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Decision-Making in Information Systems Based on New Development Framework and Business Process Mining

Olegas VASILECAS[a], Diana KALIBATIENE[a,1], Titas SAVICKAS[a] , Aidas SMAIZYS[b], Justas TRINKUNAS[a] and Evaldas LEBEDYS[a]
[a] *Vilnius Gediminas Technical University, Vilnius, Lithuania*
[b] *Klaipeda University, Klaipeda, Lithuania*

Abstract. The studies on software project failures have identified problems in capturing requirements, managing complexity and dynamic changes of the environment because of the using traditional software engineering, where requirement capturing is static and prolonged. This issue is especially important for decision-making in dynamically changing business. The paper offers modernization of information system development methods used for implementation of automated information-, rule-, knowledge-, model-based decision processes. The paper propose to assist processes by early separation and development of a business logic model and implementation of decision-making, knowledge discovery process models and business process analysis using probabilistic models by proposing an information systems development framework. The advantages of such approach are early separation and development of a business logic model and further support for business people for modification of business logic without involvement of software developers and minimizing their persistence in the latter exploitation stages. Finally, the paper presents experimental results for stochastic decision extraction from system database using process mining and probabilistic models to ease framework implementation.

Keywords. decision-making in information systems, decision model, information systems development framework, process mining, probabilistic models

Introduction

In the Chaos report, published in 2013 [1], 39% of software projects were successful, 18% - failed, 43% - challenged (that means cost overruns, budget overruns or content deficiencies). Moreover, software projects, in which agile methods were employed, were 3 times more successful than traditional ones used. Since the first Chaos report, published in 1994, (16% projects were successful, 53% of the projects were challenged, and 31% failed outright) the situation is getting better. However, the recent figures remain troublesome [2]. Many studies on software project failures have identified difficulties in capturing requirements, managing complexity and dynamic changes of the environment influenced by the changes of the evolving world around us. In addition, flexibility remains a major challenge related to decision process implementation and alignment in the scope of a constantly changing business system environment.

[1] Corresponding Author.

Nowadays information system (IS) engineering tries answer to this changing by developing a range of agile and heavyweight software development methodologies and approaches to implement better decision-support systems that point to what data might be collected and used for further interpretation, preparation and stochastic decision extraction from system database of information presented for decisions made by business managers. Currently, software architectures introduce separate components representing a business logic layer used to concentrate and simplify implementation of changes in the business logic. However, that is insufficient because a formal and informal heavyweight requirement or even model driven methods of IS engineering still require wide-range involvements of software development approaches. Moreover, business people, who are first directly responsible for the results of automated business processes, remain isolated from direct management of the rules, which are usually hidden in the code in automated decision-making processes, realised by software systems. This can be tolerated in case of simple operational decisions. However, it becomes a real problem when trying to automate more abstract tactical and strategic decisions based on complicated and unstable business logic.

The paper offers modernization of IS development methods used for implementation of automated information-, rule-, and model-based decision processes assisted by early separation and development of a business logic model and further support for business people with suitable interfaces for modification of business logic without any involvement of software developers or minimizing their persistence in the later exploitation stages. The paper also presents experimental results for stochastic decision extraction from system database using process mining and probabilistic models to ease framework implementation. The rest of the paper is structured as follows. Section 1 presents related works on decision models in intellectualized IS and comparison of the selected rule-based methods for decision automation support. Section 2 describes the framework for intellectualized IS development proposed by the authors of this paper. Section 3 presents the summary of the obtained experiment on the utilization of probabilistic models for the use in implementation of decisions by using suggested framework. Finally, Section 4 concludes the paper.

1. Related Work

This section reviews main related works on decision processes and decision models and present main definitions used in our research.

1.1. Decision Process

According to Object Management Group (OMG), decisions are presented in many business processes and process models. For example, in Business Process Management Notation (BPMN) [3] or UML Activity Diagram decisions are made in process flow forks or dedicated activities represented by the activity that is followed by the diamond. Such diamonds are usually treated as a simple point for selection of further activity alternative. However, business logics are often more complicated and require additional informational support and post decision evaluation procedures, which require particular modelling and management concerns. This makes unclear the modelling of such decision processes with separated explicit or implicit logics, since there is no Decision Model and Notation (DMN) available now [4].

We define decision-making in the scope of IS as *a process of choosing among alternative courses of action in the purpose of attaining business goals*. Decision-making is supported by analytical data processing and can be executed by human or machine agents. The analysis of intellectualized IS's evolution lead us to the conclusion that modern IS should support self-adaptation to the rapidly changing business environment and suggest or implement decision alternatives based on automated knowledge discovery and evaluation of future effect on the system. This is not a trivial task for IS engineers and should be supported by a huge amount of specific knowledge and methods, which are partially available but often incompatible with each other or have important missing parts in the scope of our interest.

1.2. Decision Process Classification

The literature survey has identified that there is no existing, well-defined and comprehensive framework for identifying individual factors and specific decision-making strategies; therefore, no existing assessment tool could be used to classify personal preferences for decision-making.

According to B. von Hale [5], decisions in business are usually grouped by three management levels according to the time, details, questions, and decisions. They are as follows: *strategic decisions* (What?), which deal with the big picture of business, its future orientation; *tactical decisions* (How?), which involve the establishment of key initiatives to achieve the overall strategy; and *operational decisions* (How are the resources utilized?), which determine how activities actually are done.

Business processes are usually guided by making decisions that are influenced by a set of environmental elements such as political, legal, economical factors and other systems. According to the Deming Cycle [6], there are four main necessary steps to align an organization with its processes on the business system level. We propose a structure of decisions along the four phases: *Plan*, *Do*, *Check*, and *Act*. Every step in such a cycle is related to the specific class of decision processes grouped by the phase. For more information about Deming Cycle can be found in [7] also.

The analysis of decision modelling methods and decision-making methods demonstrate that decisions according to the decision-making process, its behaviour and information used for decision-making can be grouped into:

- **Deterministic – structured:** this group of decisions represents decisions made according to the structured logic according to the determined process, when it is possible to describe all the possible decisions and states of the decision-making system and where the structure of information objects is known. Such decisions are usually made according to the rules specified using horn logic or decision tables;
- **Deterministic – unstructured:** the group of decisions where decision-making process can be determined but the structure of rules and facts is unknown and a set of possible solutions is huge but finite. Such decisions can be usually automated by using rule engines;
- **Stochastic:** this is the most complicated group of decisions made under uncertainty. Such decisions are made in behaviour where it is impossible to determine a structure of decision rules or specify a full set of possible solutions. Such decisions are usually made by using fuzzy logic or neural networks and flow engines.

R. Ross [8] also defines deterministic, intuitive, and ad-hoc decisions which can be repetitive or infrequent and provides several patterns of decisions by inclusion of classification, evaluation, selection, approval, assessment, assignment, allocation, and diagnosis or prediction tasks.

According to the presented information, Decisions at strategic and tactical levels are usually based on the information provided by IS's used for decision support and deliver the same value as their context has been implemented into the organizational business processes and decision-making actions directly implemented into the IS software logic.

1.3. Comparison of Decision-Making Models

Related methods are analysed, and a comparison of the methods according to the defined criteria is made. The following methods are compared: B. von Halle and L. Goldberg [5], OMG (BRG) Approach, Avdejenkov and Vasilecas method [15], Asuncion *et al.* method [16], IBM (ILOG) approach, and Microsoft Approach.

In 2010, ***B. von Halle and L. Goldberg*** [5] introduced a Decision model and defined 15 principles of the decision model development. The authors emphasize separation of business decision from business process and offer significant improvement by removing the declarative business decision from the procedural process flow. In such a way, a new task combines the completely previously sequential set of tasks into one task, denoted as a decision task, behind which a business decision executes in a declarative fusion. The proposed method allows a simpler business process model and highlights all possible combinations of conditions, permitting changes in the Decision Model without changing the business process model. However, the method is suitable only for conceptual modelling of a decision and has no guidelines for further implementation into the software system.

***OMG (BRG) Approach*:** The first discussion on the business rule approach came from a non-commercial peer group of IT professionals working on the business rule approach since 1989. The group called Business Rules Group (BRG) started by introducing discussion in 2000 [9] and defining the fundamental principles of the Business Rules Approach in Business Rules Manifesto [10]. Thence a lot of additions and developments have been made, like Business Motivation Model [11], which was adopted as a standard by OMG [12], SBVR [13], BPMN [3]. The authors of BRG focus on the use of decision tables for a structured business logic specification and SBVR [13] as a global semantic model of rules in the enterprise. The other authors, e.g. H. Linehan [14] discuss the place of DMN in the context of other existing specifications of BRG the SBVR and BPMN, where SBVR formally models the vocabulary and rules found in business sources such as corporate policies, regulations, and contracts. Later the SBVR global rules are refined and implemented in DMN decisions that may be applied as activities within BPMN processes, or in other software.

It may be concluded finally that OMG in the context of MDA provides architectural vision for model transformation driven IS software development. The new request for Decision Model and Notation (DMN) development in the context of existing specifications such as BPMN and SBVR is the next important proposition made. It will change the understanding of modern IS development and will add the missing link between the model of business logic and decisions in the business process. At this moment, DMN is being developed and is going to be approved in the nearest future.

There is suggestion in [15] ***Avdejenkov and Vasilecas*** to use the business rules for business logic separation and centralised implementation. Paper [15] propose to specify initial requirements and events in a business process model or use cases. After such definition of relations between events and actions, it is proposed to specify a decision-making process according to the business logic captured and represented as BRs. This is a typical scenario of business logic representation using ECA (event-condition-action) rules and their further implementation with later transformation into the triggers of active DBMS. The method allows making changes to the logic without direct changes of the system code in the application. However, triggers usually cannot be created and implemented into the production system or even changed in a centralized way without complicated verification of system behaviour due to unpredictable interactions at the run-time.

Asuncion et al. [16] elaborate flexible service integration through separation of business rules in the context of service mediation to provide an approach for increase of flexibility in integration solutions. The main idea of the proposition is based on combination of goal-based, model-driven and service-oriented approaches. The authors also support an idea that flexibility can be achieved by separation of dynamic parts of the business process from static parts.

The method proposed by the authors shares similar view on the problem of ensuring business process flexibility and minimization of the gap in IS software and business alignment. However, the authors focus on different topic of dynamic market demands: on achieving enterprise collaboration facilitated by Enterprise Application integration with a focus on integration of business processes of separate enterprises with different business logic when we focus on the decision process itself wherever it is implemented in the enterprise business IS.

The focus of the ***IBM (ILOG) approach*** is to provide tools and infrastructure components in IS for rule specification, management and run-time rule execution. Integration of software products is separated into several lines of products: for design-time rule base integration into the Integrated Development Environments (IDE) such as Eclipse or Visual Studio; and run-time inference engine integration with J2SE, J2EE and SOA components [17]. The technology provides support for business rules using ILOG Business Action Language (ILOG BAL), which is similar to the natural language and can be used by non-technical users to express rules in business terms. Business rules expressed in ILOG BAL can be automatically transformed into production rules for execution in the rule engine or into the BNF-like format using XML for further translation into the executable rules using XSLT or Java [18].

The analysis shows strong ***Microsoft*** positions on support for historical business information analysis, predictive analysis and mining of implicit knowledge (Data Mining Extensions to SQL (DMX), multidimensional OLAP cubes and data consolidation). The new addition in the field of rule based reasoning implementation is built by the introduction of Microsoft Windows Workflow Foundation (WWF) Rules Engine and former workflow engine focused on business communications Microsoft BizTalk. However, Microsoft focuses only on technological side of the problem and still lacks separate business rule, and business process engines or even rule repository accessed and managed by business people in their language and business terms.

The results of comparison according to the support of the proposed decision model structure and principles of intellectualized Business Information Systems (BIS) development presented in Table 1.

Table 1. Comparison of the rule-based methods for supported decisions.

Methods (Approaches) / Supported decisions	Von Hale *et al* [5]	OMG (BRG)	Avdejenkov *et al* [15]	Asuncion *et al* [16]	IBM (ILOG)	Microsoft WFF & BI	Our method*
Deterministic-structured	+	+	+	+	+	+	+
Deterministic-unstructured	-	-	-	-	+	-	+
Stochastic	-	-	-	-	-	+	+
Involvement of historical knowledge	-	-	-	-	-	+	+
Involvement of implicit knowledge	-	-	-	-	-	+	+

* The last column represents characteristics of the method proposed in this paper, and it is discussed in the next section.

The methods proposed by B. von Hale *et al* [5] and OMG (BRG) use a similar approach and involvement of decision table based business logic implementation. Avdejenkov *et al* [15] and Asuncion *et al* [16] methods are for specific solution of a separate decision problem such as ECA rule transformation into the DBMS trigger or integration of production rules executed in Jess rule engine integrated into the SOA component for collaboration between directly incompatible services. IBM (ILOG) and Microsoft WWF is technology oriented and do not provide rich scientific background.

1.4. Related Decision Support Approaches

Business people remain isolated from management of business rules automated in IS. More often than not, this leads to indirect business rule application in IS – the business rules and decisions are not automated, but performed manually perhaps even without the knowledge of business people themselves.

To solve this problem and extract those rules from systems code, automated rule extraction from IS should be performed. There are ongoing researches doing in this field. As mentioned in previous section, Microsoft predictive analysis and mining of implicit knowledge is one approach. Other approaches is process mining – techniques for automated business process model discovery, enhancement and analysis [19]

It is possible to extract decision rules from existing data in IS using business process mining. Liu et al. in [20] extract event graph from historical data stored in event logs to offer decisions on resource allocation. Rozinat et al. in [21] also performs simulation for operation decision support in the context of workflow management. The authors in the paper compare historical data with current data for decision support. Sutrisnowati et al. in [22] uses existing process mining techniques and mutual information testing approach to extract Bayesian belief network for business process analysis, but the resulting belief network is used for anomaly detection, not decision analysis.

There is also ongoing research on automated decision extraction using process mining. De Leoni in [23] attempts to discover decisions in business processes using alignments. Rozinat in [24] uses historical data together with extracted business processes and classification algorithms to extract decision trees on business control flow.

2. The Framework for Intellectualised IS Development

This section presents our proposed framework for intellectualized IS engineering. We propose to treat IS as a part of business system (BS), or as a set of software systems (SS) providing its functionality as resources needed for IS. All three systems BS, IS and SS are considered as independent deeply integrated systems and their models are made by using white box philosophy, i.e. looking from inside out of every system. We understand that different views and perspectives at separate context layers is the main issue of misunderstanding and confusing definitions of what the models of BS, IS and SS are and how they fit each other going through the layers.

To enable better understanding among people working on the separate conceptual levels, we propose to arrange framework models and to group them vertically by the concepts modelled with a focus on the shared views, which modelled across the systems abstraction levels. They represented in the horizontal rows of the proposed three layer framework (Figure 1) according to the context in the systems engineering perspective.

Introducing the framework we think that intellectualized BIS is a system threaded through all the levels of BS, IS and SS. First of all, IS is a part of BS providing functionality needed for business processes servicing all BS participants and evolving to automate more and more complex business processes going from operational to strategic levels, unlike the Zachman framework [25], which focuses on IS. SS is a part of IS, where IS is providing data analysis and communication functionality for informational BS processes represented and modelled at IS level. At the same time looking from the bottom, from the developers perspective, BIS consists of several software applications elaborated in SS, which provide resources needed for servicing informational processes of IS and BS.

Horizontally, the models of the framework are composed into three separate models: Business system model (BSM), IS model (ISM) and Software system model (SSM) at three separate layers (BS, IS, SS) in BIS context.

Vertically, the models are grouped into the columns according to the views on similar objects produced during a system engineering process. Vertical columns represent six models: Rule model, Process model, Object model, Data model, Event model, and Resource model.

There are four main concepts of the proposed model framework. They are as follows: model, metamodel, model relation, and model transformation in both horizontal and vertical directions.

Framework models are described in detail in our publication [26]. Metamodels and metamodel-based model transformations are described in [27]. The fifth important part of the framework is infrastructure needed to support development of decision automation based intellectualized BIS. An infrastructure framework was introduced in our scientific publication [28] with further improvements published later in [29, 30].

The main advantage of the suggested approach is that here a part of software dedicated to business decisions together with the rules describing business logic is separated and implemented into the central component of Business Rules Management System (BRMS). This component is responsible for business decisions and includes a model of decision propagation into the components of enterprise software through several available IS interfaces.

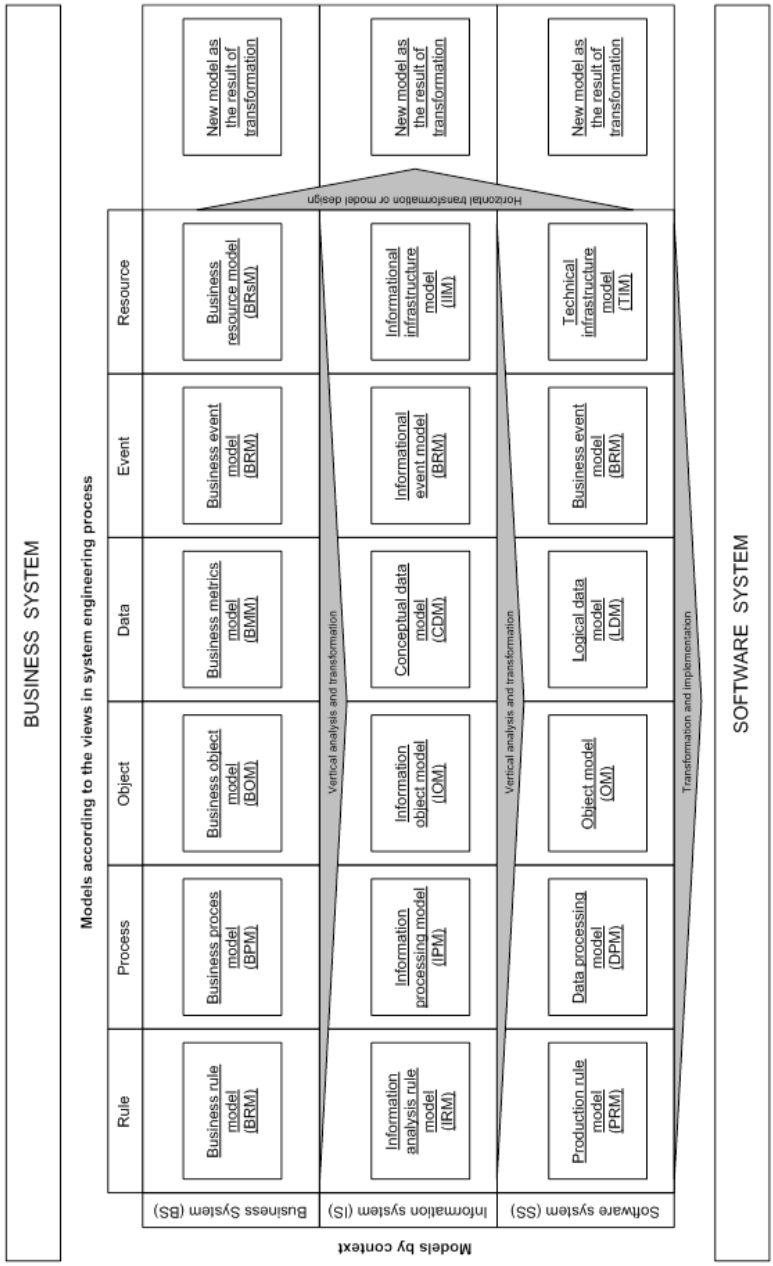

Figure 1. The three layer framework for model-driven IS engineering

Due to the huge complexity of decision-making environment it is impossible to design an effective IS that could support any type of decisions in any context or state of business environment. To deal with this engineering problem we propose a framework based lifecycle of incremental and Continuous Decision Process Design (CDPD) based on Deming Cycle and displayed in Figure 2. The lifecycle starts at BS level Act part where a business analyst analyses the existing business processes and identifies the

need for improvement. The entire engineering process is rotated according to the Deming cycle simultaneously on all three levels BS, IS and SS with some delay which is determined by an entry communication row from the Do stage to the Planning stage at the next level. Every level produces models, which are used for transformations or are integrated into the technical infrastructure and prepared for use by the separately developed executable software components used by business system users.

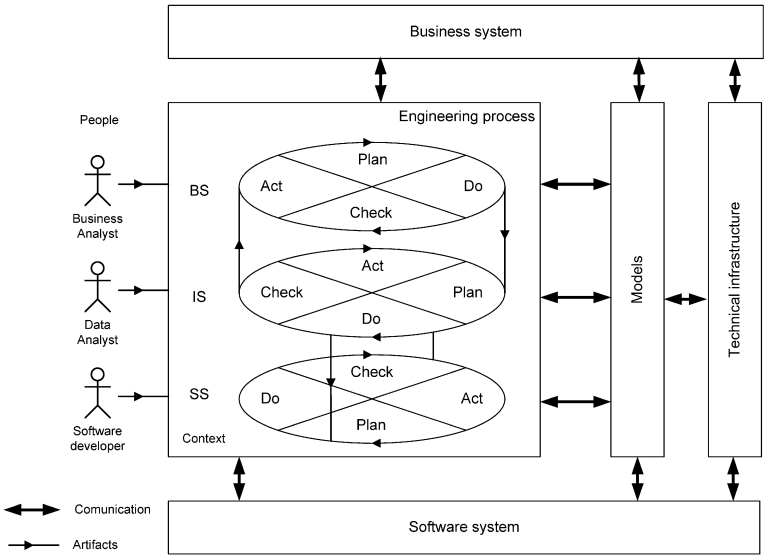

Figure 2. The lifecycle of continuous decision process design

3. Research for Stochastic Business Rule Extraction from Event Logs for Decision Automation

It is important to have integration between businesses, data and existing IS layers to improve the decision making process. For this purpose, Process mining techniques can be used in parallel with probabilistic technologies.

Process mining technologies are used to discover and analyse business processes in an automated way using event logs. Using all kinds of recorded process data, process mining techniques attempt to discover automatically the structure and properties of the business processes that can be visualized in business process models.

Since business processes are complex and stochastic by their nature, it is useful to analyse those using probabilistic methods. Probabilistic methods, if used right, can greatly support decision-making and answer questions with uncertainty.

One of such tools is Bayesian belief network, whose purpose is to model and reason with uncertain beliefs [31]. Bayesian network inference can be used to answer questions important to business. The inference itself and detailed description of Bayesian networks is out of scope of this paper, but for further reading, one can see [31] or [32].

3.1. The Proposed Approach for Business Process Analysis

It is hard to define formally stochastic business rules without research on what are the factors that affect the business process. For this reason, existing data in IS should be used by process mining techniques with application of probabilistic methods. This allows business people to discover beforehand unknown rules.

Process mining focuses on extraction of knowledge from event logs commonly available in today's IS. The process mining starts from the events stored in IS (i.e. transaction logs, audit trails, etc.). Event logs used in process mining can be of two kinds – MXML [33] and XES [34]. They are XML file formats specifically designed to define information on how business processes were enacted in IS.

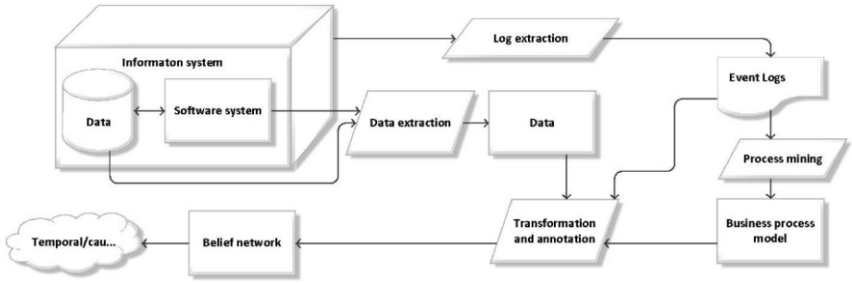

Figure 3. Proposed approach with marked area for the approach

The algorithm of the approach is as follows:

1. Existing data in IS is extracted. The data extracted is:
    a. Name of the event
    b. Timestamp on when the event occurs;
    c. Data about the event itself (i.e. age, price, place of occurrence, etc.);
2. Graph is extracted from the event logs. The graph shows the temporal dependence between the events (business process model).
3. The data in the event logs is transformed to conditional probability tables (CPT) and appended to the directed acyclic graph.

3.2. Graph Annotation with Data

The step of combining data with the graph for probabilistic model creation is not a trivial task. There are a couple ways to do it for different goals:

1. Data probability analysis is the goal:
    a. Use only the traces that incorporate all of the events – the resulting data set might become too small, but the data fully represents data dependability. In our case, less than 3% of cases had all of the events represented in the model);
    b. Use all of the traces, but the events that do not occur in a trace would account as noise and random uniform data would be generated;

2. Activity occurrence analysis is the goal:
    a. Implement additional data value *No data* representing event that activity does not occur in the set – all of the traces would be used, but activities that rarely occur could have noisy data probabilities;

b. Implement additional tag *data* representing event that activity does occur in the set – the tag could be used in analysis cases where all we care about is if the activity actually happened;

If 2.b is used with 2.a, then the extracted conditional probability tables for an activity represents probability of occurrence of the activity. If only 2.b is used, some activity is ignored (since value of tag *data* is always *1*).

3.3. Experimental Results

We used the data of the university orders concerned with Master's degree students' enrolment to test our approach. This data consists of all the orders that are made by the administration of university regarding each student, i.e. admission order, allowance to defend their thesis, grant of master's degree, etc. We took database tables of the orders, students, admission and metadata (order title, location name, etc.).

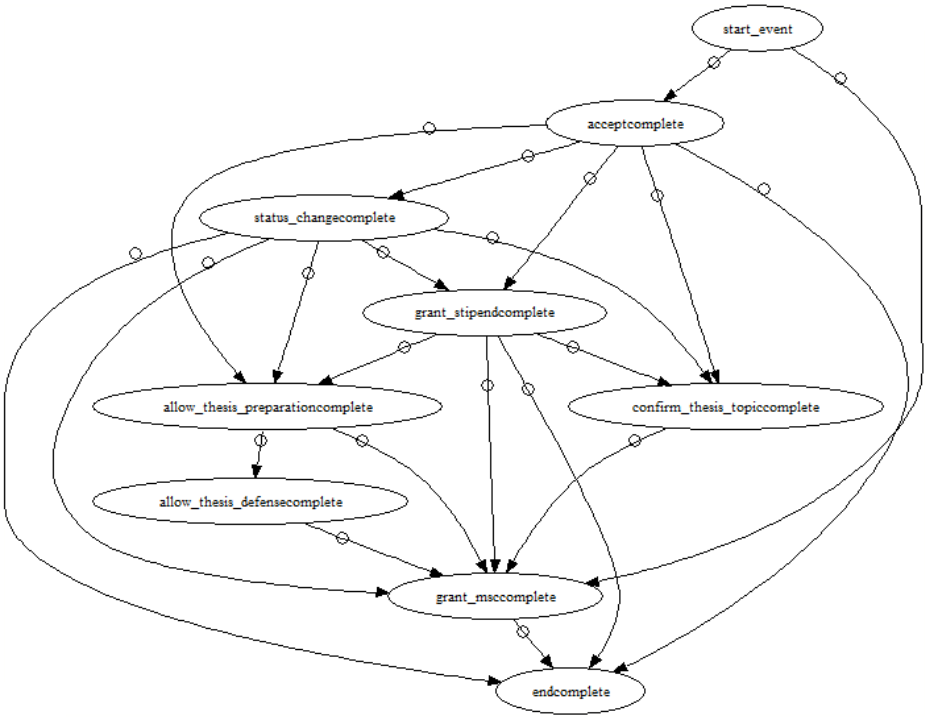

Figure 4. Extracted process model for student admission

The data consists of temporally related data – which events followed in what order – and associated data – tagged information regarding the information of the student. This would allow making insights on what attributes of a student have impact on what activities. Overall, the log consists of 4919 traces with 18227 events with timestamps ranging from years 2002 to 2013.

The data was transformed into an XES log, which has a structure as follows:

```
<trace>
<string key="concept:name" value="{studentid}"/>
<event>
<string key="{dataElementName}" value="{dataValue}"/>
<date key="time:timestamp" value="{eventTimeStamp}"/>
<string key="concept:name" value="{eventName}"/>
<string key="lifecycle:transition" value="complete"/>
</event>
…
</trace>
```

Using custom made process mining algorithm, we extracted a business process model in the form of a Directed Acyclic Graph (Figure 4). The extracted process model represents temporal causality between activities. After manual check of the data and talks with analysts, the process model was deemed to be suitable as a simplification for business process representation. The model is a simplification, since we removed events that occurred in less than 10% of traces as they make the model too complicated for business people to understand and the noise influences the further work.

The automatically extracted conditional probability tables are presented in Table 2.

Table 2. Conditional probability tables extracted from Bayesian belief network generation.

	status change complete (data)	*accept complete (nationality)*	*Grant*						
			NaN	***5-***	***6***	***7***	***8***	***9***	***10+***
with "data"	*1*	*LT*		0	0,06	0,34	0,27	0,14	0,21
		x		0,13	0,13	0,38	0,13	0,13	0,13
With "no data"	*No data*	*No data (NaN)*	0,33	0,11	0,11	0,11	0,11	0,11	0,11
		LT	0,49	0	0	0,07	0,18	0,11	0,15
		x	0,51	0,02	0,02	0,06	0,18	0,06	0,14
	1	*No data*	0,14	0,14	0,14	0,14	0,14	0,14	0,14
		LT	0,41	0	0,03	0,2	0,13	0,08	0,14

	Accept complete (admission grade)	***NaN***	***1***
With "no data" and "data" on grant stipend	*10+*	0,48	0,52
	9	0,5	0,5
	8	0,44	0,56
	7	0,49	0,51
	6	0,7	0,3
	5-	0,77	0,23
	No data (NaN)	0,75	0,25

Some conclusions extractable from the tables:

- Master students with admittance grades less than 7 are (almost)never granted a stipend during their masters' studies;
- There is an overall 50% chance to not be granted stipend during MsC studies;
- Admittance grade of 8 has the highest (18%) chance to be granted a stipend;
- Students without acceptance data or grade lower than 7 have 70+% probability to not get a stipend;
- Students with admittance grade equal or less than 7 have almost never get a stipend;

4. Summary and Conclusions

The analysis of the existing decision automation methods has identified that such model implementation is usually based on the business logic separation from the decision-making process, where the decisions are usually treated as an act of deciding made by a human actor based on information provided by the decision support systems. However, the overall process of deciding is usually left without proper attention.

Having analysed rule, business object, and business process models of the proposed framework and model transformations into the software components, we conclude that rule models (SRML, DT, PRR) together with process models (UML, BPMN) are suitable for decision process modelling. It should be selected by evaluating particular needs depending on the complexity of a decision-making process and the already existing IS infrastructure in the particular business environment.

The main reason for development of the presented framework was an idea that business people should have direct control on all business level models and especially on business logic used for automated decisions implemented into the IS. Moreover, the proposed framework is created to enable better understanding between people working on the separate system abstraction levels. Therefore, we propose to focus on the same objects by introducing shared views represented in the columns of the framework according to the context in the system engineering perspective.

The paper presents real use-case of process mining application for probabilistic model creation, which allows business users to make insights into the process and identify stochastic rules based on extracted probabilities. This approach allows close relationship between business, data and IS layers.

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