The OntoREA© Accounting and Finance Model: Inclusion of Future Uncertainty

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Abstract. The OntoREA© accounting and finance model [1] indicates already in its name a fundamental distinction, i.e. the distinction between the accounting related backward looking perspective into the past and the finance related forward looking perspective into the future. Accordingly, in accounting current economic events are recorded and persisted and in finance future related commitments are addressed. Concerning the completeness of accounting and finance concepts there is an asymmetry in the OntoREA© model. The accounting concepts are completely covered, whereas in the coverage of the forward looking finance perspective one main deficiency exists: The uncertainty surrounding the forward looking perspective is not specified.

In this article the problem of the missing uncertainty representation in the OntoREA© accounting and finance model is explicitly addressed. The novel approach consists in directly linking uncertainty to commitments. By conceptualizing uncertainty according to the stochastic concepts that underlie the option pricing [2–4] and the intertemporal equilibrium pricing theory [5], the missing representation is solved. Furthermore, the stochastic concepts have a precise ontological meaning [6, 7]. Hence, the extension of the current model with the proposed uncertainty representation gives a well-founded stochastic model of the accounting and finance domain.

Keywords: REA business ontology · OntoREA© accounting and finance model · Uncertainty representation · Stochastic process concept · UFO-B

1 Introduction

Conceptual modeling provides concise knowledge representations for the domain under investigation. In the OntoREA© accounting and finance model [1] the domains of accounting and finance are conceptually modelled with the Unified Foundational Ontology (UFO)-based modeling language OntoUML [8]. OntoUML is an UML extension that incorporates the metaphysical nature of the modelled "things" – like the principle of essence and rigidity, identity, unity and dependency – and makes them accessible in ULM class diagrams via UFO metaphysical stereotypes.

The origins of the OntoREA© accounting and finance model trace back to the *REA business ontology* [9, 10]. In the accounting and policy infrastructure of this ontology

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the informational and procedural elements, which are needed for accounting and finance purposes, are specified. Due to the focus on economic transactions with real (physical) assets the accounting infrastructure of the REA business ontology had a deficiency with respect to representation of financial assets and liabilities. This deficiency was solved by integrating the requirements from Asset-Liability-Equity (ALE) accounting [11] and the forward looking perspective from finance [12]. By using the OntoUML language [8] the integration of the forward looking perspective also was accompanied by an *ontological turn*. Instead of using the "specification of a conceptualization" definition of ontology [13], a metaphysical definition of ontology from philosophy was applied, i.e. the Unified Foundational Ontology (UFO) with respect to *endurant* (static, structural) entity types (UFO-A) [14]. The ontological turn by switching from UML modeling language to the OntoUML language enhances the expressiveness of the conceptual model by adding to each concept applied in the model its UFO-metaphysical (ontological) nature.

The ontological expressiveness provided by the OntoUML language underlying the OntoREA© accounting and finance model showed especially useful for the modeling of the *temporal modal* behavior of derivative financial instruments [15, 16]. Depending on the market value, derivative instruments can be assets, if the value is positive, or liabilities, if the value is negative. If the value is zero, then derivative instruments are off balance positions. In the case of forward contracts, which are unconditional derivatives compared to conditional derivatives in form of options, the value can change randomly in either direction, so that they can randomly switch between asset, liability and off balance positions.

The expressiveness of the OntoUML modeling language with respect to the characterization of a temporal modal behavior is fine, but it can only trace the behavior as time goes by, i.e. online. This is sufficient for accounting purposes as it allows the recognition of the (random) value changes in the ALE accounting systems. With respect to the forward looking perspective of finance, this restriction is quite severe. It prohibits the modeling of a temporal model behavior on an ex-ante basis. In order to overcome this shortcoming the future related uncertainty has to be specified explicitly. In the *probabilistic extension* of the REA business ontology, the concept of a *filtered probability space* [17, p. 350] was applied to model future events as *probabilistic events*. As probabilistic events are elements of probability spaces, they are obviously of a different type compared to economic events which represent transactions in the REA business ontology. Recognizing this difference, the probabilistic events are not connected neither to economic events nor to commitments in the extended REA business ontology. Consequently, the probabilistic events are (only) proposed for carrying objectives in form of target values for planning and control purposes that are attached to different future occurrences.

The usage of filtered probability spaces for characterizing future uncertainty is a solid conceptualization. It stems from the "golden", i.e. Nobel-laureates age of finance from the 1970's. At that time both, the option pricing theory [2–4] as well as the intertemporal equilibrium pricing theory [5] used filtered probability spaces for modeling the uncertainty that surrounds the corresponding forward looking perspectives. The main question now is, how the integration of such a stochastic conceptualization of the future uncertainty into the OntoREA© accounting and finance model can be achieved?

This question leads to the primary research objective of this article, i.e. the adequate extension of the OntoREA© model that allows the modeling of a temporal modal behavior also on an ex-ante basis like in the option pricing theory and the intertemporal equilibrium pricing theory. Furthermore, the extension should be that generic so that it can also be applied to other valuation systems as well as planning and control systems like real option pricing and decision analysis [18, 19], stochastic control problems [20, 21], approximate control problems [22] and control problems with augmented states in form of exogenous and endogenous state variables [23].

In order to achieve this objective the "event" mismatch has to be disentangled first. For this purpose *perdurant* (dynamic, non-structural) entity types – called *Event* type in UFO-B [6] – are used to define the economic events in the OntoREA© model. For precisely expressing the different concepts in the OntoREA© model the types in the model will be written with capital letters and the corresponding *perdurant* UFO-B type will be specified in *Italics*, e.g. *Event* type Economic Event, and the same notation applies to *endurant* UFO-A types, e.g. *Kind* type Economic Resource.

In the next step the future uncertainty related to filtered probability spaces will be defined in terms of the *stochastic process* concept. The advantage of using this concept is the distinction between the *sample space* that specifies the uncertainty structure and the *state space* that specifies the mapped values from the stochastic process. This distinction allows the coupling of the *Kind* type Economic Commitment to its corresponding *uncertainty information structure* without having to specify probabilities for the commitments' possible states over time. Finally, this structure, i.e. the *Kind* type Uncertainty Sample Space provides the uncertainty representing information structure upon which in the planning process future economic events (plan events) – that are specified in the *Event* type Plan Event Tree – are committed.

The structure of this article is as follows: The next section *OntoREA© accounting and finance model: Stochastic extension* gives a compact overview of the OntoREA© model expressed with the OntoUML modeling language. In the following section the meaning of the *Kind* type Uncertainty Sample Space and *Event* type Plan Event Tree – that are the central elements in the model's stochastic extension – is elaborated. The next chapter deals with the *ERP-Control Application* in order to show for demonstration purposes the stochastic foundation of the production planning module and its IT implementation. In the final section the main contribution of the paper is concluded and future research directions are given.

2 OntoREA© Accounting and Finance Model: Stochastic Extension

The OntoREA© accounting and finance model [1] formalized in the OntoUML language can be seen in Fig. 1. The metaphysical, i.e. UFO-ontological meaning of the entity types and relationship types is specified in the stereotypes, e.g. the perdurant UFO-A type «Kind». For the exploration of the model it's advisable to start with the *identity providing backbone* in form of the *Kind* types Economic Resource and

Economic Agent from the *endurant* universal types («Kind») of UFA-A as well as the Economic Event from the *perdurant* universal types («Event») of UFA-B. The Balanced Duality type expresses the *Formal* reification relationship between the *Subkind* type Debit Event and the *Subkind* type Credit Event and their monetary balancing within each economic transaction in the spot market. The *Relator* stereotype indicates that in double-entry bookkeeping accounting systems the Debit Event and the Credit Event of a *spot market contract* have the property to balance in monetary terms. Consequently, there is a legal truthmaker that mediates between individual debit and credit events.

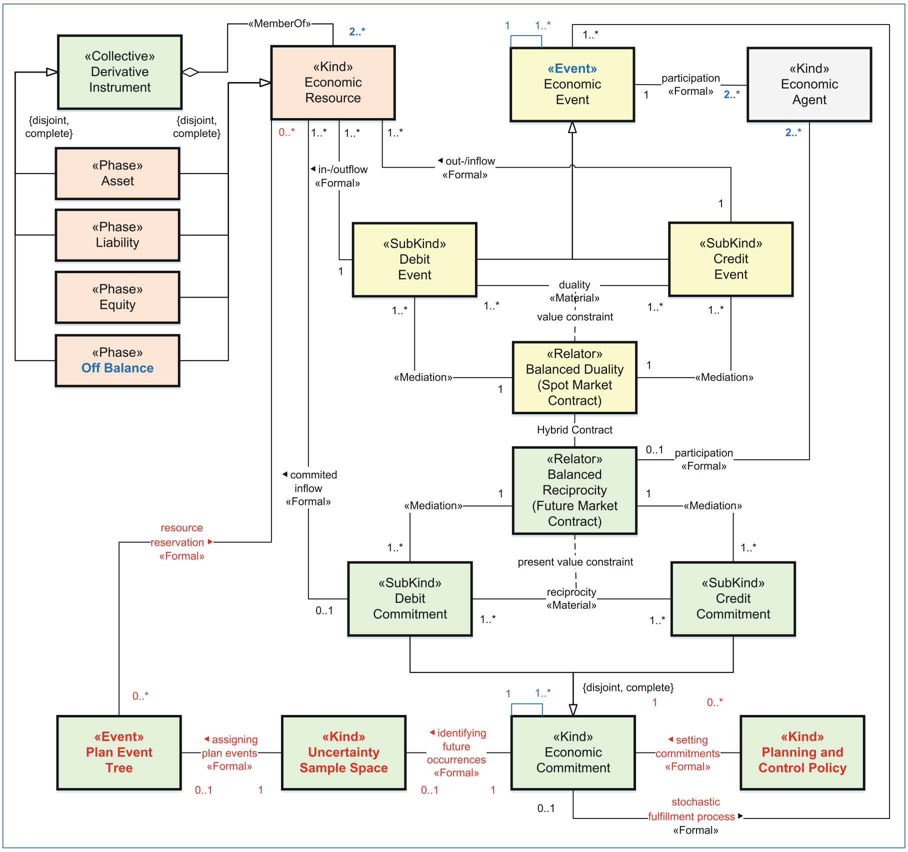


Fig. 1. OntoREA© accounting and finance model with stochastic extension (Color figure online)

A similar reasoning holds true for the *Formal* type Balanced Reciprocity that relates to the *Kind* type Economic Commitment. "Commitments are different from Economic Events since they represent obligations (of various degrees of enforceability) to trading or production partners instead of actual consumption or acquisition transactions. An example of a Commitment is a reservation for an airline flight or a reservation for a hotel stay." [9, p. 10]. Like Economic Event types the *Kind* type Economic Commitment is distinguished between *atomic* commitments and *complex* commitments that consist of more than one atomic commitment. The Balanced Reciprocity relationship related to Economic Commitment types comes from the fundamental pricing principle of finance that requires from *future market contracts* the balancing in monetary terms of a Debit and a Credit Commitment type. Consequently, the properties enforced by the truthmaker comes from finance theory. The *Relator* stereotype indicates this truthmaker which reifies the *Material* relationship between the *Subkind* type Debit Commitment and the *Subkind* type Credit Commitment and their monetary reciprocity (i.e. monetary balancing) within each economic future market transaction. The balanced reciprocity requires that the present value of the debit commitments is equal to the present value of credit commitments. Furthermore, there are hybrid contracts that are a mixture between a spot and a future contract, e.g. loan contracts settled with a bank.

The *Kind* type Economic Commitment and the *Event* type Economic Event are in a *Formal* fulfillment relationship type. Its cardinalities indicate that a commitment relates to at least one economic event, whereas an economic event can have a commitment. Finally, for completeness it is mentioned that the *Collective* type Derivative Instrument connects derivatives via a *MemberOf* relationship type to the asset and liability resources of their underlying replication portfolio. As derivative instruments are recorded by accounting law on a net basis, their constituting asset and liabilities are off balance sheet positions that are not individually reported in the balance sheet. Consequently, the *Phase* type Off Balance represents these constituting assets and liabilities.

There are five changes (marked in **blue** color in Fig. 1) in comparison to the original OntoREA© accounting and finance model [1] for enhancing understandability. The most importance change relates to the resolution of the "mismatch" problem and it consists of the switch in the Economic Event's type from the *Kind* type (UFO-A) to the *Event* type (UFO-B). According to this switch it is clear that the Economic Event is not of a static but of a dynamic nature. "Events (also called *perdurants*) are individuals composed of temporal parts. They *happen in time* in the sense that they extend in time accumulating temporal parts. Examples of events are a conversation, a football game, a symphony execution, a birthday party, or a particular business process. Whenever an event is present, it is not the case that all its temporal parts are present." [6, pp. 328–329]. Furthermore, the inclusion of an additional reflective relationship indicates that not only *atomic* events, which have no proper parts, but also *complex* events in form of aggregations of at least two disjoint (atomic) events. In complex events the temporal relationship between its constituting events is incorporated via a temporal property in each event. A reflective relationship type is also added – and this is the 2nd change – to the Kind type Economic Commitment to allow the building of *complex* from *atomic* commitments.

The remaining three changes are of minor importance compared to the *Event* type change. They eliminate narrow cardinality restrictions due to specific examples in the original OntoREA© accounting and finance model [1] with respect to Economic Agent's participation relationships and the Derivative Instruments MemberOf relationship. Next, the term *Off Balance* is chosen instead of the term *Claim* to explicitly indicate the off balance nature of claims that are defined as pending businesses. Finally, the ALE phases are specified only once and this specification is connected via generalization relationships to the Derivative Instrument type as well as to the Economic Resource type.

The stochastic extension of the OntoREA© accounting and finance model can be seen by the additional constructs (marked in **red** color) at the bottom of Fig. 1: the three entity types, i.e. the *Kind* type Uncertainty Sample Space, the *Event* type Plan Event Tree and the *Kind* type Planning and Control Policy, as well as the four related relationship types, i.e. the *Formal* relation 'identifying future occurrences', the *Formal* relation 'assigning plan events', the *Formal* relation 'resource reservation' and the *Formal* relation 'setting commitments'. The precise meaning of the additional concepts used in the stochastic extension of the OntoREA© model are given next.

3 Stochastic OntoREA© Model: Meaning of 'Uncertainty Sample Space' and 'Plan Event Tree'

The *Kind* type Uncertainty Sample Space is the information structure of the uncertainty that accompanies the future related Economic Commitment types. This uncertainty information structure is a mathematical construct. Specifically, it is the *sample space* of a stochastic process. "A *stochastic process* is a mathematical model for the occurrence at each moment after the initial time, of a random phenomenon. The randomness is captured by the introduction of a measureable space $(\Omega, \mathcal{F})$, called the *sample space*, on which probability measures can be placed. Thus, a stochastic process is a collection of random variables $X = \{X_t, 0 \leq t < \infty\}$ on $(\Omega, \mathcal{F})$, which take values in a second measurable space $(S, \mathcal{S})$, called the *state space*. … For a fixed sample point $\omega \in \Omega$, the function $t \rightarrow X_t(\omega); t \geq 0$ is a sample path (realization, trajectory) of the process X associated with ω." [24, p. 1].

The sample space of a stochastic process consists of two parts: Firstly, the sample point space Ω containing all possible sample points, i.e. all worlds that possibly occur in the future and secondly, the information structure $\mathcal{F}$ containing all *sample states* in which the possible worlds can occur over the time horizon defined by the stochastic process. The information structure is mathematically defined as a sequence of sample point space partitions. If these partitions are successively finer grained, the partition sequence is a *filtration*. Such a filtration is the core concept for specifying the concept of *revealing information*. "Uncertainties are resolved … at times $t = 0, 1, \ldots, T$. Let $\vartheta = \{\gamma_1, \gamma_1, \ldots, \gamma_S\}$ denote the (finite) set of possible states of the world. The true state of the world is revealed to the firm at time T. At intermediate times *t*, the firm possesses some information about this final state that we represent as the *time-t state of information* ω_t. Formally, these time-t states of information ω_t, are defined as subsets of ϑ that form a partition of ϑ (the possible ω_t's are mutually exclusive and their union is ϑ) and become successively finer with increasing t (each ω_{t-1}, is the union of states ω_t in the next time period)." [18, p. 797].

The revealing information concept is not only relevant for the domains of finance and decision analysis, but also for the domain of (e.g. inventory) control problems. "In open-loop minimization we select all orders u_0, …, u_{N-1} at once at time 0, without waiting to see the subsequent demand levels. In *closed-loop minimization* we postpone placing the order u_k until the last possible moment (time k) when the current stock x_k will be known. The idea is that since there is no penalty for delaying the order u_k up to time k, we can take advantage of information that becomes available between times 0 and k (the demand and stock level in past periods)." [20, p. 4]

In this article the concept of revealing information is directly connected to the stochastic process concept by defining *possible states of the world* (sample points) that live in the sample point space $\Omega = \{\omega_1, \omega_2, \ldots, \omega_S\}$ and defining *time-t sample states* $s_{t,i}$ in which the possible worlds can appear at time t. An example of a binary uncertainty sample space [3] is given in the left panel of Fig. 2. Furthermore, due to the filtration concept the binary sample space's time-t sample states also contain the corresponding sample points. By specifying the i-th sample point at time-t with $\omega_{i,t}$ the time-t sample state occurrence of the sample point can be traced over the different time points (see right panel of Fig. 2): E.g., the 1st sample point ω_1 is equal to the first time-3 sample state $s_{3,1}$ (that is equal to $\omega_{1,3}$) and it is contained in the subsets constituting the sample states s_0 (that includes $\omega_{1,0}$), $s_{1,1}$ (that includes $\omega_{1,1}$) and $s_{2,1}$ (that includes $\omega_{1,2}$). The set $\{\omega_{1,2}, \omega_{2,2}\}$ is an example of a subset that defines a sample state, i.e. the state $s_{2,1}$ in the time-2 partition.

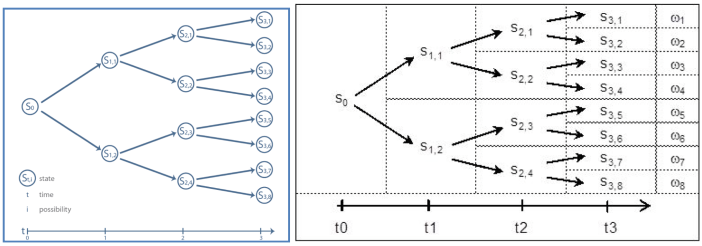


Fig. 2. Binary uncertainty sample space – possible occurrences of the worlds over time

By using the stochastic process concept for modeling the information structure related to the uncertainty of stochastically revealing complex Economic Commitment types, the uncertainty of these types becomes stochastically conceptualized with the *Kind* type Uncertainty Sample Space. This stochastic conceptualization is attached via the *Formal* relationship 'identifying future occurrences' to the *Kind* type Economic Commitment, so that it reifies the type's associated uncertainty information structure in form of a *Kind* type. The assignment of a stochastic information structure to a complex commitment is exemplified by a loan provided by a bank, which is a hybrid contract in the OntoREA© model. In the loan contract the loan taker originally gets a cash amount from the bank and she has the obligation to pay back that amount and the corresponding interest payments in the future. In this contract the balancing requirement means that the cash amount received initially is equal to the present value of the committed payments that have to be paid back in the future. The bank's uncertainty with respect to the loan taker's repayments can be represented by a sample space in form of a truncated binary tree where in each period there is the possibility that the loan taker defaults.

In the planning process future actions are anticipated and committed. In this article the committed future actions are related to the Economic Commitment type that is fulfilled later on with one or more future Economic Event types. In a stochastic planning process the committed future actions are assigned to the time-t sample states defined in the uncertainty information structure that surrounds the Economic Commitment type. E.g., in the *stochastic annual production planning context*, the quarterly production volumes are committed and attached to an Economic Commitment type. If the uncertainty information structure of the quarterly production volumes is defined e.g. according to the quarterly possible sales volumes resulting from a binary sales process then a binary uncertainty sample space arises like in Fig. 2.

The committed production volumes only specify the output that is achieved by performing the anticipated and committed production activities. Consequently, in the planning process not only volume values but beyond this also future Economic Event types in form of physical production processes are anticipated and committed. These anticipated and committed processes are plan events in form of an UFO-B *Event* type. In the case of a complex production Economic Commitment type a structured bundle of plan events is committed, i.e. the *Event* type Plan Event Tree.

In order to assure compatibility in the planning process, the Plan Event Tree type has to be established in conformity with the uncertainty structure surrounding the Economic Commitment type. This conformity is achieved via establishing the *Formal* relation ‘assigning plan events’ that aligns the *Kind* type Uncertainty Sample Space with the *Event* type Plan Event Tree.

For interpreting the *Event* type used in the stochastic extension of the OntoREA© accounting and finance model an *anti-eternalist* view [7, p. 479] is taken by considering the stochastic, tensed events as *ongoing events* that change over time in line with the successively revealing information. “According to Galton’s view, the dynamic behavior of an ongoing event concerns … the *process* that constitutes it, considered as an object (depending on the event’s participants) that is fully present in the thin temporal window where we experience things happening at the present time and moves forward as time passes by, assuming different properties at different times… In this paper I will argue in favor of rejecting … the view that events are ‘frozen in time’, by proposing a *tensed* ontological account (contrasted with the dominant *tenseless* tradition) according to which only past events are frozen in time, while ongoing and future events may have modal properties concerning their actual occurrence. At the core of this proposal there is a radical thesis: from the experiential point of view (that is, if we take tense seriously), ongoing events do change. They change by *embodying* temporal parts as time passes by, which *accumulate* with the previous parts. As a new temporal part is embodied, the event’s properties and its elapsed duration may change accordingly. … future events are conceived as *empty embodiments* at the time we refer to them…” [7, p. 480].

For completing the stochastic extension of the OntoREA© accounting and finance model in Fig. 2 three more things have to be explained. Firstly, the specification where the Economic Commitment type from the planning process comes from. For this purpose the *Kind* type Planning and Control Policy is introduced that provides the *Kind* type Economic Commitment via the *Formal* relationship 'setting commitments'. Secondly, the Plan Event Tree type has a *Formal* relationship 'resource reservation' to Economic Resource type. With this relationships materials and capacity resources are reserved that are needed for the future execution of the committed plan events specified in the Plan Event Tree type. Thirdly, the way, the commitments are fulfilled over time. According to the stochastic nature of the Economic Commitment type the fulfilment over time is itself a stochastic process which is represented by the *Formal* relationship 'stochastic fulfilment process'.

4 ERP-Control Application: Stochastic Production Planning and Control

After having specified the uncertainty representation in the stochastic extension of the OntoREA© accounting and finance model the demonstration of its applicability is addressed. For this purpose the ERP-Control application [17] is used. Of special importance it the application's stochastic planning infrastructure for the production domain [25] as it directly incorporates the Plan Event Tree type for capturing the future's uncertainty and it allows the assignment of thereupon contingent future plan events that are planned, committed, reserved and then fulfilled later on.

Figure 3 shows the stochastic production planning infrastructure from the ERP-Control application which is related to the stochastic Annual Planning Process in the module Analytical Planning. The planning task is started by activating the Production Planning entry in the right hand side menu. This initializes a new instance of an annual planning process that requires from the production planner [26] the specification of input information required in: Product Selection, Planned Production Volume, Plan Event Tree and Confirmation.

Fig. 3. ERP-Control: annual production planning process

After selecting the product (e.g. bathed candles) to be planned and after inserting the planned production volume for the next year, the binary plan event tree – shown in Fig. 4 – appears and gives the planner the possibility to overwrite the planned production volumes in all quarterly sample states. In the specific examples the binary tree relates to the uncertainty due to the stochastic demand for the selected product that can increase or decrease in each quarter according to a binary stochastic process. In the best case, the demand increases in each subsequent sample state. In this case 10000 kg are planned to be produced over the year (Yearly Quantity). According to the bill of material (BOM) and the routing with respect to the capacity resources, i.e. the personnel and the equipment resources, the resulting production costs (Personnel Costs, Material Costs, Equipment Cost, Total Costs) are calculated and shown as well. The production volume dependent production costs are also shown for the other sample paths that can possibly be realized in the uncertainty sample space.

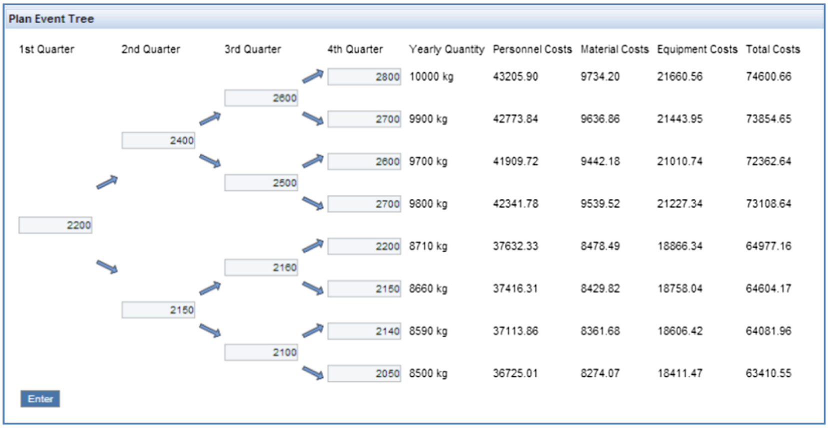


Fig. 4. Plan event tree – quarterly contingent production volumes and related costs

The last step in the Annual Planning Process is the Confirmation. By confirming the Plan Event Tree, the therein specified sample state contingent production volumes are committed and the corresponding material, personnel and equipment resource requirements are reserved.

The stochastic Annual Planning Process is accompanied by the Quarterly Planning Process. This process gets activated at the beginning of each quarter by inserting the production volumes for the three months of the quarter. In the left panel of Fig. 5 the monthly volumes are inserted for the three months of the first quarter. The right panel of Fig. 5 shows the insertion of the actual realized production volumes that is collected each month. After the third month of the quarter the overall actual production volume of the first quarter is collected. This value can be seen in the left upper part of Fig. 6. The figure also shows that the upper sample state ($s_{1,1}$) has realized which was specified by the controller who selected that state. According to the revealing information concept it can be seen that the lower sample state ($s_{1,2}$) and its following paths are grayed out indicating that they cannot be realized any more in the future. After the realization of the $s_{1,1}$-sample state only the first four sample paths can possibly be realized over the remaining three quarters of the year.

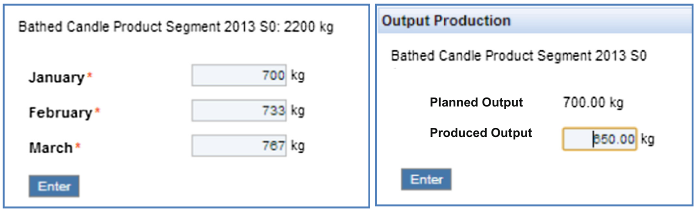


Fig. 5. Quarterly production planning and monthly production execution process

Fig. 6. Plan event tree – resolving uncertainty over time

As already indicated by its name, the ERP-Control application does not provide the stochastic planning infrastructure only for planning but also for controlling purposes by providing monitoring facilities. In the monitoring feature of ERP-Control the planned and committed production volumes are compared to the realized volumes and variances between the two are calculated. In a double loop management system the variance information can be used either to trigger corrective adjustments at the production process level e.g. by correcting the production policy or adaptive adjustments at the production planning level e.g. by adapting the sample state contingent production volumes for the forthcoming periods.

After having demonstrated the functioning of the stochastic production planning infrastructure in ERP-Control, it will be shown now which concepts from the OntoREA© accounting and finance model's stochastic extension are implemented in the application in which way.

Figure 7 shows the excerpt from ERP-Control's data model. It contains the data structure that is placed below the Economic Resource class for delivering the informational basis for the stochastic production planning infrastructure. In order to implement the bill of material (BOM) and the routing through the capacity resources the Economic Resource class is specialized into the three resource classes, i.e. Personnel, Equipment and Material. The Personnel Specification class and the Equipment

Specification class are the compositional parts of the Process Segment class that defines the routing of the production process. The Material Specification class provides the compositional parts of the Product Segment that defines the BOM. For the stochastic production planning infrastructure the Plan Events class is added.

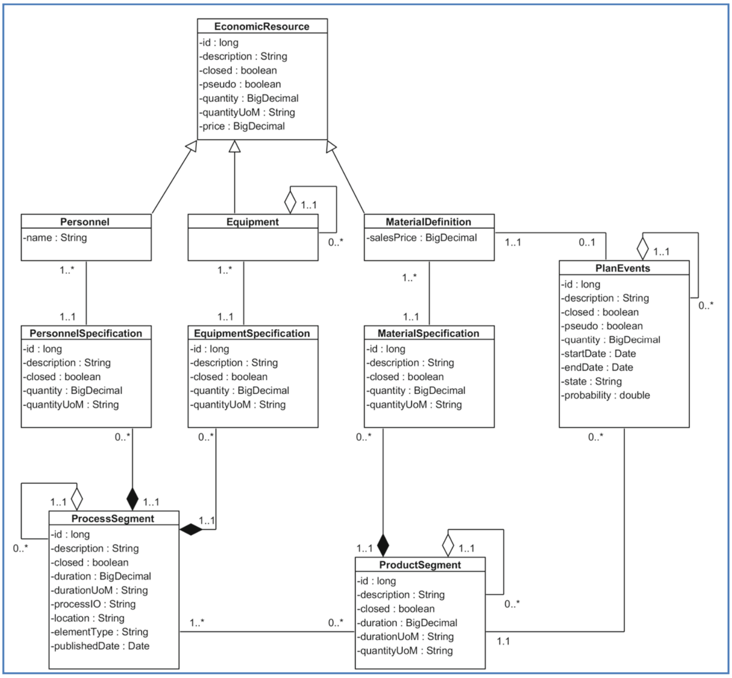


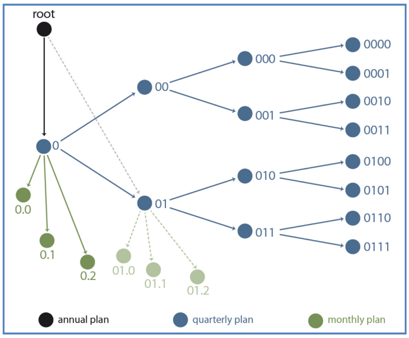
Fig. 7. ERP-Control: stochastic production planning – inclusion of plan events

The attributes of the Plan Events class contain the information with respect to the time dimension (tensed nature of future events) in the startDate and endDate attributes and to the uncertainty dimension (stochastic nature of future events) in the state attribute and the probability attribute. The Boolean pseudo attribute indicates if the instance of the Plan Event class is committed (TRUE) or not (FALSE).

The recursive relationship of the Plan Events class allows the building of tree structures. In the ERP-Control application they are used to build the binary Plan Event Tree structure (Fig. 4). This tree is constructed according to the (binary) Uncertainty Sample Space type and it contains the planned and committed production (plan) events. The committed events reserve the corresponding resources and they are executed according to the realizing sample states over time in a stochastic, i.e. a temporal modal way.

The Plan Events class is implemented – like the other classes in Fig. 7 as well – in the Java Enterprise Edition as a database persisted entity bean.

The state attribute of the Plan Events class contains the reference to the sample states defined in the (binary) Uncertainty Sample Space type. This reference is given by the binary coding of the time-t sample states that can be seen in Fig. 8. The annual production plan is called the "root" in the Plan Event Tree and it includes the planned production volumes for the selected product. To an annual production plan belong 15 possible quarterly production plans which are coded by the sample path "0nnn" where n can be 0, 1 or { }. For example: in the third quarter the four sample states are possible, i.e. 000, 001, 010 and 011. Furthermore, each quarterly production plan has three monthly plans with state 0nnn.m where m stands for the months 0, 1 and 2. For example: 0.0 for January, 0.1 for February and 0.2 for March.



Plan category	Time-t sample state	Binary coding
Annual plan	Root	
Quarterly plan	0nnn	n : ({ } | 0 | 1)
Monthly plan	0nnn.m	n : ({ } | 0 | 1), m : (0 | 1 | 2)

Fig. 8. Binary sample space representation – binary coding of time-t sample state

5 Conclusion

The primary research objective of this article was the extension of the OntoREA© accounting and finance model with an adequate representation of the uncertainty that surrounds the forward looking perspective of finance. This objective was achieved by an UFO-ontological conceptualization of the stochastic concepts, i.e. the stochastic process and the revealing information concepts from the "golden" age of finance and their integrations into the OntoREA© model. Key for the consistent integration is the connection of the Economic Commitment type with the Uncertainty Sample Space and the Plan Event Tree types. Due to the generic nature of the stochastic extension it can be applied not only for financial planning and control but also for decision analysis and different kinds of optimal control problems. The applicability of the OntoREA© model's stochastic extension was demonstrated via the ERP-CONTROL application where elements of this extension were used to provide the application's stochastic production planning and control infrastructure.

By including perdurant Event types from UFO-B for the ontological specification of the Economic Event and the Plan Event Tree types a completely new possibility arises for the conceptual modeling of different processes. Mixing UFO-B with UFO-A constructs in the stochastic OntoREA© accounting and finance model allows a convenient mixture of structural and dynamic concepts. Equipped with this new possibility the UFO-B event-based dynamic modeling can cover different types of processes at the operational level and the different management levels, i.e. operational (business) processes (business domain), managerial processes (management control domain) and policy setting (governmental) processes (governance domain). For future research it seems especially interesting to grab this new opportunity for solving the problem of integrating managerial and governmental processes in form of Balanced Scorecard management systems [27] or in form of more general strategic and management control systems [28] into different versions of the REA model and the stochastic OntoREA© accounting and finance model, respectively.

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