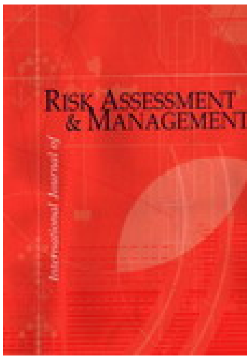

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Process-event method for operational risk assessment at enterprise

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Abstract: This paper proposes a process-event method for quantitative assessment of operational risk in dynamics and calculation of the required economic capital volume. The method is a further development of the traditional process approach to enterprise risk management. The main idea is to describe the process as a chain of random events instead of a graphical description of the process as notations. The ontology of the method includes basic definitions, mathematical foundation and method for calculation the current and integrated operational risk values, the economic capital volume with the upper and lower limits of the reservation. The integrated value of the enterprise's operational risk can be used as a rating indicating reliability of the enterprise. A timeline diagram (process-event diagram) of the event flow is introduced, its features in comparison with PERT and Gantt charts are described.

Keywords: process; event; logic; probability; operational risk; enterprise; management; event flow; event chain; PERT; Gantt chart; assessment; analysis; Karaseva's diagram.

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1 Introduction

All agents of economic systems and business are faced with the operational risk phenomenon. As a rule, operational risk is associated with the business activity of economic agents, mistakes of personnel, fraudulent actions and the consequences of external unfavourable events.

When economists and risk managers are speaking about this phenomenon they mean, as a rule, the definition given in Basel II is accepted: "Operational risk is defined as the risk of loss resulting from inadequate or failed internal processes, people and systems or from external events. This definition includes legal risk, but excludes strategic and reputational risk" (International Convergence of Capital Measurement and Capital Standards, 2006).

To manage operational risk effectively we cannot neglect the fact: operational risk influences on other types of risk (for example, market risk, credit risks, liquidity risk, etc.), makes the management procedures more complicated. The influence of operational risk on other risks was demonstrated by the united structural model of credit and operational risks in paper (Karasev and Karaseva, 2016).

Basel II defines three approaches for operational risk assessment and capital reservation in bank: the basic indicator method, the standardised method, and the advanced measurement approach AMA (International Convergence of Capital Measurement and Capital Standards, 2006).

In fact, operational risk is not unique risk for banks only. It presents in activity of any industrial enterprise, investment company, social institution, institutions of the executive and legislative bodies, the army. But there are no direct standards and regulatory documents for economic agents which are not related to the banking sector, despite the importance and urgency of the problem.

As a systemic phenomenon, operational risk is reflected in events. Events have different nature and include employee errors, failures in technical and information systems, political events, armed attacks, acts of terrorism, natural disasters, etc. The formalising and modelling such phenomenon is not trivial and complex problem, see (Kaspereit et al., 2017; McKim, 2017; Panjer, 2006).

To solve this problem in the shortest possible time and without attracting expensive resources, the author have develop a new method for operational risk assessment and management based on the well-known process approach to management, offered in (Hammer and Champy, 1993). With regard to a commercial bank, the assessment and management of operational risk by analysis the bank's business processes is detailed in (Sazykin, 2008). However, at present time there are no effective methods of operational risk analysis and calculation the capital reservation volume (economic capital) within traditional process approach.

Within process approach framework all activities of an enterprise that use resources are considered as processes, every process can be splitted into sequencies of certain operations. The output of concrete process can be the input of following one. Process approach (Hammer and Champy, 1993) is convenient for control, especially in general points (junctions) of separate processes. Moreover, process approach permits simulate various combinations and interactions of processes.

Business process management information systems (BPM systems), workflow management systems (WFM), ERP II systems, and case handling systems give possibility to fix events and keep event logs during functioning enterprise. These logs (or protocols) can be used for analysis, management and decision-making procedures. This possibility caused to wide application of event logs in many areas: industry, transport, banking, etc.

But application of events logs causes another actual problem: how to 'extract' processes from the event logs. The problem is especially relevant in situations where the formal description or precise model of the system is absent or does not correspond to the real system, that is, in 98% of cases. In van der Aalst (2011) process mining technologies are described which allow to obtain a process model from the event log, check the model by the statistics of subsequent events and improve the model if there is a deviation between the model and real process data.

In traditional process approach there are several sets of notations (conventional graphic symbols) to construct the model for business processes. Using notations only has drawbacks, the most significant ones are follows:

- Analysis efficiency decreases with increasing detailing. The efficiency of analysis is reduced with increasing the detailisation. High-level processes are described simply and the worth of such work is the highest but describing detailed processes at a lower level requires a hard work but worth is low. Detailing up to individual employees leads to over-complexity of the diagram, loss of visibility and control, while the losses at the lower levels are often negligible. By this reason 5–7 levels of processes are optimal.
- The fragmented description does not provide a complete view of the enterprise as a whole, displaying functional hierarchy, the structure of resources, and strictly identify the time stages. The enterprise model in the process approach consists of many local schemes that reflect various aspects of activities from different levels and viewpoints, but schemes are interconnected in many aspects only through the intuitive image of the whole in the developer's head (Boldachev and Shumakov, 2014).
- There are no effective numerical methods to manage operational risk based on business processes.
- The impossibility to calculate numerically the operational risk value and the reservation capital volume.

Taking into account the features of operational risk as a system phenomenon, advantages and defects of the traditional process approach, the author has developed a new process-event method that allows to move from the analysis of processes, presented in the form of static diagrams in various notations, to modelling the event flow in real time directly, describing the enterprise activity as a whole (Karaseva and Karasev, 2018; Karaseva, 2018, 2019).

2 Process-event method ontology

Usually, two ontological models are considered for modelling business systems: object model and process model. The object model operates with objects, describes them by means of sets of predicates (features, properties), defines the relationship between them through structural subordination (whole → part) and uses various principles of categorisation. The process model considers the change objects in time, that is, processes and their interaction.

In philosophy, another ontological approach to the description of the world was considered – an event-based approach. Ludwig Wittgenstein adhered to event ontology, in his "Tractatus Logico-Philosophicus" (Wittgenstein, 1922) he stated: "The world is a set of facts, not objects. ... What is happening, the fact is the existence of events". An extremely radical event approach, at the level of the ontology foundations, was declared by Bertrand Russell (Russell, 2009): "everything in the world consists of events", "matter is just convenient ways for grouping events".

The aim of the event ontology is to describe a complex system as a dynamic sequence of events (event flow). Any economic agent is a system with a finite state space, defined by a time-varying event flow.

The work (Boldachev and Shumakov, 2014) describes a new subject-eventual approach to modelling business systems, where an enterprise is considered as an organism (or integrity, distributed in time), and should be perceived as a flow of events: if we can fix a whole set of all events, occurring at the enterprise, then we will get a complete description of enterprise as an integrated system. Subject-eventual approach can be used for description and qualitative modelling but does not provide tools for numerical assessment, analysis and management.

The process-event method, proposed by the author, is based on the determination of event chains, consisting of elementary events in business processes of an enterprise. To determine the enterprise's operational risk value, we will use the logic-probabilistic method (LPM), applied earlier to develop the operational risk management technology in bank, corresponding to the Basel II requirements as AMA approach (Karaseva, 2016).

Let's introduce some basic definitions.

Process is an ordered sequence of functions (works, procedures, operations and other actions), presented as events and performed by officials and divisions of the enterprise to achieve the desired result (achieving a goal, solving a problem, implementing a program, providing a service).

Event is a successful finalisation (acceptable result) of a function (action, work, procedure, operation), or a working condition (acceptable values of parameters at a given time interval). This event is casual. Since any function may be incomplete within the allotted time (or completed with not acceptable result) due to set of reasons (for example, equipment failure, power failure, human error or other factors), this event has at time t some probability P.

Elementary event is a casual event that cannot be further divided into initiating events. An elementary event is a successful finalisation of the concrete indivisible action (work, operation, procedure, and so on) in the process.

The identification of elementary events is not simple and very important procedure. In work (Boldachev, 2015) a main principle of event allocation is stated – an event is identified as elementary if at least one of three conditions is valid:

1 the event is performed or fixed by one of the system's subjects

2 the event is performed in relation to one of the system's objects

3 presence or absence of an event leads to the condition: this event is performed by other subjects or by the same subject with another object.

Thus, an event is assigned by determination of object(s) (this event should be associated with these objects) and the subject who fixes this event. A person, specialist, role, team, software agent, sensors, etc. can operate as a subject. Events, which are not associated with any subject, but influencing on the system's functioning, should be assigned to an 'absolute subject'. The author calls the described approach subject-eventual because any event in the system is connecting with a specific subject (Boldachev and Shumakov, 2014).

Process event chain is a sequence of elementary events associated with the successful finalisation of an action (function, procedure, operation, etc.). The number and sequence of events within the chain correspond to the number and sequence of actions in the business process.

So, a business process can be viewed as a sequence of non-casual operations but result of each operation is a casual event.

Business processes can be performed both sequentially (the output of previous business process is the input for following one), and in parallel.

All enterprise's processes can be specified as a set of process event chains, therefore, the state of the enterprise at every time t is defined as set of unrealised events St from parallel processes, which are performed at time t. Events can be united by logical connections between them.

Some elementary events have a high probability of realisation, i.e., be almost reliable (for example, the event 'Preparing annual financial reports'), but other events have probability of realisation much lower, for example, in the business processes of investment project management. This fact is required to be considered when we determine probabilities of casual events.

Active process is a process where at least one function, procedure, work or action is currently being executed.

Process operational risk is the probability of non-realisation of an elementary event in the chain within given time interval. This value is varied slightly and within a specified time interval can be consider as constant value (before updating statistical data).

Enterprise operational risk is integrated operational risk (risk of entire enterprise) and calculated as a logical sum of probabilities of current elementary events in all parallel processes. This value is changing in accordance with the enterprise's functioning.

The set of all processes EP_i of the enterprise (presented as event chains) forms a non-empty finite set B, $EP_i \in B$, $i = 1, ..., k$, where k is the whole number of processes at the enterprise. Since there are parallel processes in B, at time t on the time diagram, we get a set of events St, consisting of the current elementary events (which are unrealised yet) from the chains EP_i, $i = 1, ..., k$ of active processes.

We enter logical variables X_m, $m = 1, ..., n$ for events, including in the set St, n is the number of enterprise's active processes in time t. $X_m = 1$ (the event is realised) with the probability $P(X_m = 1)$, or $X_m = 0$ (the event is not realised) with the probability $Q(X_m = 0) = 1 - P(X_m = 1)$. Any event X_m from the set St, or several events, or all events may be not realised at time t.

The logical function of the enterprise operational risk is:

$$X_{OR} = \overline{X}_1 \vee \overline{X}_2 \vee ... \vee \overline{X}_n \,, \tag{1}$$

Enterprise operational risk $P(X_{OR})$ can be obtained from the probabilistic function (Solozhentsev, 2017):

$$P(X_{OR}) = 1 - Q(X_1)Q(X_2)\dots Q(X_n) \tag{2}$$

$P(X_{OR})$ is the probability of the logical sum of events $\overline{X_i}$, $i = 1, ..., n$ of the set St. If $P(X_{OR})$ is known, the reservation capital (economic capital) volume can be calculated from the expression:

$$RC = P(X_{OR})L, \tag{3}$$

where L is the average amount of losses caused by operational risk during past three years.[1]

$P(X_{OR})$ value can permanently changes during the working day. In most cases, seems, this is impractical to calculate $P(X_{OR})$ often.

Traditional process approach means, primarily, business processes are drawn as detailed diagrams (maybe, in different notations), then simulation modelling is performed once with use special software, or diagrams are analysed 'manually'. Based on the results, weak and ineffective parts of processes are identified, and necessary actions are performed to eliminate defects. Later, modelling is performed again. As a rule, this simulation is performed after the changes in the activity of the enterprise due to implementation of new technologies, changes in the organisational structure or in the economic situation.

In our approach, we 'extract' processes and construct chains of events. In this stage we can also use the previously compiled business process diagrams. Then we neglect all impossible sets St (combinations of incompatible events) in parallel business processes. Next, all realised sets St are selected and the $P(X_{OR})$ for every set St are computed. By $P(X_{OR})$ value we can determine critical sets St (where the $P(X_{OR})$ is too large).

$P(X_{OR})$ can be interpreted as indicator of the enterprise reliability (enterprise reliability rating), because this is integrated value of all risks which are reflected in probabilities of current elementary events.

The method, offered in Karaseva (2012, 2016), uses the concept of operational risk interval (with lower and upper values), and, respectively, the interval of capital reservation with lower $RCdown$ and upper $RCup$ limits. The upper $P(X_{OR})_{up}$ is determined by the maximum value of the operational risk, obtained on the sets St, the lower $P(X_{OR})_{down}$ is determined by the minimum one.

$RCup$ and $RCdown$ is calculated by the formulas:

$$RCup = P(X_{OR})_{up} L$$

$$RCdown = P(X_{OR})_{down} L, \tag{4}$$

The choice of the reservation capital volume is determined by many factors: the political and socio-economic situation, the changing of market indices, the experience of the risk manager and the information, which accessible for manager.

3 Practical example with process-event method application

Let's demonstrate the application of the process-event method using the practical example with existing economic agent in real sector of economy. The object of research is small enterprise, tax resident of the Russian Federation, legal form is limited liability company (Ltd.), type of entrepreneurial activity: general construction work; specific activity: repair metal roofs; geographical region: St. Petersburg and the Leningrad region.

The enterprise searches customers, collects applications and makes contracts for repair work, performs repair works, buys tools, equipment and materials, prepares financial reports. We have identified four main processes:

1. making a contract (Figure 1)
2. purchase and delivery of tools, equipment and raw materials (Figure 2)
3. perform repair works according to contract (Figure 3)
4. prepare financial reports (Figure 4).

Descriptions of the events of the processes EP1–EP4 and the probability of their failure are given in Tables 1–4.

Figure 1 Event chain for process EP1 'Making a contract'

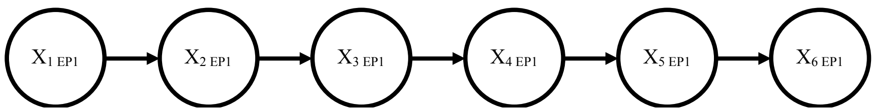


Figure 2 Event chain for process EP2 "Purchase and delivery of tools, equipment and materials"

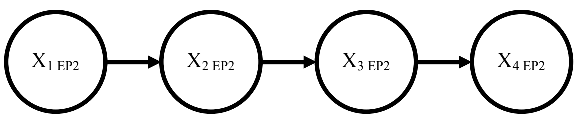


Figure 3 Event chain for process EP3 "Perform repair works according to contract"

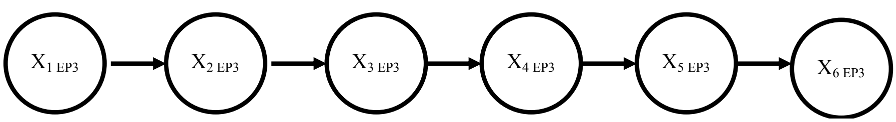


Figure 4 Event chain for process EP4 'Prepare financial reports'

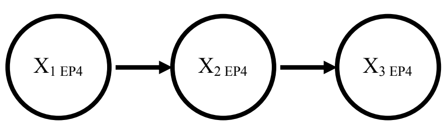


Table 1 Description of events in process EP1

Event $X_{m, EP1}$	*Description*	*Probability* $P(\overline{X}_{m, EP1})$
$X_{1\ EP1}$	Application for repair	0.2
$X_{2\ EP1}$	Work volume measurement	0.15
$X_{3\ EP1}$	Contract budgeting	0.134
$X_{4\ EP1}$	Confirmation of budget by customer	0.5
$X_{5\ EP1}$	Contract drawing	0.08
$X_{6\ EP1}$	Signing the contract by customer	0.5

Table 2 Description of events in process EP2

Event $X_{m,\,EP2}$	*Description*	*Probability* $P(\overline{X}_{m,EP2})$
$X_{1\ EP2}$	Search a supplier	0.1
$X_{2\ EP2}$	Payment for tools or raw material	0.11
$X_{3\ EP2}$	Receiving tools or raw material from supplier	0.23
$X_{4\ EP2}$	Delivery tools or raw material to enterprise	0.092

Table 3 Description of events in process EP3

Event, $X_{m,\,EP3}$	*Description*	*Probability* $P(\overline{X}_{m,EP3})$
$X_{1\ EP3}$	Customer's prepayment	0.5
$X_{2\ EP3}$	Delivery tools or raw material to consumer	0.06
$X_{3\ EP3}$	Works at consumer's roof	0.04
$X_{4\ EP3}$	Works have being finished – control the result by customers representatives	0.21
$X_{5\ EP3}$	Signing the document confirming the completed work	0.34
$X_{6\ EP3}$	Final customer's payment	0.4

Table 4 Description of events in process EP4

Event, $X_{m,\,EP4}$	*Description*	*Probability* $P(\overline{X}_{m,\,EP4})$
$X_{1\ EP4}$	Making reports	0.03
$X_{2\ EP4}$	Sending reports to tax bodies	0.12
$X_{3\ EP4}$	Acceptance of reports by tax bodies	0.18

The probabilities in Tables 1–4 are derived from enterprise statistical data. For several years, from 2009 to 2011, the enterprise kept records of the operational risk events (event log) and assess the losses as a statistical protocol. Table 5 shows a fragment of the event log. The probabilities of events $\overline{X}_m$, $m = 1, ..., n$, given in Tables 1–4, were obtained by expert way from the event log.

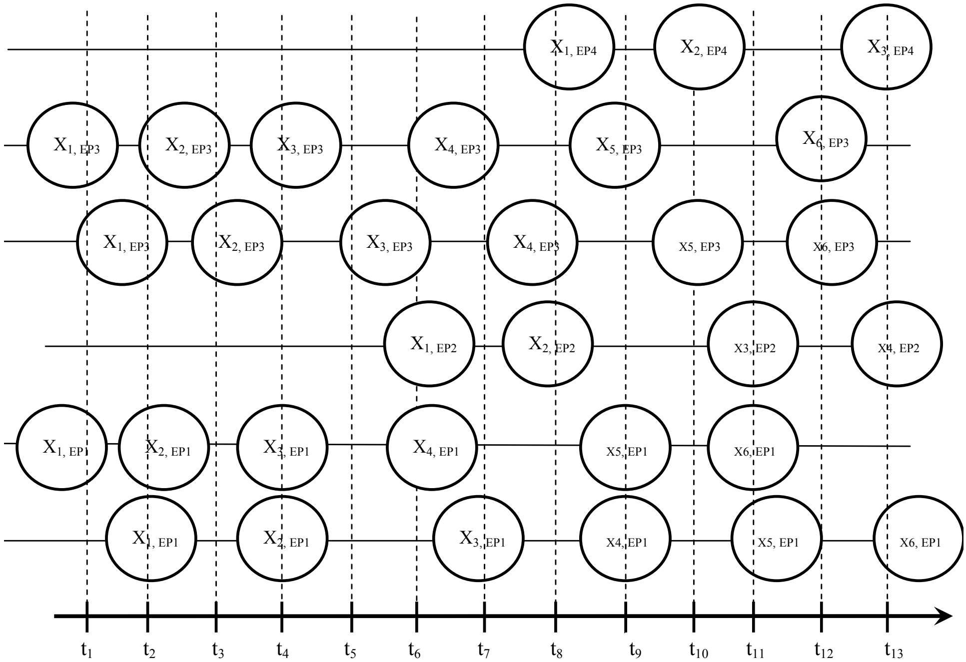
The processes EP1–EP4 can perform in time both sequentially and in parallel. From the empirical experience of the enterprise's functioning (from the beginning of 1997 to July, 2020), at each working period there will never be more than two processes EP1 and EP3 at the same time, and no more than one process EP2 and EP4, i.e., the number of active processes is $n \le 6$ always. To illustrate, we present an example process-event diagram in Figure 5.

The diagram displays the enterprise's event flow. The event flow is generated by the active processes of the enterprise. The total set of events of all processes *St* at time *t* on the vertical cut of the diagram determines the value $P(X_{OR})$ – the enterprise operational risk at time *t*. Process-event diagram demonstrates the theoretical ability to calculate enterprise operational risk value at any time. The calculation of $P(X_{OR})$ according to the formula (2) at times t_1–t_{13} is shown in Table 6.

Table 5 The fragment of operational risk event protocol

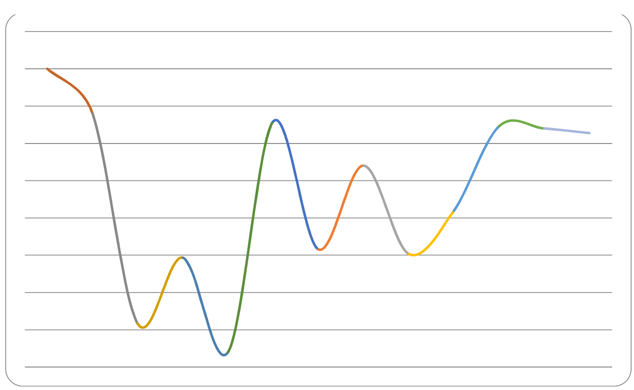
Date, time	*Event description*	*Duration*	*Process*	*Factors*	*Reasons*	*Loss amount*
…	…	…	…	…	…	…
19.10.2010, 10.50–11.15 a.m.	Power failure	25 min	EP3	Internal	Malfunction in the electrical panel, mistake of enterprise's employee	2300 roubles
20.10.2010, 9.50–10.50 a.m.	Waiting for the chief engineer of the customer (did not arrive at the agreed time)	1 h	EP1	External	–	1500 roubles
21.10.2010 time not fixed	Short rain, three times a day, breaks in work 15 min, 10 min, 10 min	35 min	EP3	External	Weather	2600 roubles
…	…	…	…	…	…	…
09.11.2010, 12.00 a.m. – 17.00 p.m.	The customer's representative did not visit the object under construction (contrary to the agreement), access to the roof was blocked	5 h	EP3	External	–	24000 roubles
14.11.2010 16.00 p.m.	Customer's representatives left the object 1 h earlier (than the time, specified by the contract), access to the roof was blocked	1 h	EP3	External	–	5000 rouibles
…	…	…	…	…	…	…
05.12.2011, 10.00 a.m.	The job was delayed, the enterprise's employee forgot a probe tool and a voltmeter	1 h	EP3	Internal	Mistake of enterprise's employee	5000 roubles
06.01.12, 12.00a.m.– 14.00 p.m.	Mistake in annual report	–	EP4	Internal	Mistake of enterprise's employee	750 roubles
…	…	…		…	…	…

Figure 5 The process-event diagram of enterprise (Karaseva's diagram)



We can see that the value of the enterprise's operational risk permanently varies according to changes in event flow intensity (the cardinality of the set *St* varies in dynamics). Changing values of $P(X_{OR})$ are shown in the graph (Figure 6).

Figure 6 Enterprise operational risk curve (see online version for colours)



In practice, of course, the event flow can be various, as well as the number of active processes at any given time (up to one active process). We do not need to spend effort modelling all possible combinations events from active processes. First of all, we are interested in sets *St*, where possible combinations of events will lead to the maximal operational risk value. In this case, combinations of inconsistent events should be determined and ignored beforehand.

Table 6 Sets *St* in separate times and enterprise operational risk value

Time	*St*	*Enterprise operational risk* $P(X_{OR})$
t_1	$X_{1,EP1}, X_{1,EP3}, X_{1,EP3}$,	0.8
t_2	$X_{1,EP1}, X_{2,EP1}, X_{1,EP3}, X_{2,EP3}$	0.6804
t_3	$X_{2,EP3}, X_{2,EP3}$	0.1164
t_4	$X_{2,EP1}, X_{3,EP1}, X_{3,EP3}$	0.293344
t_5	$X_{3,EP3}$	0.04
t_6	$X_{4,EP1}, X_{1,EP2}, X_{3,EP3}, X_{4,EP3}$	0.65872
t_7	$X_{3,EP1}, X_{4,EP3}$	0.31586
t_8	$X_{2,EP2}, X_{4,EP3}, X_{1,EP4}$	0.540408
t_9	$X_{4,EP1}, X_{5,EP1}, X_{5,EP3}$	0.3036
t_{10}	$X_{5,EP3}, X_{2,EP4}$	0.4192
t_{11}	$X_{5,EP1}, X_{6,EP1}, X_{3,EP2}$	0.6458
t_{12}	$X_{6,EP3}, X_{6,EP3}$	0.64
t_{13}	$X_{6,EP1}, X_{4,EP2}, X_{3,EP4}$	0.62772

The operational risk management with use the offered process-event method is based on identification all possible critical combinations of events when the maximum values of operational risk and losses will be. In the above example, the combination of events $X_{1,EP1}$, $X_{1,EP3}$, $X_{1,EP3}$ leads to the maximum operational risk, since the event $X_{1,EP3}$ 'Customer's prepayment' has a high probability of non-realisation (obtained from statistical protocol) and can lead to various consequences, including significant losses due to delay in job performance under the contract or termination of the contract even (leads to the loss of potential profit for enterprise).

If we identify the critical combinations, we are able to calculate the contributions of individual elementary events into operational risk and can plan the activity of the enterprise in most effective way to avoid the realisation of critical combinations.

4 The relation process-event diagram with the Gantt chart

The process-event diagram (Karaseva's diagram) shows, enterprise operational risk is a dynamic value which changes over time as the operations of processes are performed.

The final event of the process can be the finalisation/non-finalisation of work (achievement the aim), while intermediate events are finalisation/non-finalisation of operation (procedure, function, separate stage) of the work.

In this case, the connection between the Karaseva's diagram and the Gantt chart is obvious.

Any production or other process at the enterprise can be illustrated with Gantt charts (Clark et al., 1923).

The Gantt chart is a bar chart and consists of bars oriented along the time axis. Each bar on the diagram is a separate task (or stage) within the project (type of work), beginning and end every bar are the moments of the starting and finalisation of the work, length of every bar is the duration of the work. The vertical axis of the chart is the work list. You can also mark on the chart the cumulative works, percent of finalisation, indicators of the sequence and work dependencies, labels of key moments (milestones), the current time label ‘Today’, etc.

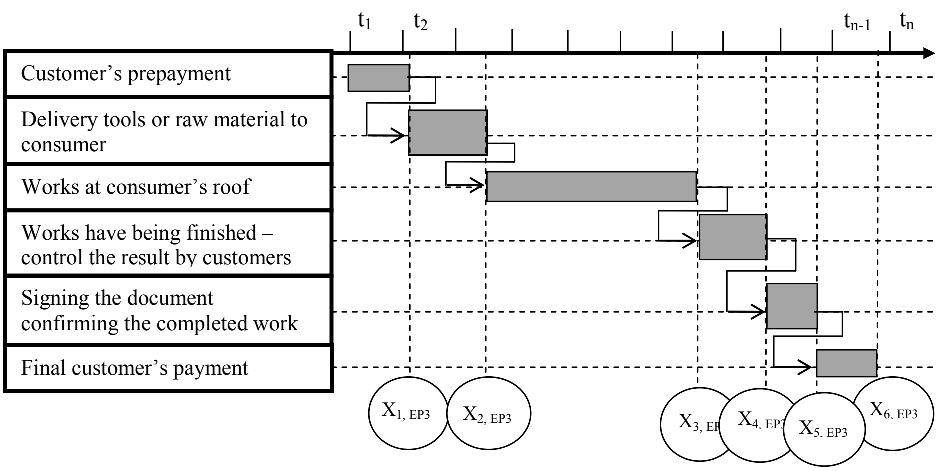
Significant moments in the work, or the common boundary of two or more works, are indicated by labels – ‘milestones’. Milestones help you to visually display the synchronisation requirements, sequence in the performance of works, but milestones are not calendar dates. A shift in a milestone will shift the entire project terms. Therefore, the Gantt chart is not a work schedule. Gantt chart does not display the significance or resource intensity of the work, the essence of the work (scope). For large projects, the Gantt chart becomes overly cumbersome and loses clarity.

If we put in accordance with the ‘milestones’ random events, which corresponds to the successful result of this working stage in given time interval, and display these events on a Gannt chart, then we get a process-event diagram with the enterprise event flow. The probabilities of these random events are probabilities of the successful finalisation of the current working stage (execution of tasks), and probabilities of non-realisation – the current operational risk of considered process.

Let’s take the EP3 process as an example. The process consists of six operations and their successful finalisation events.

If we represent the separate operations of the process as works, and the process as a separate project (repair of the customer’s roof), then for the process we can draw the Gantt chart (Figure 7). Let designate on the diagram the events (indicated by circles at Figure 7), which are the successful finalisation of the operations (procedures), we obtain the Karaseva’s diagram for this process.

Figure 7 Gantt chart with events of successful finalisation of operations



If the Gantt chart displays all processes performed in the enterprise, displays the events of successful finalisation of operations for all processes and eliminates the bands, we will get a complete process-event diagram (Karaseva’s diagram) where we see changes in the event flow and in the operational risk value of the enterprise.

We can establish analogies in the Karaseva’s diagram and the PERT diagrams of the relations between works and events (Punmia and Khandelwal, 2006). The PERT diagram is a graph, the set of vertices are events, and the arcs, connecting them, are works. Each vertex is an event of finalisation of the works, represented by the arcs, incoming in vertex, and, at the same time, the start of works, displayed by the arcs, outcoming from vertex. Thus, this reflects the condition – any work cannot be started before all the previous works (according to the project realisation technology) will be completed.

A sequence of arcs, where the end of each previous arc coincides with the beginning of the next one, is interpreted as a path from the starting vertex to the final one, and the sum of the lengths of arcs as its duration. Usually, the beginning and the end of a project are connected by many paths, their lengths differ. The longest path determines the duration of entire project, which is the minimal possible duration with the fixed parameters of the graph arcs. This path is critical, that is, the total duration of the project depends on the duration of its constituent works, if the duration of any work in project changes, then another path may become critical.

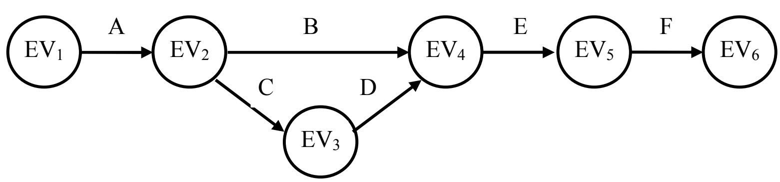
In a special case, the PERT diagram for EP1 process will be similar to the diagram in Figure 1. In more complex situations, a PERT diagram can reflect the interaction and mutual influence of two or more processes, taking into account all possible connections between events.

Basically, PERT is intended for large, complex and long-term projects. In comparison Gantt charts, this method implies the uncertainty, allowing you to develop a project's schedule without exact knowledge about details and the needed time for project's components, i.e., indirectly take into account the influence of operational risk factors.

PERT diagrams are used in analysis of tasks required to complete a project, analyse the time, which required to complete each task, and determine the time minimum, required to complete the project (critical path).

Let construct a PERT diagram (Figure 8) for the project 'Car Repair'. The processes and corresponding Karaseva's diagram are described in elsewhere (Karaseva and Karasev, 2019). At Figure 8 circles are graph vertices (events EVi, $i = 1, \ldots, 6$), and arcs are works, denoted by symbols. Description of events and works is given in Table 7.

Figure 8 PERT diagram for project 'Car repair'



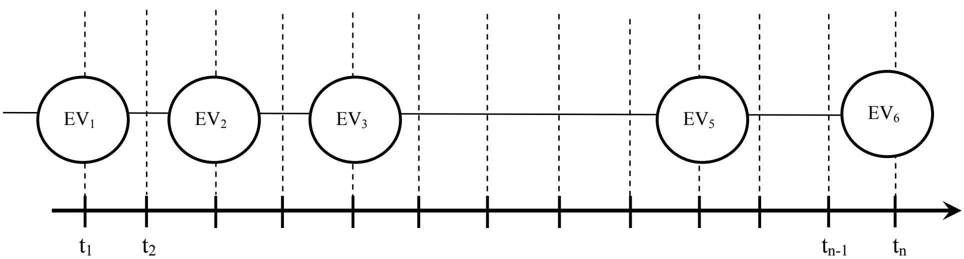
If we draw the diagram at Figure 8 in accordance with the ontology of the process-event method, then the entire project can be displayed on the process-event diagram (Karaseva's diagram) presented at Figure 9. Event EV_4 is missed, we suppose the probability $P(EV_4) = 1$ if event EV_3 is success.

In Karaseva and Karasev (2019) the assumption was made the capacity of the enterprise allows servicing two cars simultaneously. In this case the project will be shown at process-event diagram by two parallel business processes. Or, in the case of one car, the car can be repaired simultaneously with the purchase of spare parts on the assumption that part of the repair operations can be carried out in the absence of the necessary spare parts (for example, disassembling the chassis, cleaning the coating for painting, changing the settings of the on-board computer).

Table 7 Description of events and works in project 'Car repair'

Event	*Description*
EV_1	Client's application
EV_2	Fault detection
EV_3	Purchase spare parts
EV_4	Start of repair
EV_5	Finalisation the repair
EV_6	Car is delivered to the client
Work, duration	*Description*
A, 1 day	Car inspection / diagnostics
B, 1 h	Car transfer to service
C, 7 h	Purchase spare parts
D, 6 h	Delivery spare parts to service
E, 1–3 days	Car repair
F, 1 day	Delivery car to client

Figure 9 Karaseva's diagram for project 'Car repair'



PERT and Gantt charts help identify the critical path, analyse time and work schedule. However, they do not allow calculate the probability of successful project finalisation and assess operational risks.

Karaseva's diagram allows determine the current enterprise operational risk. This is the main advantage of the process-event approach for assessment and management of risks at enterprise.

For modelling, numerical calculation and analysis operational risk in dynamics, process-event diagrams and LPM should be used. The construction of such diagrams is complex task, however, in practice, the analysis of these diagrams can be performed once in order to identify critical combinations of events in which the value of operational risk exceeds the permissible value. Methods for determination the permissible values of operational risk, upper and lower boundaries of these values, are described in Karaseva (2016). Then we can calculate the reservation capital volume in dynamics. This feature allow to manage capital more effectively.

Taking into account the possibilities of process-event modelling, we make conclusion: this approach can be applied to assess and manage risk in various economic agents, in project management and investment projects.

5 Conclusion

There are many aspects in the event-process approach need to be clarified and studied.

Primarily, we need to consider the fact: operational risk is a non-financial risk and realised in unfavourable events. If we will base our models on events, we can easily formalise this problem.

This paper proposes a process-event approach for the quantitative assessment of operational risk, introduces basic definitions, presents logical and probabilistic models for enterprise operational risk.

The process-event method is a synthesis of the traditional process approach to enterprise management and the logical and probabilistic method for assessment and analysis of risks (Solozhentsev, 2017). The transition to eventual description allows solve the complex difficult-to-formalise problem of operational risk assessment and management in practice.

At the current stage of research there are several advantages of the process-event method:

1 To describe processes of enterprise functioning we need fewer variables in comparison with the usual process approach with notations.

2 Modelling of business processes with use of event chains allows obtain operational risk value in dynamics at time t, identify most dangerous sets (combinations) of events and calculate economic capital volume.

3 The process-event method allows obtain operational risk value not only as the sum of probabilities of internal process events at time t, but also include external events (changes in legislation, natural disasters, armed robberies, etc.). To do this we add the appropriate Boolean variables in formula (1). However, it should be proved, when we determine probabilities $P(Xi, m)$, $m = 1, ..., n$ using the event log (statistical data), the influence of external factors may be implicitly included in these probabilities.

4 The process-event approach is based on clear and understandable equations for numerical calculation of operational risk and economic capital volume to cover losses. But this advantage is realised when the process-event approach is applied to make operational risk assessment only. In other decisions (for example, organisational structure optimisation or enterprise management efficiency increasing) this advantage is not obvious.

The process-event approach has following features:

1 There are no clear recommendations for identification of events. We recommend identifying elementary events which have a large impact on the result of the process and which can be fixed.

2 Often, determination of probabilities $P(Xi, m)$ can be difficult. In the absence of statistics (event log), we use expert methods, which reduces the reliability of the results.

3 The specialist, applying process-event approach, should have good knowledge, enough competence and some preliminary practical experience in decomposition of processes and identification of elementary events.

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Note

[1]This period is established for banks by the Basel II Capital Accord requirements. In fact, the past period can be any and is determined by the risk manager, depending on the frequency of events, leading to operational risk losses.