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Accounting and Management Information Systems: A Semantic Integration

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ABSTRACT

Accounting information systems fulfil the purpose of recording the business transactions over time according to the legal accounting requirements. Management information systems provide the information and mechanisms that are needed to manage the enterprise in different management domains. The primary research objective of this article is the specification of the relevant concepts underlying both information systems and their integration in a comprehensive framework. The resulting framework shows the economic and managerial requirements for integrated accounting-based management information systems and it can be used for a semantic design of such systems.

For this purpose the probabilistic REA management ontology is developed by integrating the management concepts of the cybernetic management framework into the REA business ontology. Consequently the derived REA management ontology rests upon the well-established REA business ontology and it allows the semantic design and implementation of accounting-based management information systems.

Categories and Subject Descriptors

H.4.2 [**Information Systems Applications**]: Types of Systems – *Decision support (e.g., MIS)*. K.6 [**Management of Computing and Information Systems**]: K.6.0: K.6.1: Project and People Management – *Systems analysis and design*.

General Terms

Information Systems, Accounting, Finance, Management.

Keywords

Accounting information systems, management information systems, REA business ontology, cybernetic management framework, probabilistic REA management ontology.

1. INTRODUCTION

In the year 2008 the ERP market has undergone a fundamental change. The market leading providers of ERP systems expanded their businesses by buying business intelligence providers. The market leader SAP bought e.g. Business Objects for USD 4,9 bn and increased thereby its balance sheet assets by 1/3. Mergers like these require a substantial effort to integrate the ERP functionalities with the business management functionalities. The integration requires the alignment of the accounting information systems that are behind the ERP functionalities and the management information systems that implement the planning and control functionalities needed to manage the enterprise in the different management domains. In the integrated systems the accounting information is not only used for reporting purposes but it also forms the fundamental information base upon which performance management systems are constructed, calibrated and validated over time. In order to achieve such integrated information systems that provide the economic and managerial functionalities for accounting and the different management domains it is necessary to explicitly specify the relevant concepts and to coherently integrate them into a comprehensive framework. The specification of the relevant concepts in accounting and the management sciences is not an easy task. In the literature there exist different concepts and it is not really clear which of them are the relevant ones.

The primary research objective of this article is the specification of the relevant concepts underlying both information systems and their integration in a comprehensive framework. To solve this identification and integration problem a semantic approach is taken. According to Izza [1, p. 35] there *are many approaches that are semantics-based and that have been proposed for industrial information system integration. These approaches are based on the representation and the exploitation of the semantics of information systems during the integration process. 'Semantics' means meaning.* The comprehensive accounting and management semantics to be developed has to include all relevant economic and managerial concepts. Gruber [2] calls the explicit *specification of a conceptualization* as *ontology*. In this sense the specification of the relevant concepts in accounting and management and their comprehensive integration are ontologies and the semantic integration approach is an ontology-based approach.

McCarthy [3] developed the REA accounting framework for the economic structures upon which accounting is based. The framework specifies the economic principle which is known in accounting as duality principle in the sense of *there is no free lunch in the business world* or *you get what you pay*. The accounting framework was extended by Geerts and McCarthy [4] to the REA business ontology which contains an accounting infrastructure and a policy infrastructure. The policy infrastructure provides specifications for economic agreements that relate to the future and allows the specification of policies with respect to typified economic constructs. In management science there is no such well-established ontology like in the REA business ontology. Just recently a cybernetic management framework was introduced by Schwaiger [5]. In this framework the relevant managerial concepts are developed according to the principles of 1st-order cybernetics developed by Wiener [6], 2nd-order cybernetics developed by Foerster [7] and the stochastic concepts out of probability theory. By integrating the cybernetic management framework into the REA business ontology the *probabilistic REA management ontology* is derived. The consistent establishment of this framework is the central contribution of this article. The probabilistic REA management ontology allows the semantic design and implementation of accounting-based management information systems which include advanced management concepts in form of *rational planning* and *stochastic optimal control* systems and it can be used to integrate the ERP and the business intelligence functionalities of existing applications.

The article is structured as follows. In section 2 the REA business ontology is presented. The starting point is the REA accounting framework where the economic rationale in form of the duality principle is specified. Afterwards the REA business ontology is modelled in form of a class diagram so that it can be extended. In section 3 the cybernetic management framework is presented by addressing the cybernetic principle and the modelling of the cybernetic management processes as well as the uncertainty that is related to the future. Section 4 contains the main result of the paper in form of the probabilistic REA management ontology. In this ontology the policy is contextualized in the business and management domain, the management policies are specified according to the cybernetic management framework and the future uncertainty is characterized by the probabilistic nature of the future event types. In section 5 the article is summarized and concluded.

2. REA BUSINESS ONTOLOGY

McCarthy [3, p. 554] introduced the REA accounting framework. *This framework, called the REA accounting model, is developed using data modeling techniques, and its underlying structure is found to consist of sets representing economic resources, economic events, and economic agents plus relationships among those sets*. The REA accounting framework was extended by Geerts and McCarthy [4] to the REA business ontology which includes also future related information and business policy considerations.

The *economic rationale* postulates that scarce resources have a positive value that must be paid by the buyer to the seller in an exchange transaction. In Figure 1 this principle can be seen in a simplified sales transaction where the producer gives the candle to the consumer and the consumer pays the price to the producer.

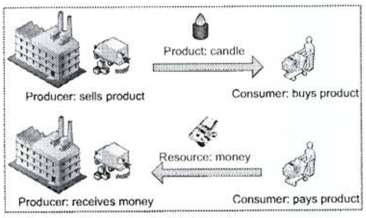

Figure 1. Economic Principle: You get what you pay.

The economic rationale underlies the double-entry bookkeeping mechanism that is used in accounting to record the business cases in the nominal ledger accounts. McCarthy [3] specified the underlying structure in form relationships between the three elements

- *economic resources (R),*
- *economic event (E) and*
- *economic agents (A).*

The relationships indicate the resource flows from and to the agents involved in the economic transaction that are connected via the duality relationship with the economic events. The three elements and the corresponding relationships are shown in Figure 2 in form of a class diagram. The class diagram modelling approach is used in the ISO/IEC 15944-4:2006 standard [8] related to the accounting and Economic Ontology (AEO) in order to model business transactions. Subsequently the class diagrams also used to represent the REA business ontology and to derive the probabilistic REA management ontology.

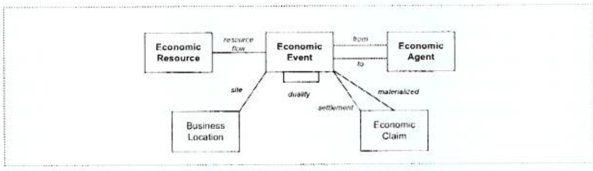

Figure 2. REA Accounting Framework.

The REA business ontology shown in Figure 3 is an extension of the REA accounting framework that was developed by Geerts and McCarthy [4]. It puts a policy infrastructure on top of the accounting infrastructure. The accounting infrastructure corresponds to the REA accounting framework. The policy infrastructure includes future related information in form of economic commitments, economic contracts and economic agreements. Furthermore it uses the typification concept to specify types of economic resources, economic events and economic agents that can be applied, i.e. used to in the formulation of business policies.

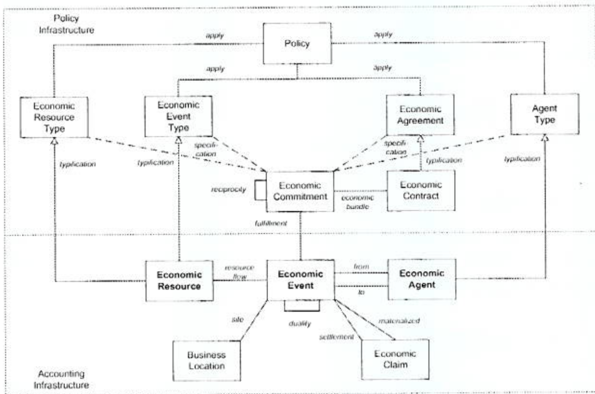

Figure 3. REA Business Ontology: Accounting and Policy Infrastructure.

We distinguish between among the following three types of policy definitions: knowledge-intensive description, validation rules, and target descriptions.

- *A knowledge-intensive description defines characteristics of a concept that apply to a group of objects. Such characteristics can take the form of a policy definition: e.g., the price of any bottle of Chanel No. 5 is $75. Actual instances, e.g., an actual bottle of Chanel No. 5, can then derive the policy-based characteristics through inference: "If a bottle is of type Chanel No. 5 then its price must be $75."*
- *A validation rule represents permissible values, and a common application of validation rules in enterprise systems is preventive controls. For example, the salary for an employee should be validated against the salary range defined for his or her employee type, such as "A staff member should earn between $25,000 and $40,000."*
- *Target descriptions provide benchmarks regarding economic phenomena, and they can take at least two different forms: standards and budgets. Generally, standards are specifications to be followed; however, they may be tweaked (like changing a cookie recipe). Standards often refer to engineering information, for example: "How much raw material does it take to manufacture a bike?" or "What are the best practices for assembling cars?" Budgets provide quantified performance measures most often related to a specific time period such as "How many cars do we expect to sell in the second quarter of 2006?".* [9, p. 39f].

Weigand et al. [10, p. 2] extend the *REA business ontology* with a *REA management ontology* by modeling management as services and establishing a general framework of services. They formalize policies *in analogy to contracts as a group of intentional resources obeying the reciprocity principle: what the agent gives in versus what he aims to achieve... As any resources, intentional resources are processed by events that we call intentional events. For instance, commitments are created or removed by commit and decommit events ... Intentional events are typically realized by means of communicative acts to be represented on the process level... In our definition, constraints are part of the policy, but always linked via the policy to goals. In our view, the "apply" relationship is a special kind of "referring".* Weigand et al. [10, p. 5]. Furthermore they distinguish between different abstraction levels in which policies are defined. *Policies can be defined on two levels, the "what" and the "how". This abstraction is important, since it allows for adaptation of the controlled system, within given boundaries. The way the abstract policy is enforced may depend on the (monitored) situation and on design choices made by the controlling system [25]. In the following, we will use the term "specification" for the enforced (and executable) policy.* [10, p. 5].

3. CYBERNETIC MANAGEMENT FRAMEWORK

The cybernetic management framework was developed by Schwaiger [5] in order to integrate risk management considerations at the process, the business and the enterprise management level. The framework is based on cybernetic principles that are applied in activity diagrams to specify the business and management activities and the therewith related information flows. The framework translates management into action.

For the cybernetic management framework there are according to Schwaiger [5, p. 421] *three cybernetic principles that are of special importance:*

- *feedback principle*
- *control and communication principle*
- *double loop principle.*

The first two principles lie at the heart of the traditional cybernetics definition introduced by Wiener [Wiener48]. The double loop principle is central to the 2nd-order cybernetics that was established by Foerster [Foer03] in the 70ies of the last century (see also Scott [Scott96]). In the literature the three principles are dealt with normally quite separated so that their combined consideration should deliver interesting and beneficial insights. [5, p. 421].

The feedback principle corresponds to a circular causality where the results of an activity are again influencing the activity. In the quality management domain this circularity is known as *PDCA-cycle* where the acronyms indicate the constituent activities, i.e. Plan-, Do-, Check- and Act-activities of the cycle. The conceptual idea of the PDCA-cycle goes back to Shewhart [11] who used this feedback mechanism about 80 years ago for the statistical process control. At present the PDCA-cycles are the international standard of modeling management systems. *The Plan – Do – Check – Act (PDCA) cycle is the operating principle of ISO's management system standards... Management system standards provide a model to follow in setting up and operating a man-agement system. This model incorporates the features on which experts in the field have reached a consensus as being the international state of the art. The Plan – Do – Check – Act (PDCA) cycle is the operating principle of ISO's management system standards.*

- *Plan – establish objectives and make plans (analyze your organization's situation, establish your overall objectives and set your interim targets, and develop plans to achieve them).*
- *Do – implement your plans (do what you planned to).*
- *Check – measure your results (measure/monitor how far your actual achievements meet your planned objectives).*
- *Act – correct and improve your plans and how you put them into practice (correct and learn from your mistakes to improve your plans in order to achieve better results next time).* [12].

In the management control theory that was established by Anthony [13] the double loop principle (self-organization principle) is incorporated in the *management system* which is decomposed into a *planning system* and a *control system*. In the planning and control framework the management process consists out of the business system's planning and its subsequent control in accordance with the objectives and rules set in the planning process. The cybernetic self-organization principle can also be found in other modern management theories. E.g. it shows in the *double loop learning principle* that was developed by Argyris [14] to model learning organizations. Furthermore this 2nd order cybernetic system thinking is also at the core of the *5th discipline principle* that was introduced by Senge [15] to comprehensively integrate the four traditional disciplines in organizational learning.

The control and communication principle imbeds the feedback into the planning and control framework where the activities and related information flows are specified: *the cybernetic planning and control framework introduced by Anthony [Anth65] is taken to put the PDCA-cycle into a managerial planning and control framework. Using the planning and control framework the business management system is composed out of a planning system and a control system that are established to manage the operating activities in the operating system... The integration of the planning and control framework, the PDCA-cycle and its related information flows is realized by using* `MGT-Activity`*-diagrams. In the* `MGT-Activity`*-diagram the object and process orientation is implemented by simultaneously modeling the managerial PDCA-activities as processes and the related information flows as objects. In the spirit of Cybernetics as the science of 'control and communication in the animal and the machine' the* `MGT-Activity`*-diagram is the object and process oriented modeling technique for planning, control and communication in management.* [5, p. 429].

In the cybernetic management framework different activity diagrams are available to allow the modelling of management processes with different complexities. The generic management process is the most advanced process that is modelled in the generic cybernetic management framework [5, p. 436]: *In the generic cybernetic management framework there are 8 managerial activities:*

- *(1)* `Plan`*-activity*
- *(2)* `Measure`*-activity*
- *(3)* `Check`*-activity*
- *(4) Corrective* `Act`*-activity*
- *(5) Adapting* `Act`*-activity*
- *(6) Process related* `Supervision`*-activity*
- *(7) Control related* `Supervision`*-activity*
- *(8) System related* `Supervision`*-activity*

The first four activities specify the *1st-oder cybernetic management framework* which allows the modelling of management systems with single loop learning mechanisms. Such systems are used in traditional performance management systems where the objectives are set in the planning activities, the performance is measured over time, the measured results are compared with the objective values and corrective actions are taken when the deviations exceed the limits. The inclusion of the fifth activity establishes the *2nd-oder cybernetic management framework* where the self-organization principle is included that allows the modelling of management systems with double loop learning mechanisms. The supervisory activities are added to ensure that the implemented business and management processes are correctly executed. The system related supervisory activities ensure the rule compliant behaviour of the overall management system architecture.

Figure 4 contains a generic management process where all 8 managerial activities and the related information flows are stereotyped. The business process that is located at the left lower corner has the <<Do>> stereotype. It is viewed according to the going concern principle which is modelled as an iterative loop. The performance of the business process executions is periodically measured and the actual performance is compared with the standard of performance. If the Check-activity shows significant deviations these are used in the Act-activities to adjust the business and the management system.

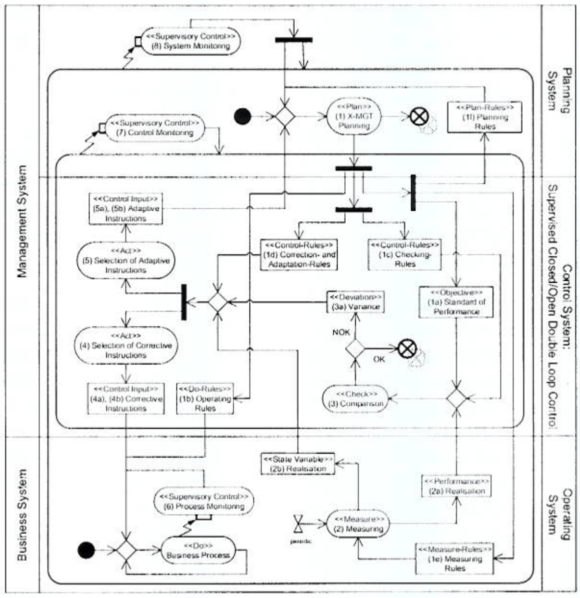

Figure 4. Generic Cybernetic MGT Framework – Double Loop Learning and Supervision. This figure is taken from Schwaiger (2012) where it is Figure 11.

In the MGT-activity diagrams there are two closed loops. One loop goes back to the business system by giving corrective instructions to eliminate the deviations in the next business process executions. In the second loop adaptive instructions are given back into the planning system in order to adjust the overall system. The first loop implements the traditional closed loop control system. The second loop implements the self-organization principle. The three supervisory control activities monitor the business process execution as well as the functioning of the control system and the overall management systems.

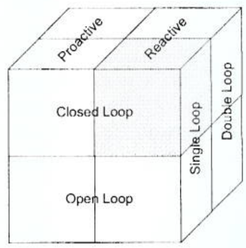

Figure 5. Control System Design – Control Process Variants. This figure is taken from Schwaiger (2012) where it is Fig. 10.

The generic structure of the cybernetic management framework with respect to different specifications of the control system can be seen in Figure 5. The grey shaded part constitutes a reactive closed single loop management system. Such systems are used e.g. in the traditional cost management domain where the costs are planned at the beginning of the budgeting period and the actual costs are compared to the targeted costs at the end of the period. The thereby derived controllable and volume variance are analyzed to determine reactive adjustments that correct the underlying processes. In proactive management systems forwards looking feedforward information is used whereas reactive systems rely on backwards looking feedback information.

Next to the cybernetic pillars there are two more pillars in the cybernetic management framework. The economic pillar carries the economic context of the framework. Its integration into the `MGT-Activity`*-diagram is over the specified* `Measure`*-rules where the performance measure and the state variable are defined. The economic context is prevailing when economic performance measures or state variables are used in an application. The third pillar of the cybernetic management framework is the stochastic pillar. The stochastic pillar carries the uncertainty that is intrinsically connected to all social systems...* [5, p. 436].

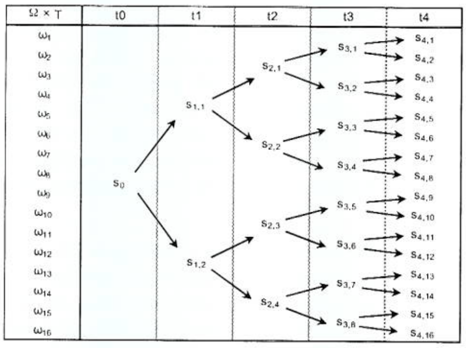

Figure 6. Modelling the Uncertainty – Event Tree Approach. This figure is taken from Schwaiger (2012) where it is Fig. 14.

For an adequate capturing of the uncertainties related to the business environment the cybernetic management framework is built upon a probability theoretic foundation. *In stochastics the binomial tree shown in Figure 6 corresponds to the event space upon which the stochastic process is defined. Stochastic processes are measurable functions that map the event space into the real numbers. The measurability of the functions means that the different elements in the event space have probabilities associated. These probabilities allow the calculation of state conditional expectations and state conditional risk measures.* [5, p. 440]. The probabilistic event tree in Figure 6 shows the simplest stochastic process where each node in the tree is followed by two subsequent nodes. Due to the probabilistic nature of the tree each node has a probability for its occurrence. The ordered sequences of nodes specify the different scenarios that can occur in the future. In the four-period model there are 16 scenarios that are numbered from ω_1 to ω_{16}. The 16 scenarios are the elementary events of the probability space. The set of the elementary events is partioned in each period. The partitions get successively more granular over time so that the binary tree generates a filtration and the probability space gets filtered. In the filtered probability space the future events are defined as sets of elementary events. Over time the number of elements in the events diminishes and at the end after all information is revealed each event corresponds to a single elementary event. Consequently the probabilistic information structure in form of a probabilistic binary tree incorporates the *revealing information concept* where over time successively more information is revealed until the end where all information is revealed.

4. PROBABILISTIC REA MANAGEMENT ONTOLOGY

The REA business ontology and the cybernetic management framework presented so far are now integrated. The resulting framework is an extension of the REA business ontology. It is called the *probabilistc REA management ontology* due to the inclusion of the probabilistic information structures. The ontology is shown in Figure 7.

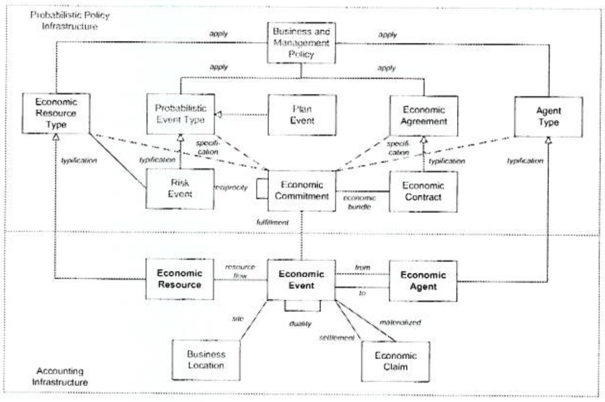

Figure 7. Probabilistic REA Management Ontology.

At the top of the probabilistic REA management ontology rests the probabilistic policy infrastructure. In this infrastructure the business policy is defined in the sense of Weigand et al. *as a group of intentional resources obeying the reciprocity principle* [10, p. 5]. These business policies are translated into concrete business rules that are executed in the business system. The execution of the business rules over time is recorded in the accounting infrastructure so that the legal accounting requirements are fulfilled.

Examples from Geerts and McCarthy [9, p. 39f] for business policy types are the *knowledge-intensive description* and the *standards*. The *budgets* and the *validation rules* relating to the business process execution are examples for management policy components. The management policies are specified according to the cybernetic principles and they are translated into management rules by modeling them with management activity diagrams.

In the probabilistic REA management ontology the probabilistic nature applies to all future related event types. The *probabilistic event type* is represented in the simplest case as a probabilistic binary tree and it is used to specify future events. The future events in form of a plan event and a risk event both inherit the probabilistic nature of the probabilistic event type so that both possess values for the future events and probabilities that indicate the likelihood of their occurrence. The plan events are future events which are explicitly distinguished from the economic events in the REA business ontology. The plan events are defined on filtered event spaces. They contain the objectives that are set in the planning processes. The risk events in the REA management ontology also possess the probabilistic nature inherited from the probabilistic event type. They are used in the risk management systems.

Due to the explicit inclusion of the probabilistic information structures the probabilistic REA management ontology is an appropriate framework that allows the consistent design and implementation of accounting-based management information systems which include advanced management concepts in form of *rational planning* and *stochastic optimal control* systems.

The plan events contain the objectives of the performance management systems. In e.g. a production planning and control system the objectives are the planned production volumes for the future periods. In the traditional production planning the production plans for the future periods are deterministically set. That means, for each future period there is one production plan with an assigned probability of 1. The deterministic planning is contrasted to the *probabilistic planning* where there is normally more than one plan for each future period. Probabilistic production plans depend on the events that can occur in the future time point where the production period under consideration starts. Furthermore they can be considered from different viewing points. In the initial planning the future event dependent plans are seen from the starting point at the beginning of the planning horizon. In the subsequent planning over time the future plans are seen conditional from the state which occurred by then and that is measured by the state variable. This *conditional planning* is important in performance management systems to allow the formation of *conditional forecasts* which are updated on the information revealed over time.

The probabilistic planning corresponds to the *rational planning* model that Lucas [16] introduced in his *rational expectations theory* where the rational plans of the economic agents are set equal to the *mathematical conditional expectations*. The *intertemporal portfolio theory* that was developed by Merton [17] is another example for an advanced planning and control model that is based on probabilistic information structures. In that theory the optimal portfolio investment strategies are selected according to the stochastic control theory. In the probabilistic REA management ontology the stochastic optimal investments in the future event space are captured with the probabilistic plan events. The *option pricing theory* developed by Black/Scholes [18] is a next example. Also this theory relies on probabilistic information structures so that the future option replication portfolios can be modelled with the probabilistic plan events.

The risk events defined in the probabilistic REA management ontology are used in risk management systems to specify future events that have a negative impact on the achievement of the objectives set in the planning system. The identification and measuring of these events enables the consistent integration of risk management activities into different management domains. Once the probabilities and impacts of the risk events are measured they can be controlled by comparing the observed values with the postulated risk limits and taking corrective and adaptive adjustments if the limits are exceeded. The inclusion of the risk events in the probabilistic REA management ontology is an important step to allow the consistent modelling of risk management principles as they are formulated e.g. in the enterprise risk management framework of the Committee of Sponsoring Organizations of the Treadway Commission [19] or the risk management standard of the International Organization of Standardization [20].

5. CONCLUSIONS

The primary research objective of this article was the specification of the relevant concepts underlying the accounting as well as management information systems and their integration in a comprehensive framework. This problem was addressed by using a semantic integration approach. For the semantic approach the most important concepts had to be identified. They were found in the REA accounting framework, the REA business ontology and the cybernetic management framework. In the REA accounting framework the duality principle is identified as relevant and specified. The concepts for modelling the future events and policies are specified in the REA business ontology. The business policy is defined as a group of intentional resources obeying the reciprocity principle. By specifying the business processes these policies are translated into operational business rules. The cybernetic management ontology contains the cybernetic principles in form of the feedback principle, the control and communication principle and the double loop (self-organization) principle. The management policy relates to the specification of the adequate management system which can be a combination out of a proactive/reactive, a closed/open and a single/double system. By specifying the management processes which are modelled as activity diagrams the management policy is translated into managerial Plan-, Check- and Act-rules. The probabilistic concepts needed to model the uncertainty in the business environment and the revealing information concept also are specified in the cybernetic framework by probabilistic information structures.

The probabilistic REA management ontology is an extension of the REA business ontology that integrates the relevant concepts of the cybernetic management framework. As such it inherits the solid foundation of the REA business ontology and modifies it with respect to the policy element and the economic event type element and adds two additional elements in form of the plan event and the risk event. The probabilistic event types are important to make the probabilistic REA management ontology a comprehensive framework that allows the inclusion of probabilistic information structure-based management concepts.

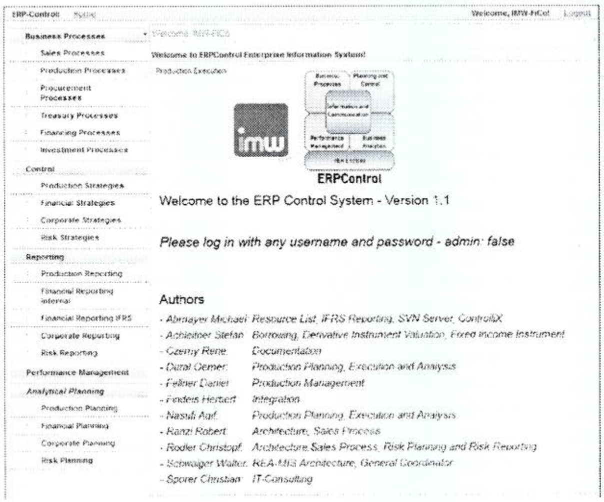

Figure 8. ERP-Control Application
http://erpcontrol.imw.tuwien.ac.at/ERPControl/home.seam

The probabilistic REA management ontology should be useful for all who have to understand the essential integration dimensions of accounting and management information systems. This is especially the case for the designers of such systems where the

REA management ontology can be used to design the business and management processes and the related data models.

At the Institute of Management Science of the Vienna University of Technology e.g. an accounting-based management information systems was designed along the lines of the probabilistic REA management ontology and implemented in modern information technology. The resulting prototype ERP-CONTROL is shown in Figure 8. ERP-CONTROL is a process driven application what can be seen by the business and management processes in the navigation bar on the left hand side of Figure 8. The business processes are structured according to the value chain model into production, procurement, treasury, financing and investment processes. These processes are supported by work flows where the corresponding accounting information is collected and recorded in the data base according to the REA business ontology. The process orientation of ERP-CONTROL prevails not only in the business domain but also in the management domain. The management processes are decomposed into planning and control processes. The probabilistic nature of the REA management ontology shows in the analytical planning processes where the future related uncertainty is modelled by event trees. In the control processes the information revealed over time is detected and transformed into corresponding actions. The execution of the actions ensures that the initially set objectives are realized as close as possible at the end of the planning horizon.

The ERP-CONTROL-application is implemented in the *jBoss Seam framework* [21]. In this framework the business and management processes are modelled as work flows in the Java Process Definition Language (jPDL) that are executed with the Java Business Process Management (jBPM)-engine. The accounting and management information is defined according to the probabilistic REA management ontology in business and management related entity beans of the Java Enterprise Edition (Java EE). The entity beans are persisted with the Hibernate persistency framework. Consequently the ERP-CONTROL-application implements the probabilistic REA management ontology in a process and object oriented way with the web-based Java technology, such that "IT follows business management".

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