Systematic Treatment of Security Risks during Requirements Engineering

Roman Wirtz and Maritta Heisel

Working Group Software Engineering, University of Duisburg - Essen, Oststr. 99, Duisburg, Germany

Keywords: Security Risk, Risk Management, Risk Treatment, Controls, Requirements Engineering, Model-based, Patterns.

Abstract: In recent years, a significant number of security breaches have been reported. A security breach can lead to value loss for stakeholders, not only financially but also in terms of reputation loss. The likelihood and consequnce of a scenario, impacting security of software, constitute a risk level. Risk management describes coordinated activities to identify, evaluate, and treat risks. Following the principle of security-by-design and treating risks as early as possible during software development, the costs can reduced significantly. Based on our previous work to identify and evaluate risks, we aim to assist developers in treating risks in one of the earliest phases, i.e. during requirements engineering. To do so, we propose a stepwise method that allows selecting and documenting suitable countermeasures, i.e. controls. As input, it takes a requirements model and a CORAS security model. A distinguishing feature of our method is that we use patterns in the form of templates to evaluate the effectiveness of controls. Furthermore, we integrate the selected controls into the requirements model following an aspect-oriented approach. The resulting model can be used as input for the design phase, thus helping to create an architecture that considers security right from the beginning.

1 INTRODUCTION

Incident scenarios in which the security of software is harmed have become more and more frequent in the recent years (BSI, 2019b). Each of those incidents may cause value and reputation loss for stakeholders, e.g. for companies dealing with sensitive data (Kaspersky Lab, 2019). The likelihood of such a scenario and its consequence for an asset is called risk. The ISO 27005 standard (ISO, 2018) provides guidelines to deal with such risks. The standard contains a risk management process describing coordinated activities to identify incident scenarios, evaluate their likelihoods and consequences, and finally to treat the identified risks. To treat a risk means identifying countermeasures that reduce that risk to a predefined acceptable level. Countermeasures, i.e. controls, can either be implemented by software, e.g. an encryption mechanism, or can be embedded in the environment, e.g. access control to a data center. The later one considers security for software under development, the higher are the costs to treat risks. Therefore, developers should identify and treat risks in the earliest stages of a software development lifecycle, following the principle of security-by-design (Haskins et al., 2004).

In previous work, we have developed methods to identify and evaluate risks based on the functional requirements of the software to be developed. We provided a template to describe incident scenarios that harm the security of software (Wirtz and Heisel, 2019d). Furthermore, we use that template to evaluate the risks related to the scenario in a semi-automatic way (Wirtz and Heisel, 2019b). Our model-based approach based on *Problem Frames* (Jackson, 2001) and *CORAS* (Lund et al., 2010) ensures consistency between the requirements model and the security model.

In the present paper, we aim to assist security engineers and software developers in selecting and documenting appropriate countermeasures. As preliminary work, we developed a template to describe controls based on a set of attributes. We now propose a method to select controls reducing the identified risks to an acceptable level. Our method takes a requirements model and a CORAS security model as input. To evaluate the effectiveness of a control, we make use of our templates and the *Common Vulnerability Scoring System (CVSS)* (FIRST.org, 2015). To bridge the gap between security and requirements, we finally integrate the selected controls in the problem frames

Wirtz, R. and Heisel, M.
Systematic Treatment of Security Risks during Requirements Engineering.
DOI: 10.5220/0009397001320143
In *Proceedings of the 15th International Conference on Evaluation of Novel Approaches to Software Engineering (ENASE 2020)*, pages 132-143
ISBN: 978-989-758-421-3

model following an aspect-oriented approach.

The resulting model can then be used as input for the design phase, thus helping to create an architecture that takes security into account right from the beginning.

The remainder of the paper is structured as follows: In Section 2, we briefly describe our relevant previous work and necessary background. In Section 3, we introduce the underlying models, i.e. requirements model and security model. The method, which is our main contribution, is described in Section 4. We discuss our results and provide an evaluation plan in Section 5, followed by related work in Section 6. Finally, we conclude the paper in Section 7 with a summary and an outlook on future research directions.

2 FUNDAMENTALS

In this section, we introduce the necessary background and our previous work in the context of risk management.

2.1 Problem Frames

For modeling requirements, we make use of problem diagrams which consist of domains, phenomena, and interfaces (Jackson, 2001). We make use of Google's Material Design[1] to illustrate the diagrams in a user-friendly way (Wirtz and Heisel, 2019c).

Machine domains (💻) represent the piece of software to be developed.

Problem domains represent entities of the real world. There are different types: biddable domains with an unpredictable behavior, e.g. persons (☺), causal domains (⚙) with a predictable behavior, e.g. technical equipment, and lexical domains (📰) for data representation. A domain can take the role of a connection domain (⇆), connecting two other domains, e.g. user interfaces or networks.

Interfaces between domains consist of phenomena. There are symbolic phenomena, representing some kind of information or a state, and causal phenomena, representing events, actions, and commands. Each phenomenon is controlled by exactly one domain and can be observed by other domains. A phenomenon controlled by one domain and observed by another is called a shared phenomenon between these two domains. Interfaces (solid lines) contain sets of shared phenomena. Such a set contains phenomena controlled by one domain indicated by *X!*{...}, where *X* stands for an abbreviation of the name of the controlling domain.

[1] Google Material - https://material.io (last access: February 20, 2020)

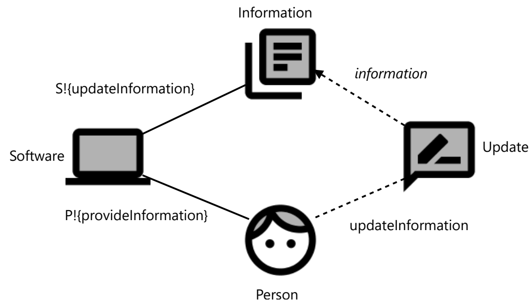


Figure 1: Example for Problem Diagram.

A problem diagram contains a statement in form of a functional requirement (represented by the symbol 📝) describing a specific functionality to be developed. A requirement is an optative statement that describes how the environment should behave when the software is installed.

Some phenomena are *referred to* by a requirement (dashed line to controlling domain), and at least one phenomenon is *constrained* by a requirement (dashed line with arrowhead and italics). The domains and their phenomena that are *referred to* by a requirement are not influenced by the machine, whereas we build the machine to influence the *constrained* domain's phenomena in such a way that the requirement is fulfilled.

In Figure 1, we show a small example describing a functional requirement for updating some information. A *Person* ☺ provides information to *Software* 💻 to be updated. We make use of a lexical domain *Information* 📰 to illustrate a database. The functional requirement *Update* 📝 refers to the phenomenon *updateInformation* and constrains the phenomenon *information*.

2.2 CORAS

CORAS is a model-based method for risk management (Lund et al., 2010). It consists of a stepwise process and different kinds of diagrams to document the results. Each step provides guidelines for the interaction with the customer on whose behalf the risk management activities are carried out. The results are documented in diagrams using the CORAS language. The method starts with the establishment of the context and ends with the suggestion of treatments to address the risk.

Identified risks can be documented in a so-called threat diagram for which we show an example in Figure 2. A threat diagram consists of the following

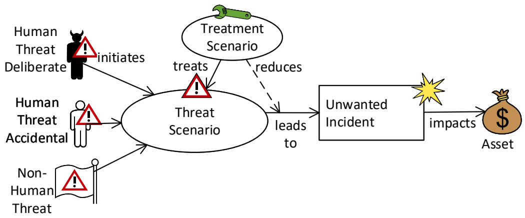


Figure 2: CORAS Threat Diagram.

elements: An *Asset* is an item of value. There are *Human-threats deliberate*, e.g. a network attacker, as well as *Human-threats accidental*, e.g. an employee pressing a wrong button accidentally. To describe technical issues there are *Non-human threats*, e.g. malfunction of software. A threat *initiates* a *Threat scenario* with a certain likelihood, and a threat scenario describes a state, which may *lead to* an unwanted incident with another likelihood. An *Unwanted incident* describes the action that actually *impacts* an asset, i.e. has a negative consequence for it.

In the following, we will use the term *incident scenario* as given in the ISO 27005 standard (ISO, 2018). In the context of CORAS, an incident scenario describes the path between threat and asset and the related elements, i.e. threat scenario and unwanted incident. It can be further specified using our template which we describe in Section 2.3.

To describe controls, there are *Treatment Scenarios*. The solid arrow points to the element which the control treats, e.g. the threat scenario. Additionally, we introduce a dashed arrow that points to the likelihood or consequence which will be reduced, e.g. the likelihood that a threat scenario leads to an unwanted incident. The template given in Section 2.4 allows describing controls in a systematic way.

Table 1: Description of *Database Injection*.

Incident Information	
LeadsTo Likelihood	
Threat Vector	☐ Network ☑ Adjacent ☐ Local ☐ Physical
Complexity	☑ Low ☐ High
Privileges Required	☐ None ☑ Low ☐ High
User Interaction	☑ None ☐ Required
Threat Scope	☐ Unchanged ☑ Changed
Consequences	
Confidentiality Impact	☐ None ☐ Low ☑ High
Integrity Impact	☑ None ☐ Low ☐ High
Availability Impact	☑ None ☐ Low ☐ High

2.3 Template for Incident Scenarios

In previous work, we proposed a pattern that describes an incident scenario based on the base metrics of the CVSS (Wirtz and Heisel, 2019d). Table 1 shows the relevant excerpt of a pattern instance for the scenario *Database Injection*. In the following, we explain the different metrics and corresponding values. For each attribute, we state its relation to the different elements and relations of the CORAS language.

The first set of attributes can be used to specify the likelihood that a threat scenario leads to an unwanted incident.

The *Threat Vector* (attack vector in CVSS) describes possible ways how to realize a threat scenario. There are four different values: (1) *network*, which means access from an external network; (2) *adjacent*, which means a local network; (3) *local*, which means direct access to the computer; and (4) *physical*, which describes access to the hardware.

The *Complexity* of a scenario is defined by two possible values: *low* and *high*. A high effort is required when a threat needs some preparation to realize the threat scenario and that the scenario cannot be repeated an arbitrary number of times.

To state whether privileges are required to successfully realize the threat scenario, we make use of the corresponding attribute. There are three possible values: (1) *None*; (2) *Low*, e.g. a user account; and (3) *High*, administrative rights.

A realization may require some *User Interaction*, for example by confirming the installation of malicious software.

The *Threat Scope* denotes the range of a scenario. A changed scope means that the part being attacked is used to reach other parts of software. For example, an attacker uses the wireless connection to access the database.

The impact on confidentiality, integrity, and availability is measured using qualitative scales. The used scale consists of three values: *None*, *Low* and *High*. In the context of CORAS, the value states the consequences that unwanted incidents have for an asset.

In previous work, we developed a method that allows evaluating risks using the CVSS metrics (Wirtz and Heisel, 2019b). We will use the calculated severities to determine the effectiveness of controls.

2.4 Template for Controls

We further provide a pattern that allows to describe controls in the same manner as incident scenarios (Wirtz and Heisel, 2019a). In Table 2, we provide an

Table 2: Description for *Encrypted Storage*.

Context	
Description	The control can be applied for software where data shall be stored persistently.
Functional Requirement	The problem diagram is given in Figure 3(a).
Benefits	
Reduction of leadsTo likelihood	
Modified Complexity	☐ Not defined ☐ Low ☑ High
Modified Privileges Required	☑ Not defined ☐ None ☐ Low ☐ High
Modified User Interaction	☑ Not defined ☐ None ☐ Required
Modified Threat Scope	☑ Not defined ☐ Unchanged ☐ Changed
Reduction of consequences	
Modified Confidentiality Impact	☐ Not defined ☐ None ☑ Low ☐ High
Modified Integrity Impact	☑ Not defined ☐ None ☐ Low ☐ High
Modified Availability Impact	☑ Not defined ☐ None ☐ Low ☐ High
Reduction of initiates likelihood	
Hints	The likelihood for initiating the threat scenario cannot be reduced.
Liabilities	
Costs	Since there are many open source libraries that can be used to implement the control, the costs do not increase significantly.
Usability	There is no impact on the usability.
Performance	Depending on the size of data, the performance may decrease. The higher the size of data, the lower the performance.
Integration	
Aspect diagram	The aspect diagram is given in Figure 3(b).

example for the control *Encrypted Storage*. It allows encrypting data before storing them persistently.

First, we informally describe the context in which a control can be applied. Furthermore, we state the functional requirement in the form of a problem diagram for which the control is suitable. Figure 3(a) shows the corresponding diagram for the example. For applying the control, it is necessary that a *Storage Machine* stores data persistently in a *Database*. The corresponding requirement constrains the lexical domain.

Furthermore, we distinguish between the benefits and liabilities of a control, and we provide an aspect-oriented integration into the requirements model.

Benefits. For specifying the benefits, we use a set of attributes according to the CVSS specifications, e.g. *Modified Complexity*. Each attribute is a counterpart for the attribute used in the incident description. Modified means that the complexity of the incident has the new value after applying the control. For example, the complexity is *high* after applying the control, because the data need to be decrypted for disclosure. The range of values for each attribute is the same as for the attributes of the incident description. Additionally, there is the value *not defined* which means that the control does not influence that specific attribute, i.e. the value specified by the incident description will stay the same after applying the control.

The *leadsTo* likelihood can be reduced by increasing the complexity, by requiring higher privileges, by requiring a user interaction, or by modifying the threat scope. The consequences can be reduced separately for confidentiality, integrity, and availability. In Section 4.6, we use the values to evaluate the effectiveness of a control concerning incidents to be treated.

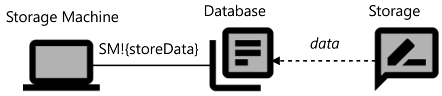
The CVSS specification does not provide attributes to specify the likelihood that a threat initiates a threat scenario. Therefore, we provide a textual description of how a control affects that likelihood. These are given as hints in the last section of the specification of benefits.

Liabilities. We distinguish between costs, usability, and performance. In Section 4.5, we use the hints together with the context description to validate the applicability of a control for a concrete software development project.

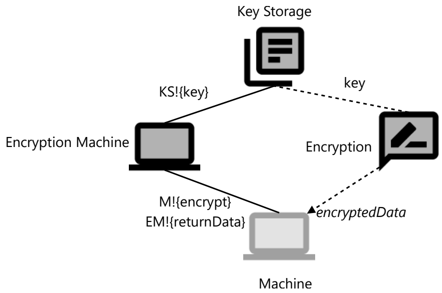
Integration. To integrate controls into the requirements model, we make use of an aspect-oriented approach that has been proposed by Faßbender et al. (Faßbender et al., 2014). For each control, we provide an aspect diagram which has a similar notation as problem diagrams. In addition to problem domains, there are placeholders called joint-points (marked in light gray). Problem domains of an aspect diagram will be added to the requirements model, whereas a placeholder will be instantiated with an existing domain. For the *Encrypted Storage*, we provide an aspect diagram in Figure 3(b). *Encryption Machine* and *Key Storage* are problem domains, *Machine* is a joint-point. The requirement for encryption refers to the key and constrains the encrypted data. In Section 4.8, we describe the integration of controls into the requirements model in more detail.

3 UNDERLYING MODELS

For our method, we consider two different models: (i) Requirements model and (ii) Security model. To en-



(a) Functional Requirement



(b) Aspect Diagram

Figure 3: Diagrams for *Symmetric Encryption*.

sure consistency, we provide references between the models. In Figure 4, we provide an overview of both models and their relations. Note, that we do not show each element explicitly. We focus on the relevant aspects for our method. In the following, we briefly describe them.

3.1 Requirements Model

To model requirements, we make use of Jackson's problem frames as described in Section 2.1. The initial requirements model is the input for our method and covers all functional requirements of the software under development. In the last step of our method, we add selected controls to the requirements model. Therefore, there is a reference between treatment scenarios of the security model and the corresponding functional requirements. Problem diagrams can be used to structure a requirements model. They contain all domains and interfaces that are relevant for a specific requirement.

3.2 Security Model

Our security model is based on CORAS. Therefore, it contains the identified risks using the CORAS elements as described in Section 2.2. Besides, it contains the security goals in the form of a piece of information that shall be protected concerning confidentiality, integrity, or availability. In the requirements model, we model a piece of information with a symbolic phenomenon. Therefore, the security goal holds a reference to the corresponding phenomenon. A threat diagram focusses on a specific incident scenario, i.e. it shows the corresponding elements contained in the model. To further specify such scenarios, we make

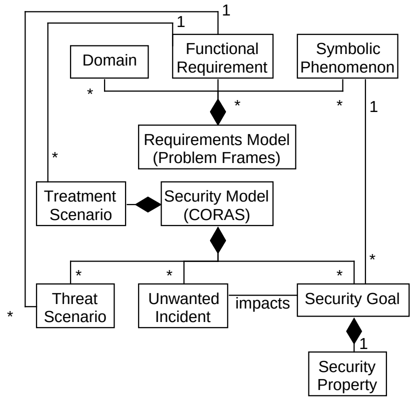


Figure 4: Models overview.

use of our template as described in Section 2.3. A threat scenario holds a reference to the functional requirement in which context it may be initiated. A security model is a required input for our method. Using treatment scenarios, we model selected controls which can be specified with our template (cf. Section 2.4). For controls that can be implemented as additional software functionality, the treatment scenario holds a reference to the added functional requirement.

4 CONTROL SELECTION & EVALUATION

Figure 5 provides an overview of the structure of the method, which consists of six steps. The six steps can be divided into two phases. The first four steps deal with the selection of an appropriate control, and the other two steps deal with its documentation. Our method is iterative, which means that we carry out the steps for all unacceptable risks, i.e. identified incident scenarios to be treated. In the following, we describe the different steps in detail. For all steps, we implicitly consider the set of available control descriptions as input.

4.1 Initial Input

To carry out our method, we require the following initial input:

1. **Requirements Model:** To decide about the applicability of controls, we require a requirements model as input. That model shall be based on Jackson's problem frames approach (cf. Section 2.1. We will later integrate the controls into that model.
2. **CORAS Security Model:** In previous steps of the risk management process, we identified in-

cidents that might lead to harm for at least one asset. Those incidents have been documented in CORAS threat diagrams. Besides, we require the corresponding template description as described in Section 2.3.

3. **Catalogue of Controls:** Controls that shall be considered for our selection process have to be specified with the template we described in Section 2.4

4.2 Running Example

To illustrate the application of our method, we make use of a smart grid scenario. A smart grid is an intelligent power supply network, which also allows measuring a customer's power consumption remotely. Since such networks are critical infrastructures, they are often subject to attacks, and due to their complexity, it is hard to analyze their security (Kumar et al., 2019; Tellbach and Li, 2018).

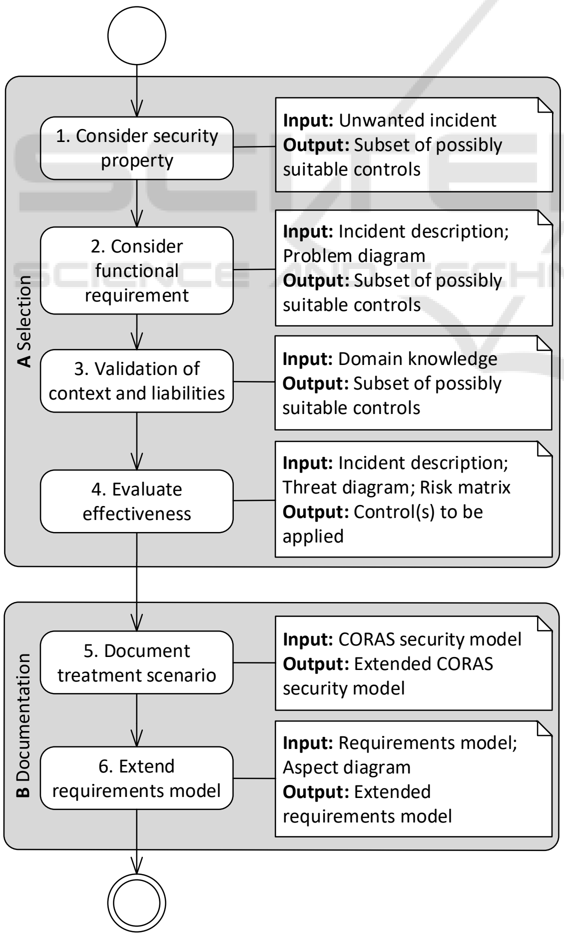


Figure 5: Method overview.

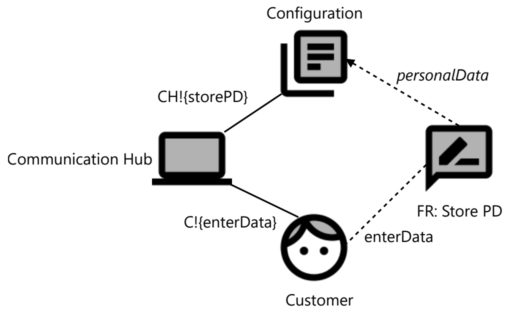


Figure 6: Example: Problem diagram for storing personal data.

Requirements Model. The software to be developed is the *Communication Hub*, which serves as the gateway between a customer's home and the energy supplier. In this paper, we focus on the functional requirement for storing personal data of a customer. We show the corresponding problem diagram in Figure 6. A customer can store his/her personal data in the communication hub's internal database.

CORAS Security Model. The personal data shall be protected regarding confidentiality. We show the simplified CORAS threat diagram in Figure 7, which is part of the security model. An attacker may inject malicious database queries via the customer's interface to disclose personal data. In this scenario, the command to store the personal data (*FR:Store PD*) will be replaced with a query. In Table 1, we presented the corresponding template instance that describes the incident scenario represented by the CORAS diagram.

Catalogue of Controls. In Table 2, we presented the template instance for the control *Encrypted Storage*. We will use this instance to exemplify our method.

In the following, we apply the steps of the method for this example.

4.3 Step 1: Consider Security Property

To decide whether a control is suitable, we first compare the violated security property with the properties that can be improved with the control.

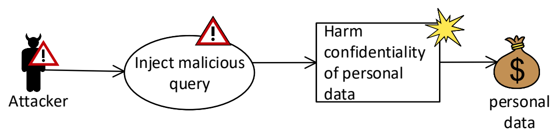


Figure 7: Example: Identified risks.

Description. For the first step, we consider the unwanted incident of the incident scenario under investigation. It denotes the security property that is harmed. We search a control that helps to preserve that property, which is indicated by its modified impact metric (cf. Section 2.3). We, therefore, consider those controls for further investigation that address the security property stated in the unwanted incident.

The first step can be automated since the required information can be stored and evaluated based on the underlying security model and template instances.

Example. The unwanted incident given in Figure 7 states the harm of confidentiality. The control *Encrypted Storage* helps to improve confidentiality. Therefore, we consider the control as relevant.

4.4 Step 2: Consider Functional Requirement

Second, we compare the functional requirement given in the incident description with the corresponding problem diagram.

Description. As mentioned in Section 3, a threat scenario references the functional requirement in which context it occurs. Not all controls can be applied to all functional requirements, e.g. controls for data transmission vs. controls for data storage. In the present step, we select those controls that are applicable to the functional requirement related to the threat scenario. To do so, we inspect the corresponding problem diagram of the requirements model. We consider a control as possibly relevant when the problem diagram contains the domains, domain interfaces, and requirement references (*constrains* and *refers to*) given in the control description. Note, that a problem diagram may contain additional elements in contrast to the control description. The description only contains a minimal set of elements.

By implementing a method for pattern matching, this step can be automated based on the information available in the models.

Example. The control description (cf. Figure 3(a)) states a problem diagram containing a *Storage Machine* and a *Database*. The requirement constrains the lexical domain. The machine and the lexical domain are connected via a domain interface. The annotated phenomenon is controlled by the machine. The problem diagram from our scenario given in Figure 6 contains those elements. Therefore, the control is applicable in the context of the requirement.

4.5 Step 3: Validation of Context and Liabilities

In the third step, we validate the context and liabilities of controls to decide about their applicability.

Description. This step requires the interaction with domain experts, for example, the software provider. Such an expert provides further necessary domain knowledge. The control description template states details about the context, as well as details about liabilities, i.e. costs, usability, and performance. Those attributes have to be compared with the environment in which the software under development will later be integrated. For example, software running on small servers does not provide much computational power for strong encryption mechanisms. Furthermore, it is necessary to consider the costs for implementing a control compared to the asset value to be protected.

Since the context and liabilities are given in natural language and the requirements model does not capture all attributes of the environment, this step requires manual interaction.

Example. Considering the control description given in Table 2, we decide to choose the control *Encrypted Storage* for treating the incident scenario. There are no liabilities concerning costs and usability. Since a customer only stores his/her personal data which has a small data size, there is no major impact on the performance.

4.6 Step 4: Evaluate Effectiveness

In the fourth step, we evaluate the effectiveness of the filtered controls. The effectiveness helps to finally choose the controls to be applied.

Description. To evaluate the effectiveness of a control, we make use of its description and the risk matrix which has been defined during risk evaluation. In previous work, we provide a method to evaluate risks using the CVSS (Wirtz and Heisel, 2019b). The first dimension of the risk matrix is the frequency per year that a threat initiates a threat scenario (cf. y-axis of Table 3). The second dimension is the severity of an incident scenario (cf. x-axis of Table 3). The severity is defined by the likelihood that a threat scenario leads to an unwanted incident and the consequence for an asset. The qualitative scale for the severity is defined by the CVSS (FIRST.org, 2015). To calculate the severity, we make use of the incident scenario description which contains the attributes defined by the CVSS specification. The CVSS provides a calculator[2] to calculate the severity. The calculator takes all attributes as input which are given in the incident scenario description (cf. Section 2.3).

To evaluate the effectiveness of a control, we use the modified metrics given in the control description. The CVSS calculator allows us to enter the modified values and to calculate the new severity. In case that the control reduces the frequency that a threat initiates a threat scenario, the new frequency has to be defined manually. The control description provides hints for that task.

Next, we use the risk matrix to evaluate effectiveness. If the combination of new frequency and new severity leads to acceptable risk, indicated by a green cell, we consider the control as applicable. Sometimes, a single control does not lead to a sufficient risk reduction, thus making it necessary to consider combinations of controls. For example, the first control reduces the severity, whereas the second one reduces the frequency. In that case, we combine the risk reduction of the controls and evaluate the corresponding reduction with the risk matrix.

The result of the effectiveness evaluation is a set of controls and control combinations that lead to a sufficient risk reduction. Finally, it is necessary to select the controls that shall be implemented. Different criteria can be used for that task, e.g. the maximum reduction or the costs for implementation. If there is no control or combination of controls to reduce the risk sufficiently, the two steps of documentation can be skipped for that incident scenario. However, it is still necessary to document that a sufficient reduction is not possible for further discussion.

The calculation of the severity can be automated based on the control and incident description and the CVSS calculator. The frequency needs to be adjusted manually. Therefore, the step can be semi-automated.

Example. In Table 3, we show the risk matrix we consider for the evaluation. We use *Inject.* as an abbreviation for the risk that an attacker injects malicious database queries.

During risk evaluation, a frequency of **40 times per year (frequently)** that the attacker injects malicious database queries has been estimated. The attributes' values given in Table 1 lead to a severity of **6.8 (medium)**. The corresponding red cell in the risk matrix indicates an unacceptable risk.

The control description is given in Table 2 and does not state any reduction of the frequency. Next, we consider the modified values for complexity and confidentiality impact which we enter in the CVSS calculator together with the values contained in the incident description. The new severity is **3.0 (low)** which we enter to the risk matrix. The risk after applying the control (*Inject.$_{treat}$*) is acceptable. Therefore, the effectiveness of the control is sufficient, and the control will be further considered.

4.7 Step 5: Document Treatment Scenario

After a suitable control has been selected, we document the corresponding treatment scenario in the security model using the CORAS language.

Description. To document the selected control, we make use of a treatment scenario (cf. Section 2.2). The solid arrow indicates which threat scenario the control treats. Furthermore, we add dashed arrows to indicate a likelihood or consequence reduction. Those arrows can have an *initiates*, *leadsTo*, or *impacts* relation as target. The control description denotes which likelihoods or consequences can be reduced, and the arrows have to be added accordingly.

Currently, there are no formal rules on how the treatment scenario has to be created. Therefore, it is necessary to extend the diagram manually. Using a model-based editor, all information can be stored in the same model to ensure consistency.

Example. We add the treatment scenario *Encrypt personal data* to the initial threat diagram (cf. Figure 8). The control treats the threat scenario which is related to the functional requirement for storing the personal data. The control description given in

Table 3: Example: Risk matrix.

	None 0.0	Low 0.1–3.9	Medium 4.0–6.9	High 7.0–8.9	Critical 9.0–10.0
Never 0 times					
Seldom ≤ 20 *times*					
Frequently ≤ 50 *times*		Inject.$_{treat}$	Inject.		
Often > 50 *times*					

[2]CVSS Calculator - https://www.first.org/cvss/calculator/3.0 (last access: 29 December 2019).

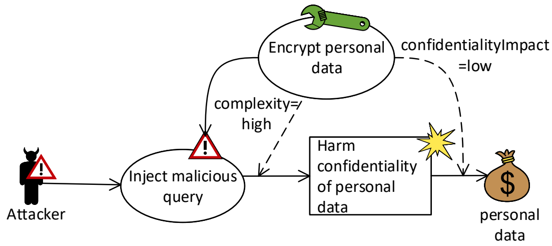


Figure 8: Example: Extended CORAS threat diagram.

Table 2 states a modified complexity and a modified confidentiality impact. Therefore, there are two dashed arrows. The first one points to the *leadsTo* relation describing the corresponding likelihood reduction. The second one points to the *impacts* relation which indicates the reduction of consequences. Figure 8 shows the resulting diagram.

4.8 Step 6: Extend Requirements Model

The final step of our method integrates the functional requirements for selected controls in the requirements model.

Description. The last step needs to be carried out for those controls that are realized as additional software functionalities, e.g. encryption mechanisms. To integrate controls into the requirements model, we follow an aspect-oriented approach for problem frames (Faßbender et al., 2014). As input for this step, we consider the problem diagram related to the threat scenario and the aspect diagram given in the control description.

We add the control to the problem diagram in the following way: The aspect diagram contains domains, joint-points and the functional requirement for the control. We add the domains to the problem diagram along with the corresponding domain interfaces. Since a joint-point represents a placeholder for a domain of the problem diagram, we instantiate it accordingly. Furthermore, we add the functional requirement for the control and the requirement references.

The resulting requirements model can be used in the following design phase. An architecture that can be created based on that model considers security right from the beginning.

Controls that influence the environment, e.g. security training for employees, will not be considered in this step. We document those controls only in the CORAS security model since they do not need to be considered for software design decisions.

There are existing tools that support aspect-oriented requirements engineering. When using such tools with our models, the step can at least be semi-automated. Some adjustments, e.g. the naming of domains and interfaces, still requires manual interaction.

Example. Figure 6 shows the problem diagram in which the control shall be integrated. The aspect diagram is given in Figure 3(b). It contains two additional domains and one joint-point. We instantiate the joint-point with the *Communication Hub* 💻, and we add all other domains and interfaces to the problem diagram. Last, we add the functional requirement and the requirement references. The new *Encryption Machine* 💻 has to be developed to provide an encryption mechanism for securely storing personal data.

Figure 9 shows the final problem diagram containing both functional requirements and related domains.

5 DISCUSSION

Based on the description of our method in Section 4 and the application to the running example, we discuss the benefits and limitations of our method. In the following, we consider usability, scalability, and precision.

5.1 Usability

For selecting and evaluating controls, we make use of templates to describe incident scenarios and controls. The templates describe incident scenarios and controls consistently and systematically based on well-known concepts such as CVSS. Security engineers do not need to fill the templates on their own but can use existing catalogs. Furthermore, the required input

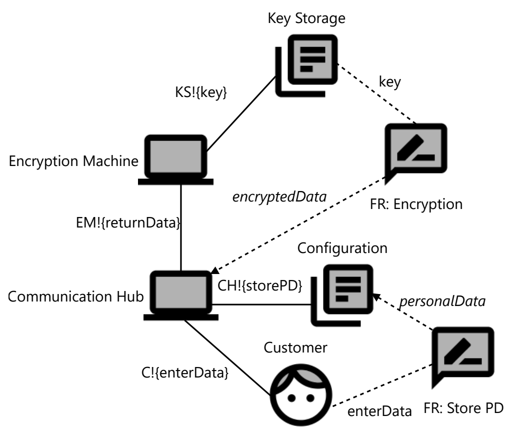


Figure 9: Example: Problem diagram with encryption.

and provided output of our method are documented in a user-friendly way, i.e. in problem diagrams and CORAS diagrams. We designed our method in such a way that it can be easily integrated into a tool (see future research directions in Section 7). We already provide tools for creating problem frame models and CORAS security models. Currently, we extend those tools to select and evaluate suitable controls. Such tool support eases the application of the method significantly.

Despite the unified template description and the user-friendly documentation, security engineers need specific domain knowledge. For example, the context has to be evaluated manually.

5.2 Scalability

The complexity of our method mainly depends on the number of unacceptable risks and the number of controls contained in the catalog. On the one hand, a larger catalog improves the results since there are more possibly suitable controls. On the other hand, the complexity increases with the number of controls. Since we reduce the set of relevant controls with each step, the complexity of the steps decreases. Therefore, the complete catalog only needs to be considered for the first step. Another possible aspect to improve the scalability will be to link controls to incident scenarios in their descriptions. In this case, adding a control to the catalogue would require to update the incident scenario description, as well.

We designed all steps in a way that they can be automated as much as possible to limit the manual effort for engineers to carry out the method. The required calculation for the effectiveness of a control is simple enough to ensure good scalability. Furthermore, the CVSS calculator helps to calculate the severity. The CVSS provides a format to store the values of the different metrics in a vector string. Such a simple format supports the scalability for larger applications since it is easy to use and does not require much storage or complex calculations. Our tool which we currently develop maintains the two models and relations between them. The *Eclipse Modeling Framework* (Steinberg et al., 2009) which we use for our tool allows efficiently storing the models. Furthermore, the different diagram types, namely problem diagrams and threat diagrams, help to structure larger models and to focus on relevant aspects.

5.3 Precision

For evaluating the effectiveness of controls, we use the CVSS. The defined metrics are widely accepted by the community and the industry to estimate the severity of vulnerabilities. The corresponding formulas to calculate the severity of incidents have been defined by security experts based on real vulnerabilities. Although the metrics and formulas have been defined on sound expertise, there are limitations in their precision. The usage of qualitative scales helps to improve usability. In contrast to quantitative scales, those values are less precise. The values do not consider a concrete context in which an incident may be realized or where a control shall be applied. To address this issue, we decided to perform a step that requires manual interaction and validates the context and liabilities of controls (cf. Section 4.5). By replacing the CVSS with other scales, the precision can be improved. As a liability, a qualitative scale may impact the usability.

6 RELATED WORK

In the following, we focus on related work dealing with control selection and evaluation in the context of risk management. Furthermore, we consider related work that may complement or support our method.

The CORAS method (Lund et al., 2010), which we use to model incident scenarios, suggests so-called structured brainstorming sessions to identify appropriate controls. Our method partially relies on brainstorming sessions, e.g. for validating the liabilities and the context of controls. For the other steps, we provide systematic guidance based on patterns.

There is an empirical study on the role of threat and control catalogs in the context of risk assessment (de Gramatica et al., 2015). The study revealed that non-security experts who made use of catalogs identified threats and controls of the same quality as security experts who did not use any catalog. We further support non-security experts by providing guidance with out method in using catalogs.

(Bojanc and Jerman-Blažič, 2013) proposed a quantitative model for risk management. The model covers the identification and analysis of possible threats to security, and it supports the identification and evaluation of controls. The authors do not propose a systematic method, and the application of the model requires specific expertise. However, the consideration of a quantitative evaluation of controls can improve precision (see Section 5).

(Barnard and von Solms, 2000) proposed a formalized approach to select and evaluate information security controls. To evaluate the effectiveness, the authors follow a model-based approach. Besides the evaluation of effectiveness to sufficiently reduce risks, the method also considers the assurance of operation during run-time. By embedding selected controls into the requirements model, we ensure the consideration of controls in the following steps of software development.

In the context of business process modeling, there is a standardized representation of controls (Varela-Vaca et al., 2012). The representation shall serve as an input for automated risk treatment. The same authors proposed an automated approach to determine and evaluate security configurations based on feature modeling and constraint programming (Varela-Vaca and Gasca, 2013).

(Asnar et al., 2011) described an extension of the Tropos language (Bresciani et al., 2004) for a goal-driven risk assessment during requirements engineering. The method analyzes risks along with stakeholders' interests based on three layers: (i) assets, (ii) events, and (iii) treatments. (Herrmann et al., 2011) proposed a risk management method based on business goals. Selected controls are linked to specific business goals. Furthermore, the method allows to prioritize controls and to justify security experts' decisions. Since we mainly focus on functional requirements for software, the consideration of goal-oriented approaches can complement our work.

There are many official resources for controls. For example, the *Bundesamt für Sicherheit in der Informationsbranche* provides the *IT-Grundschutz-Kompendium* which contains a list of countermeasures to treat security risks (BSI, 2019a). The *National Institute of Standards and Technology* published the special publication 800-53 which offers descriptions for security and privacy controls (NIST, 2013). Independently of national regulations, standards like the *Common Criteria* (Common Criteria, 2017) provide control specifications, as well. Those resources can be used as input for our method, thus providing a wide range of controls.

7 CONCLUSION

Summary. In this paper, we presented a model-based method to select and evaluate controls for treating identified risks. We designed our method to be applied during requirements engineering, i.e. we consider the functional requirements of software as an initial input. A distinguishing feature is that we use patterns to evaluate a control's effectiveness. Besides, we bridge the gap between controls and functional requirements by following an aspect-oriented approach. Software architects can use the resulting model to systematically derive an architecture.

Outlook. To evaluate our method, we cooperate with an industrial partner who analyzes security for large scale applications. We take their threat models as input and analyze the results we obtained by applying our methods. Some evaluation rounds have already taken place, but have not yet been finished. This evaluation step will help to develop our tool, as well as to improve the method itself.

Currently, we only consider confidentiality, integrity, and availability in our method. As future work, we plan to add support for additional security properties to our method, e.g. *Authenticity* and *Non-Repudiation*. Furthermore, we plan to add more fine-grained qualitative scales to our templates.

As mentioned in Section 5, we develop a prototype of a tool to support the application of our method. After undergoing a detailed evaluation, we aim to provide a stable version of the tool covering all steps of the risk management process.

Since the final requirements model can be processed in the design phase, we will investigate how architectures can be derived systematically from our model.

REFERENCES

Asnar, Y., Giorgini, P., and Mylopoulos, J. (2011). Goal-driven risk assessment in requirements engineering. *Requir. Eng.*, 16(2):101–116.

Barnard, L. and von Solms, R. (2000). A formalized approach to the effective selection and evaluation of information security controls. *Computers & Security*, 19(2):185 – 194.

Bojanc, R. and Jerman-Blažič, B. (2013). A quantitative model for information-security risk management. *Engineering Management Journal*, 25(2):25–37.

Bresciani, P., Perini, A., Giorgini, P., Giunchiglia, F., and Mylopoulos, J. (2004). Tropos: An agent-oriented software development methodology. *Autonomous Agents and Multi-Agent Systems*, 8(3):203–236.

BSI (2019a). *IT-Grundschutz-Kompendium*. Bundesamt für Sicherheit in der Informationstechnik.

BSI (2019b). State of IT Security in Germany 2019. https://www.bsi.bund.de/EN/Publications/-SecuritySituation/SecuritySituation_node.html.

Common Criteria (2017). Common Criteria for Information Technology Security Evaluation v3.1. Release 5. Standard.

de Gramatica, M., Labunets, K., Massacci, F., Paci, F., and Tedeschi, A. (2015). The role of catalogues of threats and security controls in security risk assessment: An empirical study with ATM professionals. In Fricker, S. A. and Schneider, K., editors, *Requirements Engineering: Foundation for Software Quality - 21st International Working Conference, REFSQ 2015, Essen, Germany, March 23-26, 2015. Proceedings*, volume

9013 of *Lecture Notes in Computer Science*, pages 98–114. Springer.

Faßbender, S., Heisel, M., and Meis, R. (2014). Aspect-oriented requirements engineering with problem frames. In *ICSOFT-PT 2014 - Proc. of the 9th Int. Conf. on Software Paradigm Trends*. SciTePress.

FIRST.org (2015). Common Vulnerability Scoring System v3.0: Specification Document. https://www.first.org/cvss/cvss-v30-specification-v1.8.pdf.

Haskins, B., Stecklein, J., Dick, B., Moroney, G., Lovell, R., and Dabney, J. (2004). Error cost escalation through the project life cycle. *INCOSE International Symposium*, 14:1723–1737.

Herrmann, A., Morali, A., Etalle, S., and Wieringa, R. (2011). Riskrep: Risk-based security requirements elicitation and prioritization. In *1st Intern. Workshop on Alignment of Business Process and Security Modelling, ABPSM 2011*, Lect. Notes in Business Inform. Processing. Springer Verlag.

ISO (2018). *ISO 27005:2018 Information technology – Security techniques – Information security risk management*. International Organization for Standardization.

Jackson, M. (2001). *Problem Frames. Analyzing and structuring software development problems*. Addison-Wesley.

Kaspersky Lab (2019). The Kaspersky Lab Global IT Risk Report. https://media.kaspersky.com/documents/business-/brfwn/en/The-Kaspersky-Lab-Global-IT-Risk-Report_Kaspersky-Endpoint-Security-report.pdf.

Kumar, P., Lin, Y., Bai, G., Paverd, A., Dong, J. S., and Martin, A. P. (2019). Smart grid metering networks: A survey on security, privacy and open research issues. *IEEE Communications Surveys and Tutorials*, 21(3):2886–2927.

Lund, M. S., Solhaug, B., and Stølen, K. (2010). *Model-Driven Risk Analysis. The CORAS Approach*. Springer.

NIST (2013). *Special Publication 800-53 Rev. 4*. National Institute of Standards and Technology.

Steinberg, D., Budinsky, F., Paternostro, M., and Merks, E. (2009). *EMF: Eclipse Modeling Framework 2.0*. Addison-Wesley Professional, 2nd edition.

Tellbach, D. and Li, Y.-F. (2018). Cyber-attacks on smart meters in household nanogrid: Modeling, simulation and analysis. *Energies*, 11(2):316.

Varela-Vaca, A. J. and Gasca, R. M. (2013). Towards the automatic and optimal selection of risk treatments for business processes using a constraint programming approach. *Information & Software Technology*, 55(11):1948–1973.

Varela-Vaca, A. J., Warschofsky, R., Gasca, R. M., Pozo, S., and Meinel, C. (2012). A security pattern-driven approach toward the automation of risk treatment in business processes. In Herrero, Á., Snásel, V., Abraham, A., Zelinka, I., Baruque, B., Quintián-Pardo, H., Calvo-Rolle, J. L., Sedano, J., and Corchado, E., editors, *International Joint Conference CISIS'12-ICEUTE'12-SOCO'12 Special Sessions, Ostrava, Czech Republic, September 5th-7th, 2012*, volume 189 of *Advances in Intelligent Systems and Computing*, pages 13–23. Springer.

Wirtz, R. and Heisel, M. (2019a). Managing security risks: template-based specification of controls. In Sousa, T. B., editor, *Proceedings of the 24th European Conference on Pattern Languages of Programs, EuroPLoP 2019, Irsee, Germany, July 3-7, 2019*, pages 10:1–10:13. ACM.

Wirtz, R. and Heisel, M. (2019b). Model-based risk analysis and evaluation using CORAS and CVSS. In Damiani, E., Spanoudakis, G., and Maciaszek, L. A., editors, *Evaluation of Novel Approaches to Software Engineering - 14th International Conference, ENASE 2019, Heraklion, Crete, Greece, May 4-5, 2019, Revised Selected Papers*, volume 1172 of *Communications in Computer and Information Science*, pages 108–134. Springer.

Wirtz, R. and Heisel, M. (2019c). RE4DIST: model-based elicitation of functional requirements for distributed systems. In van Sinderen, M. and Maciaszek, L. A., editors, *Proceedings of the 14th International Conference on Software Technologies, ICSOFT 2019, Prague, Czech Republic, July 26-28, 2019*, pages 71–81. SciTePress.

Wirtz, R. and Heisel, M. (2019d). A systematic method to describe and identify security threats based on functional requirements. In Zemmari, A., Mosbah, M., Cuppens-Boulahia, N., and Cuppens, F., editors, *Risks and Security of Internet and Systems*, pages 205–221, Cham. Springer International Publishing.