Association for Information Systems

AIS Electronic Library (AISeL)

ECIS 2008 Proceedings

European Conference on Information Systems (ECIS)

2008

Formalising Risk with Value-Focused Process Engineering

Kristian Rotaru

Monash University, kristian.rotaru@buseco.monash.edu.au

Carla Wilkin

Monash University, carla.wilkin@buseco.monash.edu.au

Leonid Churilov

University of Melbourne, leonid.churilov@gmail.com

Dina Neiger

Monash University, dina.neiger@infotech.monash.edu.au

FORMALISING RISK WITH VALUE-FOCUSED PROCESS ENGINEERING

Rotaru, Kristian, Monash University, Department of Accounting and Finance, 900 Dandenong Rd, Caulfield East, Victoria, 3145 Australia, kristian.rotaru@buseco.monash.edu.au

Wilkin, Carla, Monash University, Department of Accounting and Finance, 900 Dandenong Rd, Caulfield East, Victoria, 3145 Australia, carla.wilkin@buseco.monash.edu.au

Churilov, Leonid, University of Melbourne, Parkville, Victoria 3052, Australia, leonid.churilov@gmail.com

Neiger, Dina, Monash University, Faculty of Information Technology, Clayton Campus, Wellington Rd, Clayton, Victoria, 3800 Australia, dina.neiger@infotech.monash.edu.au

Abstract

Following calls to advance the integration of risk and business process modelling paradigms, this paper formalises the process of incorporating risk into business process models through the principles of Value-Focused Process Engineering (VFPE). In doing so, the paper aims to extend the existing VFPE modelling notation to create a common syntax by which to represent risk in a goal-oriented business-process model. Risk is conceptualised on the one hand, as a product of complex interactions between activity-based elements, and on the other hand, as a natural component of the value creation mechanism of an individual function or complex process. Furthermore, the extended syntax provides a formalised systems-based view of risk as an emergent property of the interaction of activity-based elements at any level of process granularity. The proposed risk-aware VFPE formalism also formulates rules for decomposing risk in process models according to the organisational values, thereby enabling better risk visibility, reducing process complexity, and ensuring continuity of business processes.

Keywords: Risk, Business process, Formalism, Value-focused process engineering.

1. INTRODUCTION

Potentially affecting "things that humans value" (Klinke & Renn 2002, p.1071), risk is no doubt an important concept that needs to be investigated and formalised. The benefits of interpenetration of the research domains of process management and risk management have been voiced in the research community (e.g. zur Muehlen and Rosemann 2005, Neiger et al. 2006), in industry guidelines (e.g. COSO 2004) and are motivated by legislative requirements (e.g. Sarbanes-Oxley Act of 2002). However, the novel research domains of process-oriented risk management and risk-oriented process management (zur Muehlen & Rosemann 2005) still remain in infant states. Both, due to their interdisciplinary nature, are limited by objective factors such as the need to build multimethod research (Mingers 2001) in order to design and operationalise the integrated risk and process aware modelling frameworks. This paper responds to calls to explore ways decision sciences and business process modelling paradigms can be integrated to enable risk-aware modelling of business processes (zur Muehlen & Rosemann 2005, Neiger et al. 2006, Mock & Corvo 2005, Lambert et al. 2006) as well as to enable process-aware representations of risk (Scandizzo 2005, Jallow et al. 2007).

Most of the existing models in the literature that combine the properties of risk and process modelling do not provide clear guidance that formalises the relationships between model components to the level of formal descriptive syntax. Consequently the following research gaps have been identified that offer the potential to advance the domain of risk-aware process modelling:

a) Existing approaches that deal with risk modelling in business processes have not yet provided a formal modelling notation that would allow seamless integration of risk as an intrinsic component of a business process model. This research gap addresses issues of concise specification, design and operationalisation of risk-aware business process conceptual models.

b) When the *extended risk-aware Event-driven Process Chain (EPC)* model was introduced, zur Muehlen and Rosemann (2005, p. 8) expressed the opinion that it was "not possible to capture risks related to process elements other than functions", which limits the representation of risk as an integral part of the EPC modelling notation. Thus, there is a need to extend the formal representation of process-based risk as an integral part of an EPC model beyond the functional view in order to 'capture' process elements other than functions that affect activity-based risk.

c) Formalised principles that decompose activity-based risks according to the *hierarchical decomposition flow* required for complex processes (Davis 2001, p. 229) have not yet been proposed in the literature.

Neiger and Churilov (2004) developed a formal model that integrates the syntax of an extended Event-driven Process Chain (e-EPC) model (Keller & Teufel 1998) with the formalised representation of the Value-Focused Thinking framework (VFT) (Keeney 1992), which enables the decision science and process modelling components to be synchronized. The obtained goal-oriented business process model is based on the principles of Value-Focused Process Engineering (VFPE) systems methodology (Neiger & Churilov 2004, 2006). It is the contention of this paper that VFPE can provide descriptive tools and methodological guidance to enable the formal representation of a risk-aware business process model and moreover to meet the research needs identified above.

The *objectives* of this research are to address the knowledge gaps identified above in the following ways: a) to extend the existing VFPE modelling notation in order to enable a common syntax for a risk-aware goal-oriented business process modelling framework; b) to present a formal descriptive model of process-based risk on the level of individual e-EPC functions thus formalising the relationship between risk and process elements assigned to individual functions; c) to show how activity-based risk related to a complex process can be formally decomposed according to the hierarchical process decomposition flow, thus, enabling the synchronization of a process flow according to a decomposed activity-based risk structure. These objectives are achieved through the application of design science research principles that are directed towards "the development of design knowledge i.e. knowledge to be used in designing solutions to problems…" (van Aken 2004, p.225). As a design research output (e.g. March & Smith, 1995), a formal risk-aware VFPE model is suggested.

The novelty and original contribution of this paper concerns the formalised representation of risk at the level of individual process functions as *a property that emerges as a result of synergetic interrelationship between process elements assigned to the function*. Moreover, a novel hierarchical view on process-based risk is formulated by formalising the procedure of decomposing risks assigned to complex processes. Notably, this research has significance in the emerging field of process-aware information systems (PAIS) engineering (Dumas et al. 2005). Here the ability to decompose risk to the level of individual functions can facilitate the design of sustainable business processes, identify process bottlenecks and assure process continuity at any phase of the PAIS lifecycle.

In achieving its objectives, the paper is structured as follows. In the following section we review a VFPE formalism that enables the integration of process modelling and objectives modelling components. In Section Three we extend the VFPE formalism in order to provide a systems-based view of risk (Hatfield & Hipel 2002) on the level of an individual e-EPC function. In Section Four we formalise the rules for decomposing process risk to the level of individual e-EPC functions (presented in Section Three). Finally, we present our conclusions and future research directions in Section Five.

2. VALUE-FOCUSED PROCESS ENGINEERING (VFPE)

In this section we provide background on VFPE first formalising the process and objectives components within a single e-EPC model (Keller & Teufel 1998, pp. 158-167, Neiger & Churilov 2004) and then in Subsection 2.2 provide global consistency criteria (Neiger and Churilov 2004) that formalise the hierarchical relations between e-EPC models.

2.1 VFPE formalism in the context of a single e-EPC

In this subsection we suggest a common VFPE syntax that enables the formal representation of: a) static objects (such as goals, functions, events, logical connectors, etc) and links between objects (including assignment, flow and decomposition links); b) relationships between levels of processes and objective decomposition structures; and c) guidelines for synchronized movement between levels of the process and goal models.

As part of the VFPE model the e-EPC and VFT model components have been formalised as two distinct tuples (Neiger & Churilov 2004). In this paper we provide an aggregated syntax of the VFPE model by describing the objects and links within VFPE using a generic 7-tuple:

$g_t^I = \left\langle I_t, \nu_t, \kappa_t, \tau_t, \tau_t^{\kappa}, \alpha_t, \alpha_t^k \right\rangle$, where *t* is the model being described by the tuple (1)

The elements of this tuple are:

- I_t is a unique identifier of a model type *t*.
- ν_t is the non-empty, finite set of nodes of a model type *t*.
- κ_t is the relationship, which describes the connections between the various types of nodes.
- τ_t, τ_t^{κ} are representations that assign a type to every node or link.
- α_t, α_t^k are representations that assign attributes to every node or link type.

For the purposes of this research, we aggregate the formal representation of EPC and VFT components of the goal-oriented business process model into one tuple. In our formal representation of the VFPE model the *t*-subscript takes the value ϕ thereby combining the formal representation of a business process, the corresponding objectives structure, as well as the links between models and model elements on any level of process hierarchy. In the context of the VFPE model, τ, τ^{κ} representations are defined as follows:

$$\tau_\phi : \nu_\phi \to \left\{ \begin{array}{l} \text{function, event, process sign, AND connector, OR connector, XOR connector,} \\ \text{hierarchically ranked function, process goal, fundamental objective, means objective} \end{array} \right\}$$

$$\tau_\phi^{\kappa} : \kappa_\phi \to \left\{ \begin{array}{l} \text{control flow link, process decomposition link, goal assignment link, means} \\ \text{decomposition link, fundamental decomposition link, process decomposition link} \end{array} \right\} \quad (2)$$

The set of nodes used to formalise a VFPE model can be defined as:

$$\begin{aligned} &\text{E} = \left\{ \text{u} \in \nu_\phi | \tau_\phi(\text{u}) = \text{event} \right\} \\ &\text{F} = \left\{ \text{u} \in \nu_\phi | \tau_\phi(\text{u}) = \text{function} \right\}, \text{F} \neq \varnothing \\ &\text{F}_\text{H} = \left\{ \text{u} \in \nu_\phi | \tau_\phi(\text{u}) = \text{hierarchically ranked function} \right\} \\ &\text{P} = \left\{ u \in \nu_\phi \mid \tau_\phi(u) = \text{process sign} \right\} \\ &\text{O}_p = \left\{ u \in \nu_\phi \mid \tau_\phi(u) = \text{process/functional goal} \right\} \end{aligned} \quad (3)$$

Within a horizontal segmentation of a VFPE model, the functional flow is decomposed using the following logical operators:

$$
\begin{aligned}
&J_{AND} = \left\{ u \in v_{\phi} | \tau_{\phi}(u) = \text{AND connector} \right\} \\
&J_{OR} = \left\{ u \in v_{\phi} | \tau_{\phi}(u) = \text{OR connector} \right\} \\
&J_{XOR} = \left\{ u \in v_{\phi} | \tau_{\phi}(u) = \text{XOR connector} \right\} \\
&J = J_{AND} \cup J_{OR} \cup J_{XOR}
\end{aligned} \tag{4}
$$

The set B was introduced to represent the union of single e-EPC functions, hierarchical e-EPC functions, processes and logical connectors:

$$
B_1 = F \cup F_H \cup P;\ B_2 = F_H \cup P;\ B_J = B_1 \cup J \tag{5}
$$

The inherited EPC-based component of the VFPE model includes flows that link process elements according to the Architecture for Integrated Information Systems (ARIS) (Scheer 1999). Placing particular emphasis on the goal component of the individual functions and processes, the VFPE syntax formalises the goal assignment link as a separate link, which is aggregated in the original e-EPC model as part of the Organisation/Resource flow link.

$$
\begin{aligned}
&(u,v) \textit{ is a link from node u to node v}: \\
&(u,v) \in K_K :\Leftrightarrow \tau_{\phi}^{\kappa}\left((u,v)\right) = \text{control flow link} \Leftrightarrow K_K = \left\{(u,v) \in (B_J \times E) \cup (E \times B_J) \cup (J \times J)\right\} \\
&(u,v) \in K_O :\Leftrightarrow \tau_{\phi}^{\kappa}\left((u,v)\right) = \text{goal assignment link} \Leftrightarrow K_O = \left\{(u,v) \in (B_1 \times O_p) \cup (O_p \times B_1)\right\}
\end{aligned} \tag{6}
$$

Keller and Teufel (1998) and Neiger and Churilov (2004) use the following concepts in order to formalise the EPC model:

Positive and negative adjacency lists of a node v:

$$
\begin{aligned}
&adj^{+}(v,w) = \left\{ u \in v \,|\, (v,u) \in \kappa_{\phi} \wedge \tau_{\phi}^{\kappa}\left((u,v)\right) = w \right\} \\
&adj^{-}(v,w) = \left\{ u \in v \,|\, (v,u) \in \kappa_{\phi} \wedge \tau_{\phi}^{\kappa}\left((v,u)\right) = w \right\}
\end{aligned} \tag{7}
$$

Output and input degrees of a node v:

$$
\gamma^{+}(v,w) = \left|adj^{+}(v,w)\right|;\ \ \gamma^{-}(v,w) = \left|adj^{-}(v,w)\right| \tag{8}
$$

Positive and negative incidence lists for node v:

$$
inz^{+}(v,w) = \left\{ (v,u) \in \kappa_{\phi} \,|\, \tau_{\phi}^{\kappa}\left((u,v)\right) = w \right\};\ \ inz^{-}(v,w) = \left\{ (u,v) \in \kappa_{\phi} \,|\, \tau_{\phi}^{\kappa}\left((u,v)\right) = w \right\} \tag{9}
$$

Number of incidence nodes for node v:

$$
z^{+}(v,w) = \left|inz^{+}(v,w)\right|;\ z^{-}(v,w) = \left|inz^{-}(v,w)\right| \tag{10}
$$

The constructs formalised in formulas 7-10 help to define the following elements of an EPC model:

Start and end events for an EPC:

$$
\begin{aligned}
&E_s = \left\{ u \in E \,|\, \gamma^{-}(u,w) = 0 \wedge \gamma^{+}(u,w) = 1, \text{ where } w \in K_K \right\}, E_s \neq \varnothing \\
&E_e = \left\{ u \in E \,|\, \gamma^{-}(u,w) = 1 \wedge \gamma^{+}(u,w) = 0, \text{ where } w \in K_K \right\}, E_e \neq \varnothing
\end{aligned} \tag{11}
$$

Events proceeding and following hierarchically ranked functions:

$$E_{ps} = \left\{ u \in E \mid \exists v,\, v \in B_2 \wedge u \in adj^{+}(v) \right\};\;\; E_{pe} = \left\{ u \in E \mid \exists v,\, v \in B_2 \wedge u \in adj^{-}(v) \right\} \quad (12)$$

Connector nodes that follow a function indicating a horizontal decomposition of a process flow:

$$\begin{aligned} FC_{AND} &= \left\{ u \in J_{AND} \mid \exists v,\, v \in B_1 \wedge u \in adj^{-}(u) \right\} \\ FC_{OR} &= \left\{ u \in J_{OR} \mid \exists v,\, v \in B_1 \wedge u \in adj^{-}(u) \right\} \\ FC_{XOR} &= \left\{ u \in J_{XOR} \mid \exists v,\, v \in B_1 \wedge u \in adj^{-}(u) \right\} \\ FC &= FC_{AND} \cup FC_{OR} \cup FC_{XOR} \end{aligned} \quad (13)$$

The VFPE methodology adopted the representation of organisational objectives provided by Value-Focused Thinking (VFT) (Keeney 1992). In order to avoid confusion, it should be emphasized that in the VFPE framework, the term "objective" rather than "goal" (e-EPC) has been used to describe "a statement of something that one wants to strive toward" (Keeney 1992, p. 34). Further, within the VFT framework objectives are classified into two major classes: *fundamental objectives* that describe business values and are structured as a hierarchy; and *means objectives* that describe the means of achieving fundamental objectives and are structured as a network referred to as the means-ends (or simply means) network.

$$\begin{aligned} O_M &= \left\{ u \in v_{\phi} \mid \tau_{\phi}(u) = \text{means objective} \right\} \\ O_D &= \left\{ u \in v_{\phi} \mid \tau_{\phi}(u) = \text{fundamental objective} \right\} \end{aligned} \quad (14)$$

The flow links assigning fundamental and means objectives have been represented as follows:

$$\begin{aligned} &(u,v) \in K_D :\Leftrightarrow \tau_{\phi}^{\kappa}((u,v)) = \text{fundamental decomposition link} \;\Leftrightarrow \\ &K_D = \left\{ (u,v) \in (O_D \times O_D) \cup (O_M \times O_D) \cup (O_D \times O_M) \right\} \end{aligned} \quad (15)$$

Neiger and Churilov (2004) have incorporated the decision science component represented by VFT into a process-based model and modified it by including logical connectors (4) within the means-ends framework and by applying directional links to connect means objectives:

$$\begin{aligned} &(u,v) \in K_M :\Leftrightarrow \tau_{\phi}^{\kappa}((u,v)) = \text{means decomposition link} \;\Leftrightarrow \\ &K_M = \left\{ (u,v) \in (O_M \times O_M) \cup (O_M \times J) \cup (J \times O_M) \right\} \end{aligned} \quad (16)$$

The notation $u \xrightarrow{C} v$ adopted from Keller and Teufel (1998, p.160) is used as part of the VFPE syntax to describe a path that is defined as a connection from node *u* to node *v* by a chain of other nodes and connectors, where *C* represents the series of nodes and connectors included in the path. For any nodes on a VFPE path the following is true:

$$u,v \in C \;\exists\; (u,v) \Leftrightarrow (u,v) \in K_K \cup K_O \quad (17)$$

The adopted VFPE objectives structure implies that the previously defined notion of process-based goal (4) that is inherited as an object of the ARIS notation (Scheer 1999, 2000), may also be referred to in the new context as a *process/functional objective*. This does not alter the initial meaning of the concept of goal attributed by ARIS. Furthermore, it allows these two notions to be used interchangeably (Neiger & Churilov 2004). Consequently, process/functional objectives are a subset of means objectives and the set of process/functional objectives does not intersect with the set of fundamental objectives for the same business:

$$\left(O_P \subseteq O_M \right) \wedge \left(O_P \cap O_D = \varnothing \right) \quad (18)$$

Process objectives are linked to each other and other means objectives that are not directly assigned to an individual function or complex process with means decomposition links:

$$\forall \mathrm{u,v} \in \mathrm{O_P}\ \exists\ \mathrm{v} \xrightarrow{\mathrm{C}} u \Leftrightarrow \forall x,y \in C,\ (x,y) \in\ \mathrm{K_M}$$
$$\forall \mathrm{u} \in \mathrm{O_P},\ \mathrm{v} \in \mathrm{O_M} \backslash \mathrm{O_P} \exists\ \mathrm{u} \xrightarrow{\mathrm{C}} \mathrm{v} \Leftrightarrow \forall x,y \in C,\ (x,y) \in\ \mathrm{K_M} \qquad (19)$$

Fundamental objectives are linked to process objectives with fundamental decomposition links:

$$\forall \mathrm{u} \in \mathrm{O_P},\ \mathrm{v} \in \mathrm{O_D}\ \textit{if}\ \exists\ \mathrm{v} \xrightarrow{\mathrm{C}} \mathrm{u} \Leftrightarrow \forall x,y \in C,(x,y) \in\ \mathrm{K_M} \cup \mathrm{K_D} \wedge \exists x,y \notin \mathrm{J},(x,y) \in \mathrm{K_D} \qquad (20)$$

A complete list of the local consistency criteria that formalise the properties of a single-level VFPE model can be found in the following sources. Keller and Teufel (1998) provide the criteria for the e-EPC component of the VFPE model, while Neiger and Churilov (2004) provide the criteria for the VFT component of the VFPE model and formalise the conceptual link between these two components.

2.2 VFPE formalism: a global process view

In order to formalise the hierarchical relations between e-EPCs, Neiger and Churilov (2004) have extended Keller and Teufel's (1998) declarative description of a single e-EPC model. They have suggested that the space of all e-EPC tuples within a business process model and the process decomposition links between e-EPCs can be represented as:

$$G_t = \bigcup_i g_t^i,\ i \in I_t$$
$$(\mathrm{u,v}) \in \mathrm{K_H} :\Leftrightarrow \tau_\phi^\kappa\left((u,v)\right) = \text{process decomposition link} \Leftrightarrow \mathrm{K_H} = \left\{(\mathrm{u,v}) \in (\mathrm{B_2} \times \mathrm{G}_\phi)\right\} \qquad (21)$$
$$\mathrm{K_{VFPE}} \in \mathrm{K_K} \cup \mathrm{K_O} \cup \mathrm{K_D} \cup \mathrm{K_M} \cup \mathrm{K_H}$$

Moreover, as part of a global view on an e-EPC, the function Ψ has been introduced that operates on that space of e-EPCs and allows all objects of the same nature from a given tuple (such as links and nodes) to be selected:

$$\Psi : \left\{G_t\right\} \times \left\{1,2,3,4,5,6,7\right\}$$
$$\Psi\left(g_t^I, n\right) := n^{th}\ \text{element of}\ g_t^I \qquad (22)$$

These definitions (see above) mean it is possible to suggest a list of global consistency criteria that describe the characteristics that are necessary for a multi-level business process model within the e-EPC notation. These are presented below:

G1. Process decomposition links cannot be used to connect nodes within an e-EPC to that e-EPC.

$$\forall i \in I_\phi,\ u \in \Psi\left(g_\phi^i, 2\right) \Rightarrow \nexists\left(u, g_\phi^i\right) \in K_H \qquad (23)$$

G2. If an e-EPC is a subordinate of another e-EPC, it cannot also be its higher level e-EPC.

$$\forall i,j \in I_\phi, u \in \Psi\left(g_\phi^i, 2\right) \cap B_2, v \in \Psi\left(g_\phi^i, 2\right) \cap B_2, \left(u, g_\phi^i\right) \in K_H \Rightarrow \nexists\left(v, g_\phi^i\right) \in K_H \qquad (24)$$

G3. A process sign doesn't include events in its adjacency list.

$$\forall i \in I_\phi, u \in \Psi\left(g_\phi^i, 2\right) \cap P, w \in \Psi\left(g_\phi^i, 2\right) \cap \left\{adj^+(u,w) \cup adj^-(u,w)\right\} \Rightarrow w \notin E \qquad (25)$$

G4. The start event of a subordinate e-EPC corresponds to the predecessor event of the hierarchically ranked function and is linked to that e-EPC using process decomposition links. Similarly, the end event of a subordinate e-EPC corresponds to the successor event of the hierarchically ranked function and is linked to that e-EPC using process decomposition links.

$$\forall i,j \in I_\phi, i \neq j, u \in \Psi\left(g_\phi^i, 2\right) \cap F_H, e_e \in \Psi\left(g_\phi^i, 2\right) \cap E_{ps}, e_e \in \Psi\left(g_\phi^i, 2\right) \cap E_{pe},$$
$$(e_s, u), (u, e_e) \in K_R, (u, g_\phi^i) \in K_H \Rightarrow e_s \in \Psi\left(g_\phi^i, 2\right) \cap E_s, e_e \in \Psi\left(g_\phi^i, 2\right) \cap E_e \qquad (26)$$

As the VFT component of VFPE describes a fully decomposed network of objectives for a business, it does not require a statement of global criteria. Thus, having outlined the basic VFPE principles, it is now possible to introduce the conceptual and formal view of risk at the level of individual e-EPC function.

3. FORMALISING A SYSTEMS VIEW OF PROCESS RISK

In this section we adopt a holistic representation of risk at the level of the individual e-EPC function. According to the systems theory view of risk (e.g. Hatfield & Hipel 2002) we define risk as an emergent property of the interaction of process elements and formalise it through the following components: *1) risk as a subset of means objectives; 2) risk sources; and 3) risk triggers.*

3.1 Conceptual representation of risk on the level of individual e-EPC function

In this paper we adopt a systems view of risk as well as of the context where risk emerges. According to Melao and Pidd (2000) a business process can be regarded as a complex dynamic system. On the other hand, risk in the context of the business process can be conceptualized as an *emergent property of a system* (White 1995, Hatfield & Hipel 2002). The adopted systems view of risk allows us to interpret risk as an emergent property of a business process that is shaped by the interaction of the elements of this business process (Daellenbach 1994). It also implies that a clear separation between risk and process elements is not achievable as risk is a product of complex interactions between process elements. However, formalising the conceptual elements that contribute towards the emergence of risk in a business process would provide a generalized view on risk as an intrinsic property of a business process. We represent below the components of the suggested '*risk emergence view'* that conceptualise risk on the level of the individual process functions.

Risk as a subset of means objectives: Using Keeney's (1992) classification of objectives into fundamental and means objectives, risk minimization is not a fundamental business objective - modelling risk in a business process *per se* would be irrelevant if the presence of risk were not to compromise the achievement of other business objectives. In a business environment the importance of modelling and analysing risk is dictated by the fact that risk is a "goal-sensitive" concept (zur Muehlen & Rosemann, 2005) and is a means that may potentially affect the achievement of business objectives. Therefore, we represent risk as a subset of functional means objectives that according to Keeney (1992) assure the achievement of business values. As part of the means objectives network, risk objectives can form part of the function/process-based set of objectives when they are specified as something that an individual function or a complex process is aimed at achieving. In order to introduce a risk-aware view on the functional value creation process we suggest that the process/functional goal introduced as part of the VFPE formalism (4) be split into two distinct objectives: 1) *performance objective* that aims to achieve activity-specific potential in terms of quality and other performance indicators; and 2) *risk objective* that aims to minimize the overall activity-based exposure to possible failure. This dual representation of activity-based objectives reflects the dichotomy of the value creation mechanism that is subject to any level of business process decomposition and puts risk in the context of other performance dimensions of an organisation. Both objectives structures are required to fulfil the high level process/functional objectives.

Risk sources: The systems view of risk makes it possible to assign risk to a set of "entities of concern" or in other words the sources of risk. The structured representation of the process/functional risk sources has been referred to as the *e-EPC taxonomy of risk sources.* This taxonomy is different to the *taxonomy of process-related risks* suggested by zur Muehlen and Rosemann (2005) and is based on the elements of the e-EPC notation enabled by the different views of the ARIS Architecture (Scheer 1999). These elements represent human, informational, and other internal and external resources assigned to an individual function that support the value creation mechanism of an individual function.

Risk triggers: According to Scandizzo (2005) process/functional-based resources have a greater potential to cause an operational level failure if they are inadequate or corrupted in at least one of the following ways: the resource may be insufficient in *quality* or *quantity*, *unavailable* at a critical stage or may be subject to a *breakdown*. These four criteria are referred to in this paper as *risk triggers*. Therefore, each function within an e-EPC is linked to different functional resource elements that may also be referred to as risk sources. Each of the risk sources, when affected by at least one risk trigger, has the potential to cause an adverse event that will have a negative impact on the achievement of at least one functional risk objective. The same applies to complex e-EPC processes.

Therefore, we conceptualise the notion of an *activity risk* as an activity-related emergent property that: a) is a result of a systemic interaction between risk triggers and internal and external resources utilised by this activity; b) can be directly evaluated through a scale uniquely linked to a specific activity-related risk objective; and c) can potentially result in an adverse event that immediately succeeds the activity under consideration. Note that one obvious example of an appropriate evaluation scale may include a suitably chosen combination of probability and impact ratings of an adverse event. Detailed discussion of scale development for risk objectives evaluation is addressed in VFT component (Keeney, 1992) of VFPE methodology and is beyond the scope of this paper.

3.2 Formal integrated risk model on the level of individual e-EPC function

We extend the VFPE formalism in order to introduce the concept of risk on an individual e-EPC function level. As per Section 2.1, the formal risk-aware e-EPC model is formally represented as a generic 7-tuple (1) and the *t*-subscript that defines the type of model being described by the tuple takes the value *r*. Therefore the relationship between the elements of the VFPE model represented in Section 2.1 and the risk-aware VFPE model elements can be formally represented as follows:

$$\tau_\phi \cup \tau_r \subseteq \tau_t,\ \tau_\phi^k \cup \tau_r^k \subseteq \tau_t^k \qquad (27)$$

The following types of nodes and links based on the representation of the ARIS Architecture (Scheer 1999) have been added to the VFPE model (Section 2.1) to enable the integration of risk:

$$\tau_r : v_r \to \left\{ \begin{array}{l} \text{environmental data, application software, activity output, human output,} \\ \text{computer hardware resource, machine resource, organisational unit,} \\ \text{process/functional risk objective, process/functional performance objective,} \\ \text{adverse event, activity-based source affected by one or a set of risk triggers} \end{array} \right\} \qquad (28)$$

$$\tau_r^\kappa : \kappa_r \to \{\text{organisation/resource/information flow link}\}$$

To facilitate our objective of demonstrating how risk can be formally represented as part of the VFPE formalism, we extend the model's notation by introducing seven additional elements. These elements represent the list of e-EPC classes provided by Scheer (1999) and are referred to as functional resource elements.

$$\begin{array}{l} \mathrm{D} = \{u \in v_\phi \mid \tau_\phi(u) = \text{environmental data}\} \\ \mathrm{AS} = \{u \in v_\phi \mid \tau_\phi(u) = \text{application software}\} \\ \mathrm{IO} = \{u \in v_\phi \mid \tau_\phi(u) = \text{activity input/output}\} \\ \mathrm{H} = \{u \in v_\phi \mid \tau_\phi(u) = \text{human output}\} \\ \mathrm{C} = \{u \in v_\phi \mid \tau_\phi(u) = \text{computer hardware resource}\} \\ \mathrm{M} = \{u \in v_\phi \mid \tau_\phi(u) = \text{machine resource}\} \\ \mathrm{OU} = \{u \in v_\phi \mid \tau_\phi(u) = \text{organisational unit}\} \end{array} \qquad (29)$$

The set of resource elements assigned to a process or an individual function can also be represented as:

$$S = D \cup AS \cup IO \cup H \cup C \cup M \cup OU \qquad (30)$$

In this paper, for simplicity's sake, the non-directional assignment links such as organisation flow, output flow, resource flow, human output flow and information flow have been proposed according to Scheer (1999) and have been aggregated as follows:

$(u,v) \in \kappa$ is a link from node u to node v

$$(u,v) \in K_{ORI} :\Leftrightarrow \tau_{\phi}^{\kappa}\left((u,v)\right) = \text{aggregated organisation/resource/information flow link} \Leftrightarrow \qquad (31)$$

$$K_{ORI} = \left\{(u,v) \in (B_1 \times S) \cup (S \times B_1)\right\}$$

The set of all types of links presented in a risk-aware VFPE model is expressed as:

$$K_{VFPE}^{R} \in K_K \cup K_O \cup K_{ORI} \cup K_D \cup K_M \cup K_H \qquad (32)$$

As discussed in the previous subsection, for each individual process function the process/functional goal (3) is split into a process/functional risk objective and process/functional performance objective. These are later referred to as *process risk objective* and *process performance objective.*

$$O_R = \left\{u \in \nu_r | \alpha_r(u) = \text{ process/functional risk objective}\right\},\ O_R \neq \varnothing$$

$$O_{pf} = \left\{u \in \nu_r | \alpha_r(u) = \text{ process/functional performance objective}\right\},\ O_{pf} \neq \varnothing \qquad (33)$$

An adverse event as well as an aggregated set of process/functional risk sources is defined:

$$E_R = \left\{u \in \nu_r | \alpha_r(u) = \text{adverse event}\right\};\ S_R = \left\{u \in \nu_r | \alpha_r(u) = \text{process/functional risk source}\right\} \qquad (34)$$

In order to represent the risk sources that are affected by one or a set of risk triggers (see Subsection 3.1 'Risk triggers'), an R-index is assigned to the process/functional resource elements (29).

$$S_R = D_R \cup AS_R \cup IO_R \cup H_R \cup C_R \cup M_R \cup OU_R \qquad (35)$$

The rules presented below formalise the risk-aware view of an e-EPC model on the level of an individual e-EPC function:

E1. The union of all process risk objectives and process performance objectives is logically equivalent to the set of all process objectives.

$$O_R \cup O_{pf} :\Leftrightarrow O_P \qquad (36)$$

E2. The set of all risk sources assigned to an individual function or complex process is a subset of the set of all sources assigned to this function or process.

$$S_R \subseteq S,\ S \neq \varnothing \qquad (37)$$

E3. There is at least one process risk objective and at least one performance risk objective assigned to an individual function:

$$\forall u \in O_R \cup O_{pf} : \exists v \in F : v \xrightarrow{C} u,\ \left(O_R \neq \varnothing\right) \wedge \left(O_{pf} \neq \varnothing\right) \qquad (38)$$

E4. In the context of risk-aware goal-oriented business process modelling, each function is linked to its risk and performance objectives with the goal assignment link:

$$\forall u \in B_1 : \left(\exists v \in O_R : (u,v) \in K_O\right) \wedge \left(\exists v \in O_{pf} : (u,v) \in K_O\right) \qquad (39)$$

E5. In the context of risk-aware goal-oriented business process modelling, each individual function is linked to its risk sources with the organisation/resource/information flow links:

$$\forall u \in B_1\ \exists v \in S_R : (u,v) \in K_{ORI} \qquad (40)$$

E6. In the context of risk-aware VFPE, each individual function can be followed by an adverse event, which is linked to this function with the control flow link:

$$\forall u \in B_1 \ \exists v \in E_R : (u,v) \in K_K \wedge v \in adj^-(u) \tag{41}$$

In this section we have shown how risk can be integrated in a business process model such as e-EPC. Further, the components of the 'risk emergence view' that conceptualise risk on the level of the individual e-EPC function have been proposed. Then the relationship between risk and process elements assigned to individual process functions has been formalised based on the VFPE modelling principles.

4. RISK DECOMPOSITION WITH VFPE

In Section 4 a hierarchical approach to risk decomposition in complex processes is represented. The VFT component of VFPE provides the rules to guide the process of risk and performance objectives decomposition (Neiger & Churilov 2006, Neiger et al. 2008).

4.1 Conceptualizing the hierarchical decomposition of risk in a business process

According to Neiger et al. (2006) and Neiger et al. (2008) VFPE inherits the properties of VFT and e-EPC components and acquires emergent properties that are unique to VFPE as a result of the synergetic interrelationship between these components. These properties include the decomposition of business objectives to each level of business activity. Further we map the generic workflow patterns introduced by van der Aalst et al. (2003) to the means network structure in order to link the order activities are executed to the achievement of objectives.

Scheer (2000) acknowledges that the association between functions and objectives can be inherited by higher levels of process hierarchy. According to the *synchronized decomposition* principles (Neiger & Churilov 2006, Neiger et al. 2008), the top-down approach to process risk and performance objectives decomposition would decompose the associated process-based risk and performance objectives. After risk and performance objectives are decomposed to the elementary "atomic level" (Neiger & Churilov 2006, p. 5), engineering of the corresponding process can be enabled.

4.2 Formalising the hierarchical decomposition of risk in a business process

Since risk objectives structure and risk performance structure connect at the higher level of the objectives network (see Subsection 3.1), for ease of representation and without loss of generality, only rules applied to risk objectives decomposition are represented below.

R1. Process risk objectives represent a subset of process objectives which are, consequently, a subset of means objectives. According to the VFPE modelling principles (Neiger & Churliov 2004), the set of process risk objectives does not intersect with the set of fundamental objectives for the same business.

$$\left(O_R \subseteq O_P \subseteq O_M\right) \wedge \left(O_P \cap O_D = \varnothing\right) \Rightarrow O_R \cap O_D = \varnothing \tag{42}$$

R2. Process risk objectives are linked to each other and other process and means objectives with means decomposition links.

$$\begin{aligned} &\forall u, v \in O_R \ \exists \ v \xrightarrow{C} u \Leftrightarrow \forall x, y \in C,\ (x,y) \in K_M \\ &\forall u \in O_R,\ v \in O_M \backslash O_R \ \exists \ u \xrightarrow{C} v \Leftrightarrow \forall x, y \in C,\ (x,y) \in K_M \end{aligned} \tag{43}$$

R3. As part of the means objectives network, process risk objectives have one inbound and/or one or several outbound means objective decomposition links.

$$\forall u \in O_R, v \in K_M : \left(z^-(u,v) = 0 \vee z^-(u,v) = 1\right) \wedge \left(z^+(u,v) = 0 \vee z^+(u,v) \geq 1\right) \tag{44}$$

R4. Each process risk objective is part of a path that starts at a fundamental objective.

$$\forall \mathrm{u} \in \mathrm{O_R} : \exists v \in \mathrm{O_D} : \mathrm{v} \xrightarrow{\mathrm{C}} u \quad (45)$$

R5. Fundamental objectives are linked to process risk objectives with fundamental decomposition links.

$$\forall \mathrm{u} \in \mathrm{O_R},\ \mathrm{v} \in \mathrm{O_D}\ \text{if}\ \exists\ \mathrm{v} \xrightarrow{\mathrm{C}} \mathrm{u} \Leftrightarrow \forall x, y \in \mathrm{C},\ (x,y) \in \mathrm{K^R_{VFPE}} \wedge \exists x, y \notin \mathrm{J}, (x,y) \in \mathrm{K_D} \quad (46)$$

R6. Functions within the highest level of process hierarchy must be linked to at least one risk objective within the highest level of the means network.

$$\begin{aligned} &\forall g^i_\phi \in \mathrm{L_{HE}},\ \mathrm{v} \in \left(\Psi(g^i_\phi, 2) \cap \mathrm{B_2}\right) : \exists u \in (\mathrm{L_{HE}} \cap \mathrm{O_R}) \wedge (v,u) \in \mathrm{K_0}\ \text{where} \\ &\mathrm{L_{HE}} = \left\{ g^i_\phi \in \mathrm{G_j} \mid \forall j \in \mathrm{I_j} \nexists \mathrm{v} \in \Psi(g^i_\phi, 2) \cap \mathrm{B_2} : (\mathrm{v}, g^i_\phi) \in \mathrm{K_H} \right\} \\ &\mathrm{L_{HM}} = \left\{ \mathrm{u} \in \mathrm{O_M} \mid \nexists v \in \mathrm{O_M} : (v,u) \in \mathrm{K_M} \right\} \end{aligned} \quad (47)$$

R7. The remaining unconnected means objectives corresponding to a process path that consists of functions and events should be decomposed into process risk objectives using an AND connector. It assures that lower level functions can contribute to multiple sub-process objectives.

$$\begin{aligned} &\forall \left(o \in \mathrm{O_M}, o_1, o_2 \in \mathrm{O_R}, j \in J, u_1, u_2 \in B_1, e \in E\right) : \\ &\left(o_1 \to j \to o\right) \wedge \left(o_2 \to j \to o\right) \wedge (u_1, o_1), (u_2, o_2) \in K_0 \wedge u_2 \to e \to u_1 \Rightarrow j \in FC_{AND} \end{aligned} \quad (48)$$

R8. A means objective corresponding to one or more path within a process flow split should be decomposed into process risk objectives using the same connector as is used to split process flows. This requirement assures the correct mapping of the logical relationships when synchronizing the objectives and process flow patterns of a risk-aware VFPE model.

$$\begin{aligned} &\forall o \in \mathrm{O_M}, o_1, o_2 \in \mathrm{O_R}, j_p \in \mathrm{FC}, j_0 \in J, u_1, u_2 \in \mathrm{B_1}, e_1, e_2 \in E : \\ &\left(o_1 \to j_0 \to o\right) \wedge \left(o_2 \to j_o \to o\right) \wedge \left((u_1, o_2) \in \mathrm{K_o}\right) \wedge \\ &\left(u_1 \to e_1 \to j_p\right) \wedge \left(u_2 \to e_2 \to j_p\right) \Rightarrow j_0 = j_p \end{aligned} \quad (49)$$

The risk-aware VFPE formalism is built using the principles of synchronized decomposition and allows activities to be linked to adverse events from a decomposed risk objectives structure. Overall, this enables better risk visibility and ensures continuity of business processes.

5. CONCLUSIONS AND FUTURE DIRECTIONS

We have responded to the research limitations provided in Section 1 (Introduction) by: 1) suggesting that risk be conceptualized as an emergent property of the predefined components of a '*risk emergence view*' such as *process risk objectives*, *risk sources* and *risk triggers*; 2) extending the VFPE modelling notation in order to allow the formal representation of risk on the level of the individual e-EPC function; and 3) based on the principles of synchronized decomposition (Neiger & Churilov 2006), which is a part of the VFPE methodology, we have provided a formal guideline to decompose risk assigned to a complex process on any level of process granularity. By representing risk as part of the VFT structure through objectives-driven risk decomposition, a holistic value-driven view on risk has been made possible and a direct link to the mathematical modelling approaches to process-aware risk management has been provided, which gives rise to a number of future research directions.

The suggested risk-aware VFPE formalism, being an output of design research process, provides another step towards reliable risk-aware process engineering. Some possible research directions that would extend and operationalise the current risk-aware VFPE framework include, but are not limited to:

- Development of evaluation scales and risk-assessment techniques based on the VFT component of risk-aware VFPE. This would allow converting risk objectives to quantitative measures and using these measures to assess process-based risk.
- Empirical testing and implementation of the process-based risk analysis techniques based on the suggested formalism and integrated into PAISs.

References

van der Aalst, W.M.P., ter Hofstede, A.H.M., Kiepuzewski B., Barros, A.P. (2003). Workflow patterns. Distributed and Parallel Databases, 14(1), 5-51.

van Aken, J.E. (2004). Management research based on the paradigm of the design sciences: the quest for field-tested and grounded technological rules. Journal of Manangement studies, 41(2), 219-246.

Committee of Sponsoring Organizations of the Treadway Commission (COSO). (2004). Enterprise Risk Management – Integrated Framework. Executive Summary Framework. American Institute of Certified Public Accountants, New York.

Daellenbach, H.G. (1994). Systems and decision making: a management science approach. John Wiley & Sons, Chichester.

Davis, R. (2001). Business Process Modelling with ARIS: a Practical Guide. Springer-Verlag, London.

Dumas, M., W. van der Aalst and A.H.M. ter Hofstede (Eds.) (2005). Process-Aware Information Systems: Bridging People and Software Through Process Technology. John Wiley & Sons, Hoboken, New Jersey.

Hatfield, A.J. and Hipel, K.W. (2002). Risk and systems theory. Risk Analysis, 22 (6), 1043-1057.

Jallow, A.K., Majeed, B., Vergidis, K., Tiwari, A., Roy, R. (2007). Operational risk analysis in business processes. BT Technology Journal, 25(1), 168-177.

Keeney, R.L. (1992). Value-focused thinking: a path to creative decision making. Harvard University Press, Cambridge, Mass.

Keller, G. and T. Teufel (1998). SAP R/3 Process - oriented implementation: iterative process prototyping. Addison Wesley Longman, Harlow.

Klinke, A. and Renn, O. (2002). A new approach to risk evaluation and management: risk-based, precaution-based, and discourse-based strategies. Risk Analysis, 22 (6), 1071-1094.

Lambert, J.H., Jennings, R.K. and Joshi, N.N. (2006). Integration of risk identification with business process models. Systems Engineering, 9(3), 187-198.

March, S. and Smith, G. (1995). Design and natural science research on information technology. Decision Support Systems, 15, 251-266.

Melao, N. and Pidd, M. (2000). A conceptual framework for understanding business processes and business process modelling. Information Systems Journal, 10, 105-129.

Mingers, J. (2001). Combining IS research methods: towards a pluralist methodology. Information Systems Research, 12(3), 240-259.

Mock, R. and Corvo, M. (2005). Risk analysis of information systems by event process chains. International Journal of Critical Infrastructures 1(2/3), 247-257.

zur Muehlen, M. and M. Rosemann (2005). Integrating Risks in Business Process Models. In Proceedings of the 16th Australasian Conference on Information Systems (ACIS 2005), Sydney, Australia.

Neiger, D. and L. Churilov (2004). Goal-oriented and business process modelling with EPCs and value-focused thinking. Business Process Management LNCS 3080 (Eds. Desel J., Pernici B. and Weske M.), Springer, Berlin, 98-115.

Neiger, D. and L. Churilov (2006). Intelligent Decision Support through Synchronized Decomposition of Process and Objectives Structures. In Proceedings of the Thirty-Ninth Annual Hawaii International Conference on System Sciences (HICSS 2006), IEEE Computer Society.

Neiger, D., L. Churilov, M. zur Muehlen, M. Rosemann (2006). Integrating risks in business process models with value focused process engineering. In Proceedings of the 14th European Conference on Information Systems (ECIS 2006), Göteborg, Sweden.
Neiger, D., Rotaru, K. and Churilov, L. (2008). Supply chain risk identification with value-focused process engineering. Journal of Operations Management, doi:10.1016/j.jom.2007.11.003.
Sarbanes-Oxley Act of 2002 http://news.findlaw.com/hdocs/docs/gwbush/sarbanesoxley072302.pdf.
Scandizzo, S. (2005). Risk mapping and key risk indicators in operational risk management. Economic Notes, 34(2), 231-256.
Scheer, A.-W. (1999). ARIS – Business Process Frameworks. 3rd Edition. Springer-Verlag, Berlin.
Scheer, A.-W. (2000). ARIS – Business Process Modeling. 3rd Edition. Springer-Verlag, Berlin.
White, D. (1995). Applications of systems thinking to risk management: a review of the literature. Management Decision, 33(10), 35-45.