionally, an appropriate type of the *Operations Area* performs a number of actions on different types of events. To be more specific, the *Production* department is responsible for the *Missing Resource Events* handling and the *Engineering* department for either *Non-Conformity Events* or *Change Technology Events*. *Other Domains* of a manufacturing company have responsibility for decision-making in the context of *Other Unplanned Events*. All of these events are types of *Unplanned Events*. Irrespective of the reason, a *Missing Resource Event* is raised when a required resource is not available in planning of production or in life production. It may be triggered by a *Non-Conformity Event*, a *Change-Technology Event* or an *Other Unplanned Event*, referring to sources that are not explicitly elaborated in the model.

A *Non-Conformity (NC) Event* may lead to a *Missing Resource Event*, since at the moment a product is declared "non-conformant", it is no longer available for use during production processes. An *NC Event* is considered to have ended when the final solution has been applied, since any intermediate solution can only mitigate the propagation of the event. A *Technology Change Event*, which may also trigger a *Missing Resource Event*, implies that a change of the used technology has been defined by an engineer and has to be implemented in the production line. In addition, each *Operations Area* specifies the responsibility of a *Role*, which may reflect the right or the obligation an actor with a specific role may have to act or decide.

V. HEC AND HPC SUPPORT

With many modern and often dynamical and interactive application scenarios, the term "high performance" is covering demanding applications that are on the one hand compute- and on the other hand data-centric. It is a common understanding that parts of the respective scenarios will support the exploitation of parallelism for their implementation.

High End Computing (HEC) systems can range from a desktop computer, through clusters of servers and data centres up to high-end custom supercomputers. Resources can be physically close to each other, e.g., in a highly performant compute cluster, or the compute power can be distributed on a large number of computers as with most Grid and Cloud computing concepts. Mostly, these architectures are used for task-parallel problems in classical capacity computing.

High Performance Computing (HPC) systems are based on architectures with a large number of processors, for exploiting massive parallelism. Commonly used models are Massively Parallel Processing and Symmetric Multi-Processing, used with the concept of local islands. Due to physically shared memory usage and compute communication, the physical architectures with these HPC systems are different.

Handling of RM processes will therefore focus on distributed components. Due to the physically different structure of highly distributed and massively parallel resources, the following aspects can be considered.

In the case of HEC, e.g., Cloud Computing, these components can be system resources acting autonomously like servers, being connected by external network means, being the ideal resources for events processing at capacity level. HEC resources can provide efficient means for massively distributed tasks. The non-availability of resources can be handled on a job or task base.

In the case of HPC, e.g., common with Scientific Computing on Supercomputing resources, the components can be internal network resources only, compute nodes on the one hand, being controlled by a management network and software, and management nodes on the other hand. The communication intensive modelling especially for the overall results and visualisation as well as the pre- and post-processing for the models will be suitable for use of HPC resources. In order to optimise the efficiency and economic use of the HPC resources and minimising the effects of job size fragmentation these resources should be used for a defined class of suitable large tasks within the workflow. Available resources can be configured as distributed HPC resources within the network provided for the described systems. Software Defined Networks (SDN) can provide modular solutions for this purpose.

VI. DISCUSSION

On corporate level risk is addressed by Enterprise Risk Management providing the integrating structure of strategies and proceedings as approached by actuarial sciences addressing both risk in terms of insurance business and of real industry with a comparing idea. "A major challenge here is a more substantial and realistic description and modeling of the various complex dependence structures between risks showing up on all scales" [15]. To our research, related work focuses on stochastic models not addressing the ambiguity of scenes and therefore neither takes a semantic approach nor is able of discrete, event-driven simulation or control. Although our work is still in a very early stadium, the industrial use-cases provide confidence that the particular computational approach discussed above at least will add a promising strategy to risk management in real economy under exceptional circumstances.Conclusion and Future Work

For operation and management, it has shown appropriate to focus on the RM concept and service levels [11] [12]. Therefore, MR or CT Events and related processes can be handled with less interference if services are defined and interfaces for the processes are created. This is especially important for the HEC, HPC, and communication resources required. For the HEC processes, this can be done on a service level Cloud base, whereas for the HPC resources available in research environments, this mostly will have to be assisted by service level agreement policies.

In both fields of semantic modelling and computation of industrial landscapes of risk, further work is to be done. One issue is that hybrid models require the integration of semantic conceptualisation with the mathematics of the neo-Bayesian school of probability [15]that significantly goes beyond the eEV-model used in this paper. Another aspect is that the relation between ontological and process-based reasoning (things and flows) may have to be revised [9].

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