Multi-level Risk Modelling for Interoperability of Risk Information

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Abstract: The digital transformation driven by the rise of Industry 4.0 leads to an increase use of data standards and information systems for management and decision making. With the emerging of new software ecosystems, industries are facing heterogeneous systems and a lack of interoperability for information including risk information. The lack of interoperability in risk management leads again to a slow and often incorrect information transfer, which affects the timely response to risks. In this paper, we propose a new risk modelling approach that combines existing multi-level modelling and multi-view modelling approaches to structure and hence simplify interoperability.

1 INTRODUCTION

Industry 4.0 pushes digital transformation of industry and is changing the way people live and industry operates, accompanied by the increasingly common use of digital systems to manage, monitor and control business process in the industry (Ghobakhloo, 2020; Sony and Naik, 2019).

In large industries, risks occur in different departments and at different levels. Data silos and lack of interoperability pose a challenge affecting the ability of organizations to gain insights from risk analysis. Therefore, it is significant to have a comprehensive understanding of risks at a system and system-of-systems level and provide a holistic view.

Within the FEnEx CRC[1] we look at different scenarios for risk modelling in asset management. The assets of concern are usually large physical assets that are composed of a number of complex components, where components may consist of sub-components and each component may be manufactured by different suppliers. With new components in can be assumed that they are fitted with sensors and maybe even come with analytical capabilities in a software package which makes them Industry 4.0-ready. Existing legacy components are often re-fitted with sensors so data can be collected, analysed and used for decision making. The problem at hand comes in two dimensions: (1) On the vertical dimension, we are dealing with a component hierarchy and on each component level you may deal with different data formats and how data is captured and structured. This becomes increasingly challenging with new business models of manufactures where data might be provided only through online services for which a subscription has to be paid. (2) On the horizontal dimension, we are dealing with the communication between systems, departments and may be event external partners or government each working with a different software ecosystems. The exchange of information becomes inherently more difficult. If risks are not captured and communicated appropriately to stakeholders and decision makers then this can lead to catastrophic consequences in extreme cases (Haimes, 2005; Dunbar et al., 2011; Fraser et al., 2013; Urlainis et al., 2022).

It is crucial that risk analysis is carried out across departments and holistically across the whole organization spanning multiple risk models. One risk event affects other departments and sectors such as agricul-

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ture, forestry, coal, construction and more than thirty other industries were affected in the disasters mention above due to interdependent nature of the industries as well as the cascading effects of the inter-connection risks. To handle such risks, an enhanced risk modelling approach is required which covers the cross-departmental risk models in the horizontal direction as well as risk models across multiple level in the vertical direction. This intersection of modelling both horizontal and vertical angle will provide risk managers a clear picture of the risks across multiple levels and views.

The research goal of this paper is to propose a hybrid risk modelling approach for effectively reducing unexpected complexity in the model and making it clearer, thereby making it easier for the risk stakeholders to focus on the information they need and to achieve a comprehensive view in both horizontal and vertical directions.

2 MOTIVATION AND CASE STUDY

2.1 Motivation

Risk is a measure of the probability and severity of adverse effects. The main factors in assessing risk include the potential loss (consequence) and the probability of occurrence (Haimes, 2005). In public utilities, such as the energy industry, risk assessment is important and necessary. This helps in the repair and maintenance of infrastructure, as well as the timely response to emergencies and risks to safety-critical systems (Haimes, 2005). Imagine if the infrastructure is not well repaired and maintained, or the response to emergencies is not timely, it can lead to a series of problems, such as energy supply shortages. Risk modelling is an effective way to help with risk assessment. Through risk modelling, risk-related metrics can be represented in a model diagram which can be used for risk simulation and analysis, and documentation and code generation. Stakeholders can understand the probability of a particular risk occurring and the severity of the consequences, and develop solutions to avoid or reduce the adverse impact of the risk.

We investigate risk modelling from a model-driven engineering (MDE) perspective. MDE has the advantage of abstracting from the real-world through models that can be used as a lingua franca between IT and non-IT stakeholders. MDE has a close relationship to software engineering and we can use existing MDE techniques for software development and increase the automation for interoperability. A traditional modelling language in MDE is the Unified Modelling Language (UML), which can also be used in the field of risk modelling. Since UML is a visual modelling language, this makes it more intuitive for model developers to build models and easier to check for model deficiencies. It provides a clearer understanding of the model architecture. Based on the fact that UML is a universally accepted and agreed modelling language, the information contained in the model can be understood by different stakeholders of the model. UML can be effectively used to model the flow of risk information. Through risk modelling, potential risks can also be clearly represented for all stakeholders to gain the information they need. Meanwhile, the relevant attributes of the risk, such as probability and consequence, can also be clearly represented. These are vital information for risk analysis. Risk control measures can also be developed and linked to the relevant risks and displayed in the model and hence provide effective ways of avoiding risks and reducing losses.

However, the current business processes in the energy industry are large and complex, and the risks associated with business processes are also often diverse and complex. This poses a challenge for risk modelling. For example, there are interoperability issues between large heterogeneous ecosystems. Traditional modelling approaches, such as UML, models within two categorization levels, the model and metamodel levels (Igamberdiev et al., 2016). At the same time, UML instantiation models do not clearly scale to multiple modelling levels, and they do not support a natural modelling approach when using UML concepts to describe the hierarchy of instantiated class levels (Atkinson and Kühne, 2001). This introduces a number of problems, such as unexpected complexity (Atkinson and Kühne, 2008). This makes the models relatively difficult to understand, error-prone in their construction and use, and prevents the representation of risk information arising from multiple levels in an organisation. For example, a risk event occurring at a component (e.g. sensor) level needs to be represented and cascaded to the higher levels such as the encompassing system level and the systems on top of it, reaching up to the higher level systems. Thus, enabling the aggregation of risk information from the bottom most level to the top most level, where the decision making team including risk managers get to see the broader risks. Domain modellers may decrease accidental complexity by naturally representing the entities, relationships, and constraints of their domain (Selway et al., 2017). Therefore, an instantiation mechanism is needed in which the properties of classes of modelling elements can be automatically obtained through the instantiation step (Atkinson and Kühne, 2001). Multi-level modelling proposed by Atkinson and Kühne in 2001 (Atkinson and Kühne, 2001) provides a better way to model multi-level risk models, since it supports unlimited number of levels while modelling, as contrast to the limit of two levels in the UML model. The natural propagation of constraints on multi-level instantiation that a multilevel modelling approach can bring is necessary (Selway et al., 2017). Through this approach, the detailed information available at lower level will be aggregated to the higher level, which will enable decision makers to gain a more comprehensive and specific understanding of potential risks.

Moreover, within the energy industry, there are numerous heterogeneous software systems. Establishing interoperability across various systems is one of the greatest problems in the design of information systems (Selway et al., 2017). In particular, significant compatibility and interoperability issues arise when each heterogeneous software system defines its own non-standard language extension mechanism (Atkinson et al., 2015). In the energy industry, such problems are very serious. This may lead to the failure to transmit anomaly information from sensors to risk control department in a timely manner, or the information is not properly recognized when transmitted across systems. This can lead to serious problems, such as the power interruptions.

There is also the issue that within the energy industry, as well as other large companies, contains many different departments, each with their own associated risks. For example, the finance department may face the risk of insufficient funds, the procurement department may face the risk of insufficient inventory of supplier, and the production department may face the risk of insufficient production capacity. In the traditional view of the risk model, all risks are in one view, which makes it relatively difficult for the employees dealing with risks in each department to get the information they need. This not only reduces efficiency, but in some cases important information may be missed. Therefore, there is a need to create a method that can separate different concerns, which will not only increase efficiency but also improve accuracy.

We agree with Thabet et al. that business processes and associated risks need to be considered simultaneously (Thabet et al., 2021). This approach to risk management, which combines risk and business process, is called Risk-aware Business Process Management (R-BPM) and helps to classify risks into their respective departments.

In order to solve the above problems, we have adopted a new modelling approach combining a multi-level modelling approach called SLICER (Specification with Levels based on Instantiation, Categorisation, Extension and Refinement) (Selway et al., 2017) which has been chosen as the basis for risk modelling and a multi-view modelling approach called e-BPRIM (e-Business Process-Risk Management – Integrated Method) (Lamine et al., 2022) in our work. In the next section we will describe the multi-level modelling approach and the multi-view modelling approach separately on a case study in the energy sector.

2.2 Case Study

The case study is about an energy company and two of its departments, the procurement and the production department, which are related through a chain risk: The cause was the delay of procurement, which led to the reduction in producing capacity. Each department has a corresponding risk management system that is used to assess risks. Moreover, a condition monitoring system in the production department monitors the operating conditions of the power generation facilities and the production management system calculates the loss of capacity. In the procurement department, the procurement management system places orders when required and records delivery times. Finally, these data are transferred to each department's corresponding risk management system, where risk consequence is calculated according to risk assessment criteria. In this case, the problem is to build efficient and stable interoperability between multiple systems and to ensure that the information at the bottom of the risk model can be delivered to the top in a timely manner. Figure 1 shows the model of the case study created using UML.

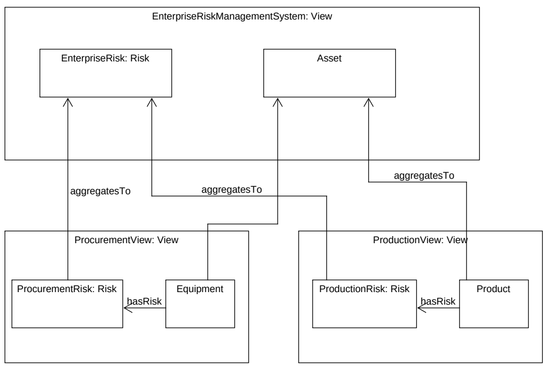

Figure 1: UML model of the case study.

Figure 1 shows a simple UML diagram representing the case study. The *procurement view* is located on the bottom left and contains procurement risk and related equipment. On the bottom right is the *production view* which contains production risk and related product. The information of both views is aggregated to the top view, the *enterprise-level risk management system*.

3 RELATED WORK

In this section, related literature about multi-level modelling and multi-view modelling are discussed and briefly mention the relation to ontologies.

3.1 Multi-level Modelling

In this subsection, we present two multi-level modelling approaches which are Deep Instantiation and SLICER (Atkinson and Kühne, 2001; Selway et al., 2017).

3.1.1 Deep Instantiation

In 2001, Atkinson and Kühne proposed the first multi-level modelling approach, which is essentially Deep Instantiation (DI) (Atkinson and Kühne, 2001). This approach solves some problems existing in traditional UML modelling method as below.

- The instantiation model of UML can not clearly extend to multiple modelling levels;
- When using UML concepts to describe the hierarchy of instantiated class levels, e.g. the UML metamodel hierarchy (M2), natural modelling approach is not supported;
- UML can not adequately describe a model element at the M1 level that represents not only an object but also a class (for further instantiation);
- Although an instance can also represent a class, it only acquires object-specific properties as a result of the instantiation;
- All attributes and associations created for the M2-level element when it is instantiated into an M1-level element become slots and links for the M1-level element and cannot be utilised for subsequent instantiations;
- Classes cannot affect entities formed via additional instantiation and they can only determine the semantics of their immediate instances.

DI adopts the element called clabject and the concept called potency to solve the above problems. A unique element called a cabject represents both a class and an object, which combines the characteristics of class and object. Potency represents the number of times an element or an attribute can be instantiated. These two concepts effectively solve the above problem which is shallow instantiation and are the core concepts pf multi-level modelling.

The objective of DI is to minimise the components of the conceptual model, which entails hiding the components by folding them into a single object at the highest level (Selway et al., 2017). We agree with Matt et al. that the DI approach is ineffective, particularly for scenarios involving system interoperability, because it obscures significant distinctions that exist in the domain being represented, resulting in a one-to-many relationship between model elements and the domain entities they represent, which prevents the domain modeller from thinking in terms of the entity but rather in terms of how it is encoded in the model (Selway et al., 2017).

3.1.2 SLICER

In 2017, Matt et al. proposed the SLICER approach for solving interoperability problems between large-scale ecosystems. This framework uses specialisation, instantiation, specification, and classification—basic semantic relationships—to create models dynamically and offers a natural propagation of constraints across multi-level instantiation (Selway et al., 2017). There multi-level modelling framework has the following features.

- This framework is based on a flexible horizontal concept that is the result of applying specific semantic relations;
- This framework adds detail or specification through adding modeled features, behaviors, and/or constraints;
- This framework explicitly identifies the features (specifications) of the model that describe the device;
- This framework performs second-level classification by identifying categories and the objects they are categorized under;
- This framework achieves an orthogonal focus on different stakeholders and lifecycle stages.

With the unique relationships in the framework, elements are flexibly instantiated or specialized. We believe that the risk model built based on this framework can clearly display and flexibly combine the risk concept and the entity concept. The definition of the relationships in SLICER will be shown in the next section, as we will also apply them.

3.2 Multi-view Modelling

In this subsection, we present a new Multi-View modelling approach called e-BPRIM.

3.2.1 e-BPRIM

BPRIM was first proposed as a risk management approach by Sienou et al. in 2009 (Sienou et al., 2009). This approach is a risk-driven process engineering focusing on making risk-driven business process design as an integral part of enterprise engineering. In 2019, Lamine et al. introduced the concept of multi-view modelling in BPRIM, creating a multi-view modelling approach called e-BPRIM and providing a multi-view modelling platform called AdoBPRIM based on AdoXX(Lamine et al., 2019). e-BPRIM, which is based on the agile development methodology, offers insight and value-driven models to assist risk and process managers in carrying out their duties (Lamine et al., 2022). This method is founded on the black box, which seeks to build relationships between the inputs and outputs of various phases that make up the two cycles (Lamine et al., 2022). In AdoBPRIM, the authors designed navigation techniques to ensure consistency between these views. In this multi-view modelling approach, the modelling operations that maintain consistency are as follows.

- Decomposition: Further abstract a given view and produce a new one;
- Extend: Append syntax concepts to extend the given view and produce a new one;
- Reuse: Reuse some syntax and/or semantics from some existing views and produce a new one;
- Merge: Merge some syntax concepts from some existing views and produce a new one;
- Compositing: Collect information from some existing views and produce a new one;
- Synchronization: Execute modifications of overlapping concepts synchronously in all other views through the algorithm.

We believe that multi-view modelling approach is well suited for applying in large ecosystems. It allows the risk model in large ecosystems to be divided into several sub-views and ensures consistency between these sub-views, which facilitates interoperability between large ecosystems and allows information to be transferred in a timely manner across different systems. And risk controllers in different departments can more easily and clearly acquire the information they need to understand potential, probable risks to make risk management plan and respond in a timely manner. At the same time, the complexity of risk models can be significantly reduced by using the black box approach. Therefore, we combine this multi-view modelling approach into the SLICER multi-level modelling approach to further improve the interoperability and efficiency between systems and reduce the complexity of risk models.

3.3 Risk Management Ontology

The use of ontology for risk management has various advantages (Zhong and Li, 2015). We have identified the following ones relevant to our case study:

- Provide an agreement on the meaning of terms;
- Explain the meaning of a term;
- Integrate all other forms of;
- Strict formalization allows for additional automization, such as querying, consistency checking.

Obviously, these advantages of ontology can unify terms in large heterogeneous ecosystems to enhance interoperability. In the future research, we will extend a suitable existing risk ontology to implement in the current project.

4 A MULTI-LEVEL AND MULTI-VIEW FRAMEWORK FOR RISK MODELLING

In this section, we will show how our modelling approach works with the case study introduced in Section 2.

4.1 Modelling Approach Definition

As mentioned above, in our approach, we combine a multi-level modelling and a multi-view modelling approach in order to create a new risk management model. The model has the advantage of low complexity and ease of readability, while achieving a separation of concerns. Furthermore, we adopts syntactic overlap relationship and extend relationship from multi-view modelling approach to achieve consistency among different views.

Figure 2 shows the example of what we have built through this combined risk modelling approach. In Figure 2, we introduce the relationships in SLICER and e-BPRIM. We adopted SpecX, InstX, InstN and SbS from SLICER and Syntactic Overlap and Extend from e-BPRIM. We have explained them below.

- *SpecX*: SpecX is a special specialisation relationship. It can add new attributes or relationships to comparing with traditional specialisation;
- *InstX*: InstX is a special instantiation relationship. It can add new attributes or relationships comparing with the traditional instantiation;
- *InstN*: InstN is the traditional instantiation relationship. It acquires the attributes and relationships from the element being instantiated and cannot be further instantiated;
- *SbS*: SbS is used to specialise the parent class. The specialised subclass is at the same level as the parent class, which can refer the properties of the instance.
- *Syntactic Overlap*: Syntactic Overlap is used to maintain consistency between classes with the same name, by promptly updating changes to values in either class.
- *Extend*: Extend is used to extend views, from the black box to the white box.

Clearly, through these relationships, elements in the model can be flexibly extended or instantiated.

UOM is an abbreviation for Unit of Measurement, which represents a data format with unit of measurement.

In Figure 2, each risk and asset type is considered as a black box, which is in the upper part. By using the concept of syntactic overlap, when elements in any one view change, the corresponding overlapping syntax in other views is updated in time. This concept from multi-view modelling approach ensures consistency among views and enables the transfer of risk information across systems thus improving interoperability.

In this model, each sub-view is treated as a white box. They are detailed representation of the corresponding black box in the metamodel. With this approach, the risk managers in each department can only see the risk view that belongs to their department. Also, with the consistency between views, the values of the attributes in the views are updated in time. Obviously, it is easier to focus on and get information from just one of the views than to get information in the whole figure. This is particularly the case in the larger, more complex industrial ecosystems. With the concept from multi-view approach, the risks and the entities corresponding to the risks are distinguished in each risk view, which further increases the readability of the model and reduces complexity.

In each sub-view, risk consequence has its own measure. For example, in the procurement risk view, risk consequence is measured regarding to missing quantity and delay time, formula is as follow.

$$RQ = \frac{LQ}{TQ} * DT \qquad (1)$$

RQ is Risk Consequence, LQ is Lack Quantity (sqm/pcs), DT is Delay Time (day) and TQ is Total Quantity for Production (sqm/pcs).

In the production risk view, risk consequence is regarding to the percentage of production capacity reduction compared to total production capacity. Table 1 shows the assessment criteria of risk consequence for production risk.

Based on Table 1, the risk consequence for the both two risk views can be derived automatically.

Table 1: Assessment criteria of risk consequence for production risk and finance risk.

Risk Consequence	Percentage of production capacity reduction
0.1	0%- 5%
0.2	6%- 15%
0.3	16%- 25%
0.4	26%- 35%
0.5	36%- 45%
0.6	46%- 55%
0.7	56%- 60%
0.8	61%- 65%
0.9	66%- 70%
1	>70%

4.2 Model Validation

To validate the proposed risk modelling approach, we will apply this approach in the on-going Project "Open Analytics Interoperability"[2]. This project provides a framework for facilitating inter-operable analytics by enabling sharing of outputs from various analytical systems such as risk analysis using standardized interfaces. Existing standards and specifications are leveraged where possible. For example, the Open Industrial Interoperability Ecosystem (OIIE^{TM}) specification published by MIMOSA as part of ISO/TS 18101-1:2019 (ISO, 2019) is being actively used in the project. In terms of risk management, good interoperability facilitates early warning and fault detection as well as risk analysis of assets.

5 CONCLUSIONS AND FUTURE RESEARCH

In this paper, we demonstrate a new risk modelling approach that combines an existing multi-level mod-

[2]https://www.fenex.org.au/project/program-3-open-specification-for-analytics-interoperability-20-rp3-0048/

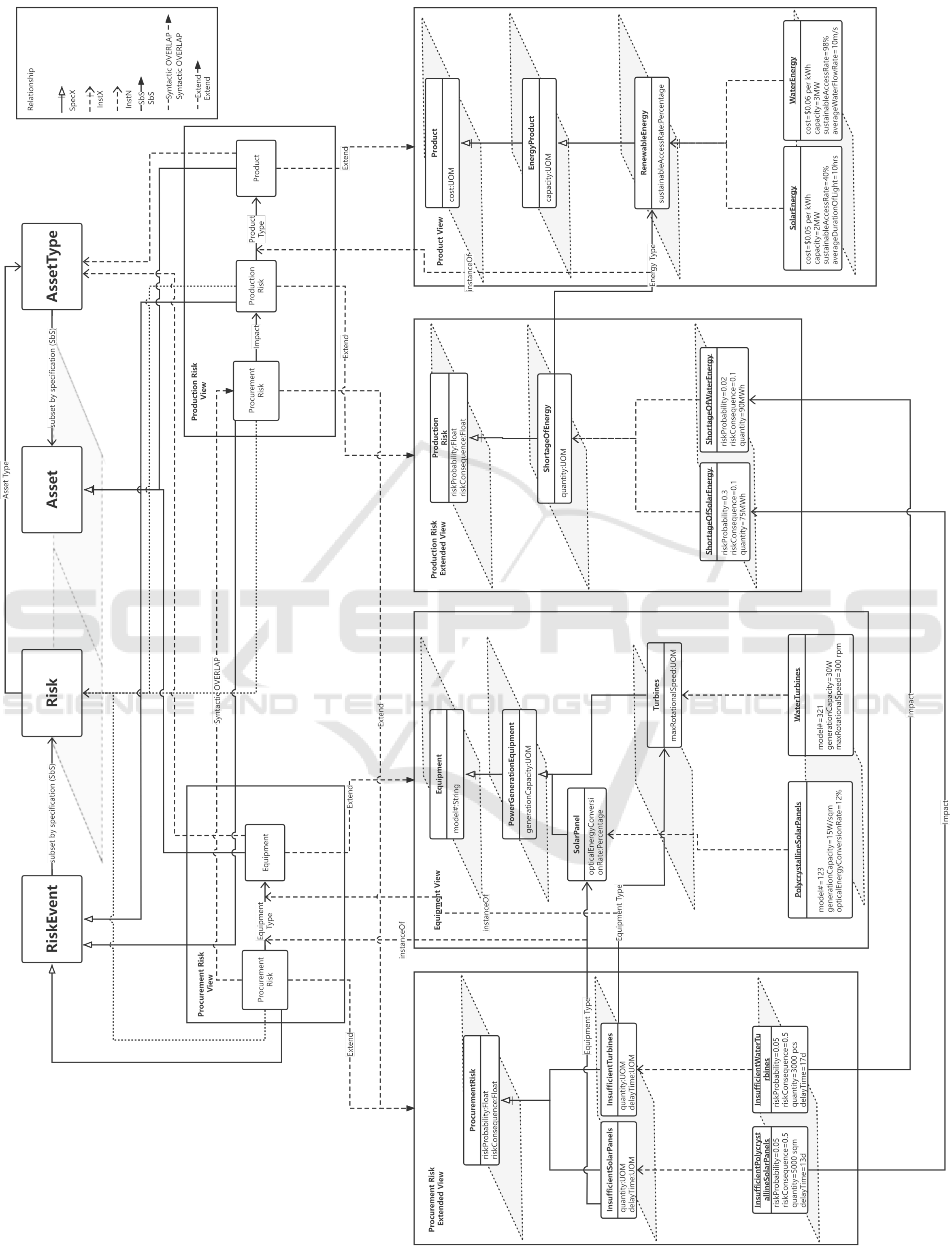

Figure 2: Example of the risk model created by the combined risk modelling approach.

elling approach and a multi-view modelling approach. This approach is applied to large ecosystems to address the lack of interoperability between existing heterogeneous systems. By taking advantages from the multi-level modelling approach, the complexity of the model is reduced and the model is made clearer. While the benefits from the multi-view modelling approach ensures that interoperability is enhanced and makes it easier for risk managers to focus on relevant information.

In future research, we will continue to refine this risk modelling approach by further incorporating the multi-view modeling approach at the meta-model level to achieve multi-view modeling of business processes, risks, risk management measures, and risk matrices. At the model level, multi-level modelling is implemented for each risk to reduce model complexity across the heterogeneous ecosystem and make model levels clear and informative. We will also develop algorithms to automatically calculate the probability and severity of risks and display them automatically in a risk matrix. Moreover, for most risks, we will link each risk with a corresponding management measure to achieve timely response and timely treatment. Furthermore, we will expand the current risk ontology to achieve system integration via semantic mapping, which can avoid the restrictions imposed by UML.

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