Access Control Verification in Software Systems

Bachelor's Thesis of

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I declare that I have developed and written the enclosed thesis completely by myself, and have not used sources or means without declaration in the text.

Karlsruhe, October 11, 2018

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(Julian Hinrichs)

Abstract

In the last few the software systems became more complex and interconnected. Therefore, security in general and privacy in particular becomes more important. So the idea for a architectural security analysis emerged. To conduct an architectural security analysis one of many approaches is a data-based privacy analysis. Such approaches cannot be evaluated formally. Instead case studies are used for the evaluation. Since case studies create qualitative data, the creation of usable case studies for an evaluation is not trivial. In this thesis, we develop a procedure. With this procedure usable case studies for a software system may be generated. The security have to be modeled via access rights. We further applied the procedure to a software system and created a case study. The created case study consists of two parts. First, the defined access rights that are stored in a matrix and the system model extended by data flows. We then evaluated the created case study based on two aspect. First the quality of the defined access rights and, secondly, the covered information flow classes. Further, the procedure itself is evaluated regarding the applicability. Finally, the chosen modeling language is evaluated in terms of its expressiveness.

Zusammenfassung

In den letzten Jahren wurden die Softwaresysteme immer komplexer und vernetzter. Daher wird die Sicherheit im Allgemeinen und die Privatsphäre im Besonderen immer wichtiger. So entstand die Idee zu einer architekturbasierten Sicherheitsanalyse. Um eine architekturbasierte Sicherheitsanalyse durchzuführen, ist einer von vielen Ansätzen eine datenbasierte Datenschutzanalyse. Solche Ansätze können nicht formal bewertet werden. Stattdessen werden für die Auswertung Fallstudien verwendet. Da Fallstudien qualitative Daten liefern, ist die Erstellung von brauchbaren Fallstudien für eine Bewertung nicht trivial. In dieser Arbeit entwickeln wir ein Verfahren. Mit diesem Verfahren können brauchbare Fallstudien für ein Softwaresystem erstellt werden. Die Sicherheit muss über Zugriffsrechte abgebildet werden. Wir haben das Verfahren auch auf ein Softwaresystem angewendet und eine Fallstudie erstellt. Die erstellte Fallstudie besteht aus zwei Teilen. Erstens, den definierten Zugriffsrechte, die in einer Matrix gespeichert sind und das um Datenflüsse erweiterterte Systemmodell . Wir haben dann die erstellte Fallstudie anhand von zwei Aspekten bewertet. Zum einen die Qualität der definierten Zugriffsrechte und zum anderen die abgedeckten Informationsflussklassen. Weiterhin wird das Verfahren selbst hinsichtlich der Anwendbarkeit bewertet. Schließlich wird die gewählte Modellierungssprache hinsichtlich ihrer Aussagekraft bewertet.

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1. Introduction

1.1. Motivation

In the course of the last few years, software systems became more interconnected and complex. Security in general and data protection in particular became increasingly important. Therefore, for software systems it became mandatory to ensure security. If a system does not ensure privacy a lot of damage could be done. First of all, the financial loss through possible leaks are immense [17]. But the betrayal of the customer by not protecting their data might be the greater issue. Often this results in a loss of trust in the system. So, for all commercially deployed systems the guarantee of privacy should be a primary design goal. Privacy, on the other hand, is a non-functional requirement and it is difficult to ensure compliance. Due to the importance of privacy, the idea emerged to review security on an architectural level. These approaches offers two main benefits. Currently, the system model and the security documentation are stored at different places which leads to inconsistency between those two. IThere is no guarantee that changes to one model will be transferred to the other. Therefore, architectural security analysis store the two aspects, system model and security documentation, in one model. Further the system model can be adapted in an early stage. Early stage here refers to the stage before the implementation or the model is added to an already existing implementation. To conduct a architectural security analysis various approaches are available. One popular approach is UMLsec [7]. This approach utilize the UML modeling language and extends the mate model to add security specifications. Then an attacker model is used to evaluate the security. Another approach is data-based approaches. Seifermann's approach [15]. The approach utilizes component-based systems by extending them with data flows. The security is evaluated by analyzing the data flows with a constraint solving system.
One big disadvantage of the data-based security analysis approaches is that these approaches cannot be validated by a formal proof. Therefore, case studies are used. It is not trivial to create usable case studies for evaluation. Case studies are qualitative data and therefore require a lot of effort in categorizing and analyzing all aspects of a specific case. The goal of this thesis is to support the process for creating case studies. We introduced a procedure to create case studies for a component-based system with the restriction that the security is modeled based on access rights. The thesis was evaluated based on three aspects:

- the introduced procedure.
- the used modeling language for component-based systems.

- the created example case study by applying the procedure to a system. The case study has been evaluated based on two aspects: the defined access rights and the covered information flow classes.

We verified the applicability of the introduced procedure by applying it to the Component Community Modeling Example (CoCoME). We chose data-centric Palladio Component Model (PCM) as our modeling language. We also verified that PCM is able to express the case study. Nonetheless, currently it is rather cumbersome to add access rights to the model. Therefore, a meta model element for the access rights is missing. At last , we evaluated the created case study. The defined access rights achieved to cover about 43% of the access right criteria introduced by Evered and Bögeholz [4]. Further, half of the defined information flow classes for Non-influence [10] are covered int he case study.

1.2. Contributions

The two main contribution of the thesis are the presented procedure and the created case study by applying the procedure to CoCoME.
We presented a detailed procedure for creating a case study for component-based systems. The general process is derived from Runeson and Höst [14]. We have refined the general process so that it is possible to create case studies of component-based systems. Further, inside the procedure, we defined evaluation points during the procedure for verifying the quality of the created case study.
Second, we created a case study for CoCoME. During the process, we defined system extensions for CoCoME to clearly define some vague system elements. We have also created a concrete example for access rights in component-based systems according to the definition of Evered and Bögeholz [4]. At last, we identified and defined data flows for CoCoME and added the data flows to the system model.

1.3. Outline of the thesis

The thesis is organized as follows. In chapter 2 the foundations for the thesis are presented. This includes the used terminology, the foundations for case study creation and the used evaluation method. In chapter 3 we put the thesis in the context of related work. The in chapter 4 the procedure is presented in detail. chapter 5 then analyzes the current status of CoCoME and defines corresponding system extensions. The chapter concludes with an evaluation of the access rights. Afterwards, in chapter 6, the case study is created. The chapter concludes with an evaluation of the defined data flows. Then, in chapter 7 the three aspects of the thesis are evaluated. Further, the threats to validity are discussed. At last, the thesis is concluded in chapter 8 with a discussion of the results and the possible future work.

2. Foundations

In this chapter, we will introduce the foundations that we are using in my thesis. For each, we will give a short definition and an explanatory example.

2.1. Terminology

2.1.1. security relevant data

The term *security relevant data* as used in this thesis, describes data which should be protected by the system. Security relevant data describes the data that causes harm for user or the system. As an example the security relevant data for a software system may consist of personal related informations, like name, address, credit card, etc. But the security relevant data is from system to system different. The term security relevant data is used in this thesis to describe data that is worth protecting in a system.

2.1.2. Data flow

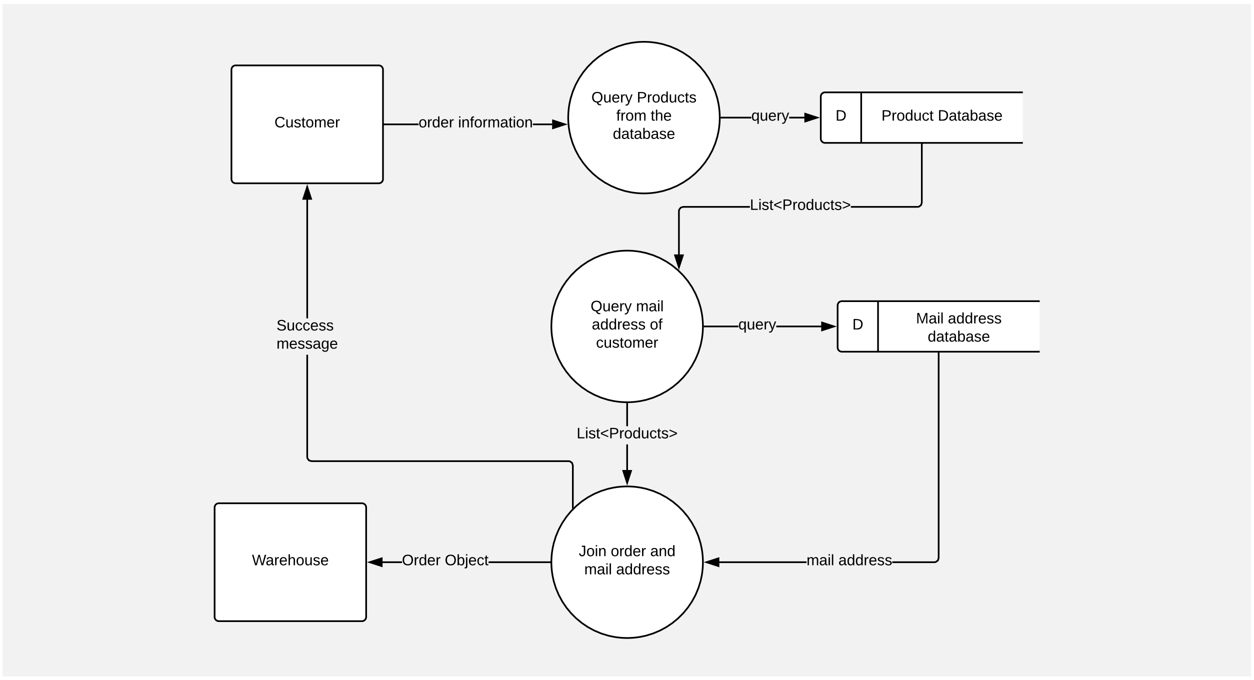


Figure 2.1.: Simple data flow diagram for linking an order of different products to a mail address

The term data flow is used in different fields of computer science. To name a few examples, data flow is used in software architecture, hardware architecture, networking, etc. We mainly use data flow in our architectural models
Data flow describes the way of data through a system. One can imagine data flows like an activity diagram. Each node in the diagram is either a process or an external entity. Processes are operations which processes the data. External entities are users or other systems which request or submit data. The edges between the nodes containing the type of the data passed. Also different data stores (most likely databases) are part of the diagram. These data stores holds different information, like the credentials, and are accessed via a process.
Figure 2.1 shows the simple process of ordering products and linking them to a mail address. The customer is already authenticated and inserts the order informations. Then the system queries all the necessary informations for the products from the database and adds them to a list. After that, the mail address of the customer is queried and packed in an object together with the product list. This object is then send to the warehouse and the customer is presented a success message. Later, the warehouse will collect the products and pack them in a delivery, but this is not a part of the diagram. For the sake of simplicity, eventual errors aren't modeled.

2.2. Palladio Component Model

The Palladio Component Model (PCM) is an architecture description language (ADL) , that allows more than only a componment-basede system modeling a system. The strength of PCM is compute performance predictions for the modeled system [13]. A PCM model consists of four different models, each of them encapsulate their specific design knowledge and the models build on each other. After the system is complete, an system architect may compute different predictions how the system will perform when it is deployed. The predictions are for cost, reliability, performance and maintainability.

2.2.1. Component based systems

Component based system are systems that consist out of components. Each component in a system is usually designed to fulfill one functionality, like connecting to a database, handling the user input, etc. It is possible that a component consists of multiply component. In such a composite component, each component also handles a single task. This allows to split larger tasks into smaller ones and assign each of them to a single component. This allows to reuse components that are designed to handle general tasks, like formatting data to a String.The definition of a component is that a component provides or requires an interface. The provided or required interfaces are used for communication between the components. Each of the interfaces is clearly defined. The components are chained together to a system using the interfaces. The main strength of the component based systems are the modularity by design. As simple example is shown in Figure 2.2. In the model a simple oline shop is shown. As shown, there is a component for managing the warehouse, a component for handling the business logic e.g. selling products and

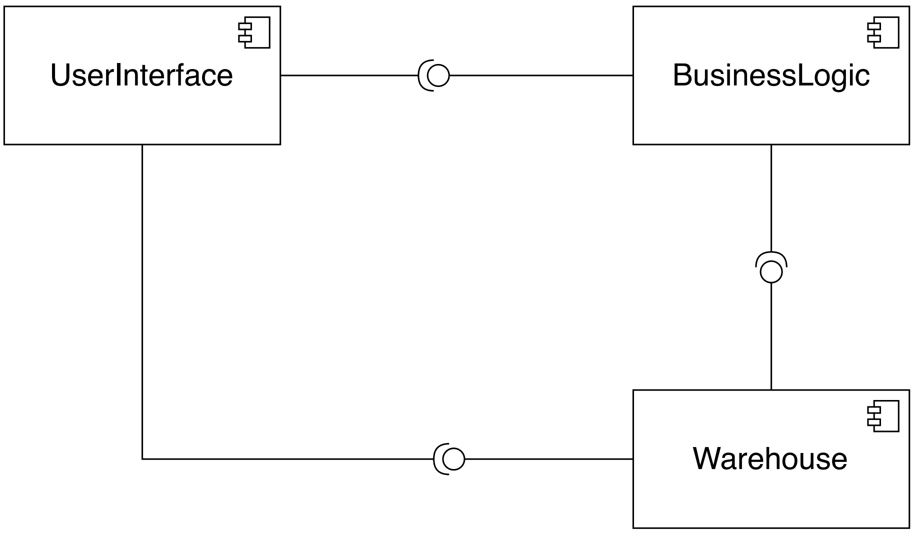


Figure 2.2.: A simple component based system

a component for the user interface. In this component based system the user interface is used by both customers and employees. Usually each of the components consists of different components for th different tasks.

2.2.2. Data Centric PCM

2.2.3. Concept

Here, we explain the concept of PCM in detail.
First of all, for each model a PCM role is assigned, which will be explained in detail later. Each of role conserve their design knowledge in a specific model which is used by the next role. The hierarchy of the different roles , from top to bottom, is:

- **Component Developer**
  The component developer specifies and implements a component. Furthermore, the role provides additional information, that will later be used for the predictions that PCM is able to compute. The resulting model is stored in the *repository model* and can there be accessed by the system architect.

- **Software Architect**
  The system architect builds the system using components. S/He connects the different components provided by component developers to a fully functional system. The resulting model is called *system model* and is used by the system deployer.

- **System Deployer**
  The system deployer decides how the system is distributed between the available resources. This role creates two resulting models. First, the *resource model*, in which the resources characteristics, for example transfer rate. Second, the *allocation model*,

in which the allocation of the different resources to the different parts of the system is conserved. These models are used by the domain expert.

- **Domain Expert**
  Domain experts creates the *usage model* for the system. This describes user behavior. Also they specify the user workload. This workloads can be open or closed. In the closed case, a finite number of user interact with the system, in the open case the domain expert specifies the user arrival per time slice.
  As the domain expert is the last role in the chain, the models aren't used by another role. With the addition of the usage model the creation of the system model is complete.

After all the different models are created, a prediction may be computed and without a line of code is written and the architects can see if there are flaws in the architecture. The PCM models are more than just a system model. A lot of domain knowledge is encapsulated in the resulting models. The result are more a simulation for the upcoming system than a system model.

2.2.4. Meta model extension for data centric PCM

In this section, we are going to explain the meta model extension to the PCM provided by Seifermann [16]. The extension is lightweight. It aims to embed data flows in an already existing PCM model.
In the current state of PCM, it is not possible to model data flows. Therefore Seifermann created a meta model extension. The meta model extension is called data processing.
The meta models extends the Service Effect Specification (SEFF) for a component in the repository model. SEFFs are similar to UML activity diagrams. Like Activity diagrams, SEFFs specify the observable behavior for a system, in the case of PCM SEFFs specify the observable behavior for a component. SEFFS are used to model different types of actions. These actions holds various information about the systems performance and are chained together to create a sequence of events to model the (observable) behavior of a specific component.
The meta model extension is specially for these SEFFs. The main goal for this meta model extension was to model data processing. For each action in a SEFF an operation may be defined that specifies the data processing for this action. The defined operations model the different types how data can be processed. All SEFFs chained together in model already create a model similar to an activity diagram. For each activity a operation that processes data is specified. With this operations chained together it is possible to create a data flow for the model.

2.3. Privacy approaches

As mentioned before, the resulting case study can be used in data-based privacy analysis. The assurance for privacy is there evaluated by using information flows. As a fundamental work, we used the publication from McLean [9]. In this McLean describes different security

models for different types of systems. McLean mainly focus information flows inside the different types of systems. Also the problem statement *Non-interference* is mentioned. A problem statement describes a threat to the security of system.
In this thesis, we use the problem statement *Non-influence* described by Oheimb [10]. Non-influence consists of two problem statements: non-interference and non-leakage. Non-interference describes that in the program flow inputs from a high level user no influence on the outputs for a low level user. Non-leakage describes that for an outsider it is not possible to determine if an certain, like the authentication of an user, has taken place.

2.4. Case study methodology

Case studies are already a probate tool in software engineering. Runeson and Höst [14] categorized the research methodology *case study* in the context of other related methodologies like surveys. According to Rune and Höst case studies are a exploratory method with flexible design that produces qualitative data. Exploratory in this context refers to the process of finding out what happens in a specific case and generating new ideas for general research. Often case studies are seen to as an investigation how different challenges in software engineering are tackled and a discussion of the different solutions. But, case study also may be used for our purpose: investigating a system and find out how data is processed inside.
Further, Runeson and Höst have published detailed instructions on how to create a case study and what to look out for during the creation process. The general process contains five steps.

1. Case study design: define the studied object.
2. Data collection: procedure how data is collected.
3. Collecting data: collecting data for the studied case.
4. Analysis: analyze the collected data.
5. Report: report the findings.

We utilized this general description to create our procedure (see chapter 4). The five basic steps can also be found.

2.5. Goal-Question-Metric approach

This appraoch was first introduced by Basili [1]. A evaluation base don a Goal-Question-Metric (GQM) plan ensures a high reproducibility, a clearly defined structure and evaluability for the results at the end of a bachelor's thesis, for instance. The Goal-Question-Metric approach divides the evaluation process into three steps. First a *goal* that he evaluation aims to achieve is defined. Afterwards, one or more questions are defined. The answer to the question indicates if the question has been answered. Then metrics are used to measure to which degree the questions are answered. Usually only one goal is defined, but it is possible to define various questions. For each questions at least one metric has to be used.

3. Related work

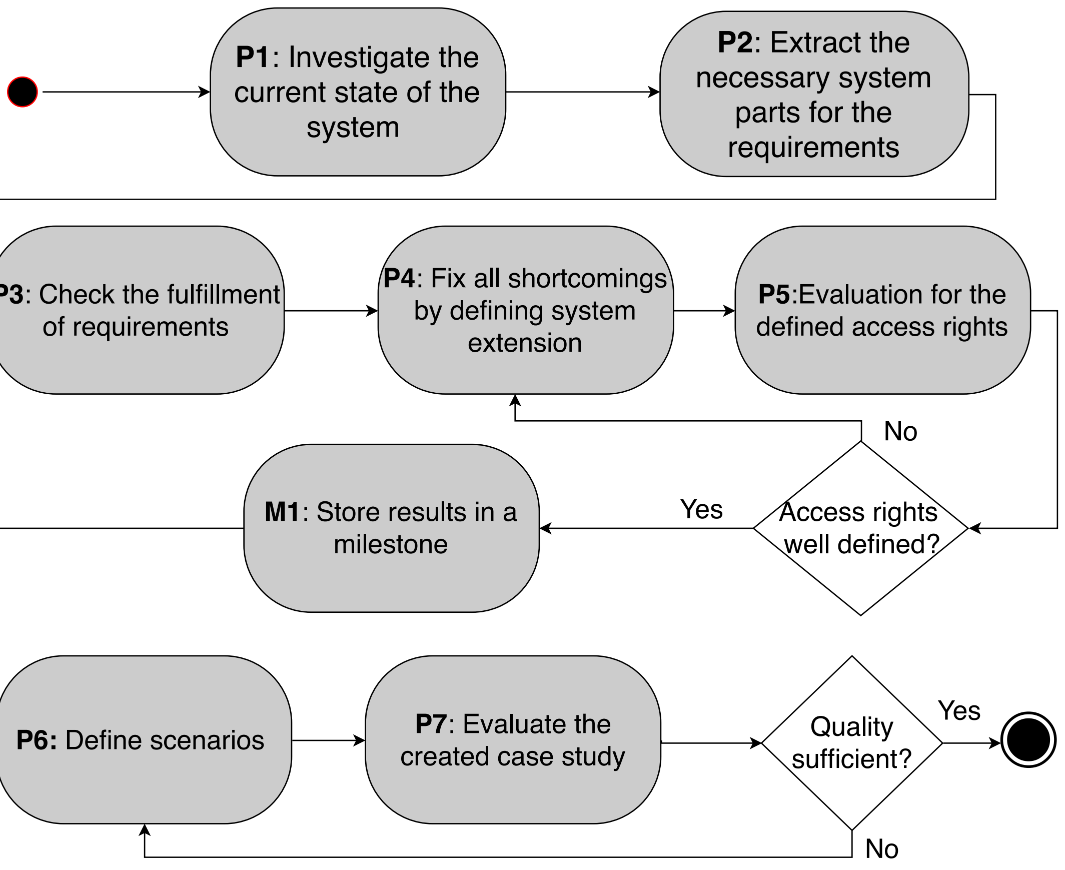
After the foundations were presented, we discuss here the related work. In this chapter, we discuss the related work for this thesis. In this thesis, we strayed away from the most common use of case studies. Case studies are most commonly used to investigate a certain problem and collect the different approaches. Then, the different approaches are discussed. In contrast, the purpose of the created case study strays away from the common use of case studies. Therefore, we searched for related work from researchers that are creating a case study on the base of a software system.
The publication from Jürjens [6] creates a case study for the architectural security analysis approach UMLSec [7]. UMLSec utilizes a meta model extension for the UML language. Compared to the procedure presented in this thesis, only the process for the creation of a case study is similar.
Another related publication is the publication of Katlakov et al. [8]. In this publication, a case study based on information flows for a software systems is build. The presented procedure also utilize information flow to later allow to check the security of a software system. The contrast to our work is that this publication also works on an UML model.
The last related work to our thesis is the one from evered and Bögeholz [4]. This publication is the most adjacent to our work. The researcher also create a case study on the basis of a component-based system. For the definition of the access rights, we adopted the their definition for component-based systems. Further, Evered and Bögeholz defined evaluation criteria for good access rights. We also adopted the defined criteria for our evaluation of the access rights. most importantly, Evered and Bögeholz also created a case study for a component-based system. The focus whilst the creation were on the access rights. So the created case study has a much smaller scope. Similar to the procedure in this thesis, a component-based system was used.
To conclude the related work. We found in different publications characteristic aspects for the created case study in this thesis and compared the corresponding parts. From Jürjens [6] we could compare the basic procedure and further , Jürjens showcased a concrete example for an architectural security analysis. From Katlakov et al. [8], we could compare the usage of data flows in an architectural security analysis. From Evered and Bögeholz [4] we adopted the definition of access rights in component-based system and the criteria to measure well defined access rights. Further an example case study for a much smaller scope was created which we could compare to ours.

4. Procedure

In this chapter we are going to present a procedure to create a case study that can be used to evaluate a data-based privacy analysis. The privacy is defined by access rights. We will describe the procedure step by step and the places where the case study will be evaluated. During the process, the case study is evaluated based on two aspects,the quality of the access rights and the covered information flow classes. Overall, the resulting case study consists of an extended system model. The extensions include the access rights and the added data flows.
First, we give a brief overview over the procedure shown in Figure 4.1. After that each step will be explained in detail.
The procedure consists of seven consecutive steps. First the current state of the system is reviewed, secondly the necessary elements for the requirements are extracted. Thereafter the fulfillment of the requirements is reviewed and the required system extensions are defined in the next step. Afterwards, the access rights are evaluated and the results are stored in a milestone. Then scenarios for the system are defined. In the final step, the information flow classes covered by the scenarios are evaluated. Finally, it is decided whether the case study is sufficient for the intended use.

4.1. General procedure for the creation of a viable case study

Here we describe the procedure for creating a case study. An overview is shown in Figure 4.1. We cover the steps P1-P7 that are necessary to create a case study. We further explain places when the evaluations are conducted.
The first step is to decide whether it is worthwhile to prepare a case study based on the system under investigation. This is decided by reviewing the current documentation. The goal is to In a second step, six requirements for creating a case study are introduced (see . The first requirement is that the system is modeled as a component based system or components can be derived from the current documentation of the system. The second requirements is the definition of use cases. The third requirement is to identify the data in the system and identify which of the data is security relevant. The fourth requirement is the definition of user roles in the examined system. The fifth requirement is definition of access rights between (security relevant) data and the user roles. The access rights can either be generated from the previous requirements or extracted from the documentation. The sixth and last requirement is the identification or definition of the different types of data processing. Furthermore, for each component it is either defined or identified which data is processed as in the individual component.
In the third step, the current fulfillment of requirements are analyzed and collected in a summary. Usually there are shortcomings. If there are none, the next step can be skipped.



P1: Investigate the current state of the system
P2: Extract the necessary system parts for the requirements
P3: Check the fulfillment of requirements
P4: Fix all shortcomings by defining system extension
P5:Evaluation for the defined access rights
No
Access rights well defined?
Yes
M1: Store results in a milestone
P6: Define scenarios
P7: Evaluate the created case study
Quality sufficient?
Yes
No

Figure 4.1.: General overview over the procedure for creating a viable case study

In the fourth system extensions for the missing parts of the requirements are defined.
In the next step, the evaluation for the the access rights is conducted.
After the evaluation is done and the results are sufficient, the milestone is reached. All necessary parts of the system are present, so that a case study can be created. If the results are not sufficient the procedure iterates back to the fourth step. In the sixth step, scenarios are defined, from which data flows are derived. Finally, the data flows and the access rights are added to the system model.
In the seventh step the covered information flow classes are evaluated. Then it is decided if enough information flow classes are covered for the planned use of the case study. If not, the procedure iterates back to the sixth step. Otherwise, the procedure is concluded and the case study is created. The case study finally consists of the system model extended by data flows and the access rights.

4.2. P1: Investigate the current state of the system

Before the process is started, a first glance at the present system is taken. This first glance is taken to decide whether it is worthwhile to start the process. It is checked if the system is sufficiently defined in *width* and *depth*. *Width* checks how many different system models are already defined. *Depth* checks how detailed each model is defined. The outcome is system dependent. For example, it could be important how much work one is willing to do before starting the process. The idea behind this step is to decide beforehand if the system is in a state where it is more than just a bare concept and the case study can be constructed with reasonable effort.

4.3. P2: Extract necessary system parts for the requirements

The second step in the procedure is to extract the corresponding elements or definitions from the system for each requirement. Altogether, six requirements are necessary for the creation of a viable case study.

R1: Modeled as component based system The first requirement is that the system is modeled as a component based system or it is possible to derive a component based system from the current state. The allows to use all benefits that a component based systems has and make it much easier to construct a case study. Firstly, in component based system there are well defined interfaces. These interfaces defining points in the architecture where data is transmitted. This ease up the creation of data flows, because one can directly identify where the data is processed. Secondly, component based systems are easy to extend. Therefore, it is not that complex to add missing elements to the model. Thirdly, the component based structure enables modularity. So it is relatively easy to just took an excerpt and take a close look on just this excerpt. All in all combined, component based systems excel in their modularity and their clear defined interfaces, that ease up the creation of a case study.

Requirements	
R1	component based system
R2	Definition of use cases
R3	Security relevant data
R4	Definition of user roles
R5	Definition of access rights
R6	Definition of the type of data processing in the components

Table 4.1.: An overview over all the requirements for the creation of a case study.

R2: Definition of use cases The second requirement is the definition of use cases in the system or it is possible to derive use cases from, for example, the documentation. This allows to get a good idea how the different users are going to interact with the system. Further, the use cases give a basic idea of the general interaction with the system.

R3: Existence of security relevant data The third requirement for a viable case study is the existence of security relevant data in the system. If there is no critical data in the system, the entire case study that is created to verify the protection of security relevant data is pointless. The definition of security-relevant data is highly dependent on the system under investigation. This means for each system and each context there are other data that is considered security relevant, therefore a lot of domain knowledge is required to identify the data. Breier [2] introduced a basic approach to valuate assets. The basic idea of the approach is to value the various assets in terms of their priority within the system.

R4: Existence of different user roles The fourth requirement for the case study is the definition of user roles, in the following briefly roles, for the system. Roles are used to model different types of user for a system. Each role maps to one type of user. Roles are used to model the different users that are interacting with the system. Different roles uses on different data inside the system. For example the security relevant data mentioned in R3. The roles depend heavily on the system being studied. Each system defines different roles. For each system under investigation the use cases (R2) are a good source of informations. One can use business processes [11] to identify roles in a system.

R5: Definition of access rights The fifth requirement is the definition of access rights. For the definition of access rights, we use the fine-grained, higher level form proposed by Evered and Bögeholz [4] in contrast to the familiar used read/write semantics. For this step, we assume the system is in a correct state. The access rights are define on the basis of the current state of the system. As already mentioned, each component has a clearly defined interface. These interfaces are used for communication with other components. This structure is used to define a higher level, finer grained form of access control. For each component and each role, the access rights for the data types in the component are defined individually. The access rights are stored in a matrix, the so called access control matrix (ACM). In Figure 4.2 an minimal ACM is shown to get a better idea of the concept. The matrix shows that the role *Employee* in the component *Usermanager* has full access

ACM	Usermanager
Employee	username: fullAccess
	password: noAccess

Figure 4.2.: Reduced ACM to the show the concept.

	Login data
User interface	transmit

Table 4.2.: A simple example to showcase an OpM.

to username. Also it is shown, that the same role in the same component has no access to the password. It may happen that data is the combination of different data types. In this case, the more restrictive access rights applies. To clarify this, if the employee tries to access a (*username, password*) tuple, s/he is granted no access to the tuple.

R6: Definition of type of data processing in the components In the sixth requirement the type of data processing for each data type in each component is defined. As the the requirement R5, the necessary elements for this requirement may be derived from previous ones, namely R1, R2 and R3. In R1 ensures that the system is modeled as a component-based system. With R2 (definition of use cases) and R3 (security relevant data) it is possible to identify how which data is processed. The different processing types are described through different operations. The various operations describe how and which data is processed in a specific component. Each operation has one more inputs and produces one or more outputs. The operations needed are highly system-dependent. Operations could describe the transmission of data, processing of user inputs or operations used in the relational algebra. The identified operations are stored in an operations matrix (OpM). In this matrix, for each component it is stored with which operations data can be processed. In Table 4.2 an excerpt of an OpM is shown. As one can see, in the component *User interface* it is only possible to transmit the login data to other components.

4.4. P3: Check fulfillment of requirements

In this step the current state of requirements is reviewed. The best case is, that all requirements are fulfilled. If this is the case, one can skip the next step. If it is not the case, create a summary of all shortcomings for the fulfillment of requirements in the system. After the first two steps of the procedure are done the usual case is that some of the requirements are not fulfilled. It may even happen that for some requirements are no elements present in the system. The review of the shortcomings is important to outline which parts of the system are vague. Vague in the context of the thesis means that some elements (e.g roles, access rights) are not well defined. To give an example, it may happen that roles are just mentioned but a clear definition of the role is missing. This summary of shortcomings may also show parts where the model is not well defined. This may lead to an improvement of the model in the next step. After the summary is complete, the procedure moves to the next step. The summary is done due to two reasons. Firstly, to get a comprehensive overview of the current state of the system and secondly, to enable a division of tasks. The second reason is that you get an overview of the big picture and define possible system extensions not as soon as a shortcoming is encountered but with the big picture in mind. This ensures that system extensions are defined in the context of the whole system.

4.5. P4: Fix all shortcomings by defining system extensions

In the previous step, a summary of the shortcomings in the system was created. In this summary, all system components that stand in the way of fulfilling the requirements are stored. In this step, the system extensions are defined to fulfill all requirements. When defining system extensions, the first step is to derive the needed extensions from the documentation. In the case, the documentation isn't clear or it is not possible to derive extensions for the shortcomings, the option left is to define the system extensions to the best of your knowledge. This is sometimes necessary, but there are some dangers involved. It may happen that the resulting case study is less realistic and therefore provides less satisfying results, when used in a later analysis.

4.6. P5: Evaluation of the access rights

In this part of the procedure, the access rights are evaluated. The evaluation follows a GQM-plan, shown in Figure 4.3. The access rights are evaluated based on seven criteria presented by Evered and Bögeholz [4]. We divided the seven criteria in three categories: *specification*, *comprehensibility* and *implementation*. *Specification* how the access rights are defined. *Comprehensibility* evaluates how well access rights can be understood by others. *Implementation* evaluates the way the access rights are embedded in the code. It may not be possible for all systems to evaluate all seven criteria. The seven criteria are:

- Concise : Access rights should be precise and simple.
- Clear: At first glance one can see what the access rights state.
- Aspect-oriented: The access rights may be used in different contexts
- Need-to-know: each role only should have the absolute necessary informations
- Positive: Each right to data has to be given specifically to each role.
- Fundamental: The access rights are realized inside the code
- Efficient: The overhead caused by the checks of the access rights is reasonable.

The evaluation is done in a checklist manner. For each criterion it is checked whether the system fulfills the criterion or not.
After the evaluation of the access rights is done, the results are analyzed. If sufficient

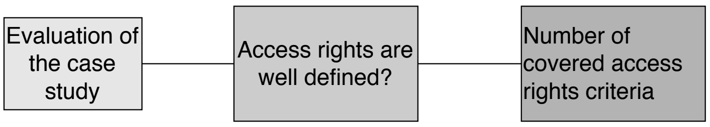

Evaluation of the case study
Access rights are well defined?
Number of covered access rights criteria

Figure 4.3.: Overview of the evaluation of the access rights.

criteria for the purpose of the case study are fulfilled, the current state of the system is considered correct. If the results are unsatisfying, the procedure moves back to the previous step P4. Otherwise the milestone is reached. The system is sufficiently defined so that is possible to add data flows and create a case study.

4.7. M1: Store the results in a milestone

After the evaluation results are sufficient, the current state of the system is stored in a milestone. This includes all definitions made for the each requirement.

- R1: The system model.
- R2: Use case diagram, definition for each use case.
- R3: The data types and the examination, which data is security relevant.
- R4: The different user roles.
- R5: The created ACM.
- R6: The created OpM.

4.8. P6: Definition of scenarios

After the milestone is reached, scenarios for the case study are defined. Scenarios are a concrete characteristic of a use case or a concrete characteristic of an interaction with the system. The scenarios are defined taking into account requirements R2, R3, R4 and R6. R5 is omitted in order to reduce the bias of the system architects that not only scenarios are created that are consistent with the access rights. The main part of this step is to transform the created scenarios into data flows that are later added to the model. We will provide a procedure how to add data flows to the model. This is done step-by-step. The defined scenarios serve as the basis for the transformation. To realize the transformation three successive steps are needed.
In the first step, the components that are needed to realize the specific scenario are identified. Then these components are collected and added to a reduced model. In the second step, the reduced model is analyzed. The aim of the analysis is to map data and the respective type of processing to components. Then the data flows can be created and added to the reduced model. In an last optional step, the reduced model is added back to the originally model. This can be done,so all data flows are available in the original model.

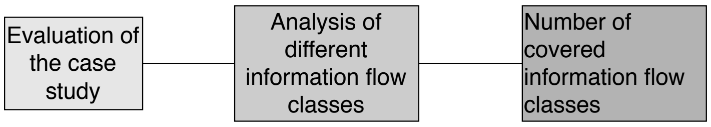

Evaluation of the case study
Analysis of different information flow classes
Number of covered information flow classes

Figure 4.4.: Overview over the GQM plan for the evaluation of the added data flows.

This procedure is repeated for each scenario. After that, the access rights are also added to the component model. The structure of the access control matrix is used. For each component, the respective access rights of a role to the data types of a component are added to the respective components. After this is done, the definition of the scenarios is complete and the added data flows can be evaluated.

4.9. P7:Evaluation of the covered information flow classes

The last step, is the evaluation of the defined scenarios for the system. The scenarios are evaluated on the basis of the information flow classes covered, which may differ according to the objective or use of the case study. The evaluation follows a GQM-plan. The plan is shown in Figure 4.4. We propose to use Non-influence [10] and the included information flow classes to evaluate the scenarios. Non-influence consist of the two part: non-interference and non-leakage. Non-interference describes, that in a program flow inputs of high users do not influence the output for low users. Non-leakage describes that it is not possible to observe if a specific action in the system has taken place.
non-interference and non-leakage are covered by the following four information flow classes:

- No illegal information flow:
- No information flow from high to low:
- No direct information flow:
- No observable information flow:

4.10. Conclusion of the procedure

After the second evaluation is conducted, it is necessary to decide if the coverage of the information flow classes are sufficient for the goal of the cases study. If so, the procedure is finalized and the case study is created. Otherwise, the procedure moves back to the P6. The created case study in the end consist of the system model extended with data flows and the ACM.

5. Analysis of CoCoME

In this chapter we are starting to apply the procedure described in chapter 4 to CoCoME. The procedure is applied up until the milestone is reached, as seen in First we describe CoCoME briefly. Then the steps P1-P5 of the presented procedure are carried out. First we briefly examine the current state of CoCoME, then the system parts necessary for the requirements are identified and/or extracted from the documentation. After that, a summary of the shortcomings is created and in the next step the identified shortcomings are eliminated by defining system extensions. The defined access rights are then evaluated. Finally, the current state of the system is saved in the milestone.

5.1. CoCoME overview

CoCoME is short for Common Component Modeling Example. The goal of CoCoME is to provide an open source environment, in which different paradigms for component based software development can be tested. CoCoME tries to be as close as possible to the reality to provide a realistic environment to test new modeling approaches. CoCoME abstract the selling process and the warehousing of supermarket and provides three core functions:

- Operating of a register cash system.
- Management of a warehouse.
- Management of different enterprises.

CoCoME allows to abstract various enterprises, where each one models a supermarket group like Lidl or Aldi. Each enterprise may consist of one more store. Each enterprise may has various stores, with each of them selling products . Each of these stores has various cash desks, where products are sold. Furthermore, CoCoME also handles the management of the warehouses for each store. When a product is sold at a cash desk or a delivery from a supplier is accepted, the current stock is automatically updated.
CoCoME was introduced as a result of a seminar more than 10 years ago at the university Clausthal. CoCoME has been in development ever since. Over the years different variants emerged. Each variant was introduced to either react to new model pattern or solve problems that arose in the development or the deployment process. To keep this short, we will explain in detail only the hybrid cloud-based variant, as this is the variant we are using to apply the procedure.
The hybrid cloud based variant emerged from an earlier version. We use the description of the system provided in the CoCoME tech report [5]. The hybrid cloud based variant was created by adding four evolutionary scenarios . These four evolutionary scenarios

are : Platform Migration, addition of a pickup shop, database migration and addition of a service adapter. First, we will give a quick overview over the general architecture, then we will describe each of the evolutionary scenarios briefly.
The general architecture for the hybrid cloud based variant are shown in Figure 5.1. As shown, the architecture is divided in three different layers plus one layer to abstract the database.
The first layer is the user interface. This layer includes the *PickupShop* and the *Webfrontend* components. The user interface is the point where the different users interact with CoCoME. Their request are transmitted to the underlying components and the results are displayed in this layer.
The second layer is called web service. This layer transmit the requests from the user interface to the business logic. Further this layer is used to add dynamically functionality to CoCoME.
The third layer is the business logic, namely *Tradingssystem.* The *Tradingssystem* component is split up in two main parts. First the *Tradingssystem:cashdeskline* and secondly the *Tradingssystem:inventory. Tradingssystem:cashdeskline* represents the register cash system. The *Tradingssystem:inventory* represents the management of a warehouse. Each request from customer or employees is processed in the *Tradingssystem.*
At last, the *ServiceAdapter* component doesn't match to any of the previously mentioned layer. This component abstracts the access to the database.

5.1.1. Platform migration

The first evolutionary scenario is platform migration. This is done to reduce the costs. The CoCoME system is moved to a cloud environment for easier scalability. If, for example, the pickup shop is heavily used due to a large advertisement campaign, additional resources in order to compensate for bottlenecks, can easily be purchased.

5.1.2. Addition of a Pickup shop

The next evolutionary scenario is the addition of a Pickup shop to CoCoME. The Pickup shop offers a second Point-of-Sale for CoCoME to concurrent with web shops like Amazon. Customer may order products online and pick them up in their chosen store. Therefore an account in the CoCoME system is required. With the Pick up shop, CoCoME changes from a closed to an open system. As shown in Figure 5.1, the *PickupShop* bypasses the *Tradingssystem:cashdeskline* and directly accesses the*Tradingssystem:inventory.* The payment process is carried out in the *PickupShop* component.

5.1.3. Database migration

In this evolutionary scenario the database is migrated to a cloud service. Due to the fact, that the PickupShop and the stores both operate on the inventory, a higher amount of database request is expected. In order to avoid possible shortcomings in the performance,

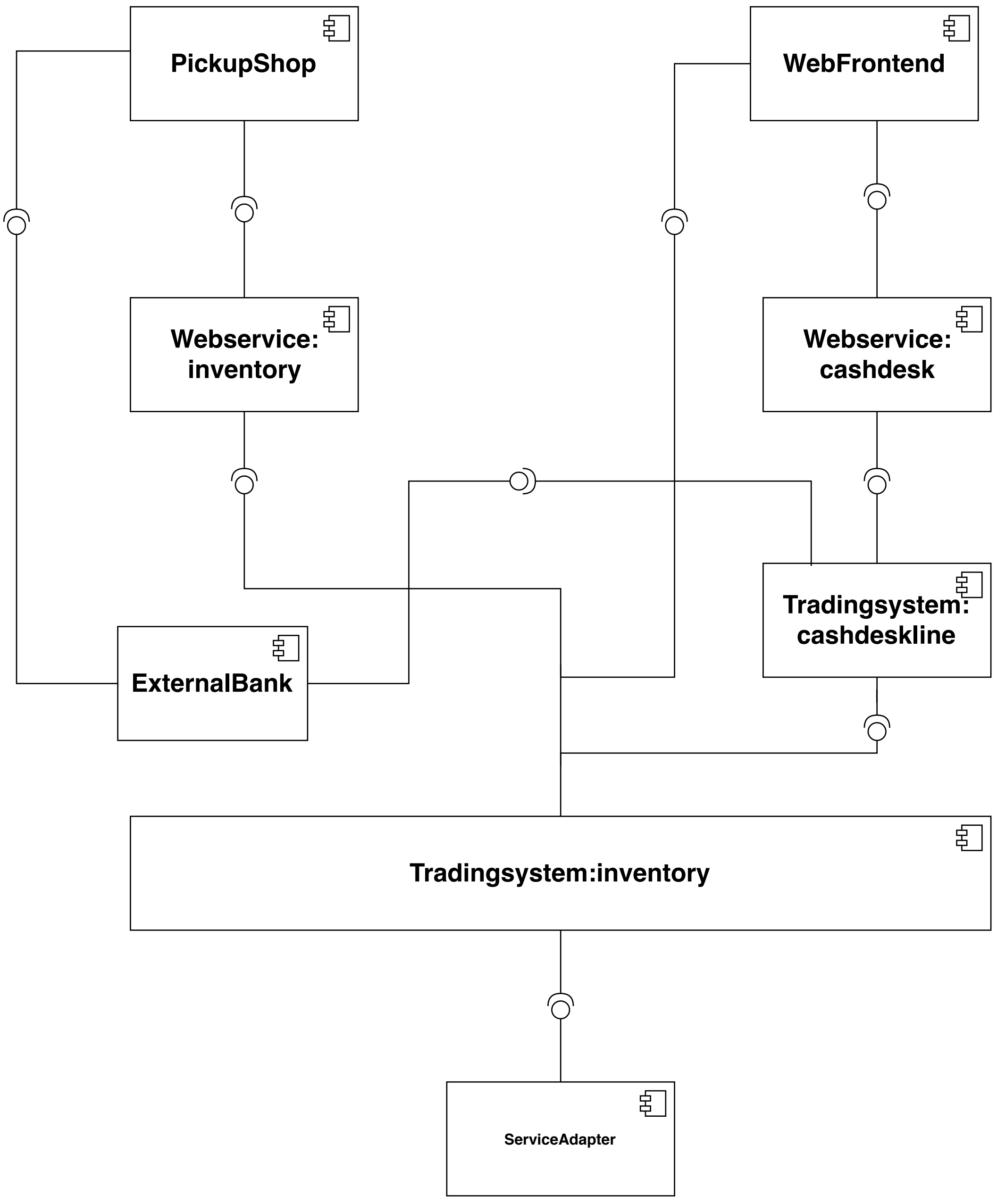


Figure 5.1.: The figure shows a simplified overview over the hybrid cloud based variant

the database was moved to a cloud environment. This allows to easily purchase additional bandwidth or space to solve upcoming scalability issues. With the migration of the database a new issue arise. It may happen, for example, that data from enterprises that are located in the European Union (EU) are stored outside the EU, which does not comply with the current law.

5.1.4. Service adapter

Since CoCoME was always in development, CoCoME currently consists of a relatively large code base. Since this does not have to be understood by every single developer to work with CoCoME, a service adapter has been added. The service adapter allows CoCoME to dynamically add functionality.

Reasons for CoCoME to apply our procedure on The decision to use CoCoME as the system for applying the method was based on many reasons. CoCoME is already modeled as a component-based system and described in detail in [5] and the CoCoME book [12]. On the other hand, CoCoME is more of a minimal solution to what is actually planned to achieve with the system. One can say, CoCoME is rather a proof of concept than a fully functional system.

5.2. Application of the method

After an short overview over CoCoME in the previous section, we are starting with the procedure for the creation of a case study. The presented paper from Runeson and Höst [14], which is could be seen as a fundamental source for the creation of case studies, states that one should use more than one source of information for the investigated case. We used as our main source of information the CoCoME tech report [5] and the CoCoMe book [12], were the system is described in detail. Further we used the code of the implementation [3]. If there are differences between documentation and code, the definitions from the documentation applies. We favor the documentation over the code because CoCoME is still in development. The documentation represents a stable version of CoCoME. In the implementation it may possible that at the moment new features are tested that are later quashed.
We do not apply the process to the entire CoCoME system, but concentrate on only part of the system. The selected part of CoCoME are components that belong to the PickupShop (subsection 5.1.2).

5.2.1. P1: Investigation of the current state of CoCoME

In this first step we take a first look at CoCoME. We are looking for two main aspects here. First, if the system is extendable. Secondly, how wide spread the system model already is defined. The CoCoME include a book [12], a tech report [5] and an implementation. In the documentation CoCoME various system models for CoCoME are available and CoCoME is modeled as an component-based system and therefore extendable. So we decided that

Requirements	
R1	Component based system
R2	Use cases
R3	Security relevant data
R4	User roles
R5	Access rights
R6	Type of data processing in components

Table 5.1.: Overview for the requirements for a case study

the system is in viable state.In the case of CoCoME, a tech report [5], a book [12] and an implementation is available. For the fact, that CoCoME is modeled as a component-based system, the system is also extendable.

5.2.2. P2: Extract the necessary system parts for the requirements

In the next step, we identify the necessary system parts in CoCoME for the six requirements listed in Table 5.1. In the following, for each requirement the related system parts are extracted.

5.2.2.1. R1: Component based system

This requirement is met because a component-based system model is defined in the CoCoME tech report[5].

5.2.2.2. R2: Existence of use cases

The CoCoME documentation defines thirteen use cases, so this requirement is also met. The use cases are defined in detail either in the CoCoME book [12] in the CoCoME tech report [5].

5.2.2.3. R3: Security relevant data

Since the amount of data is relatively large in the investigated excerpt of CoCoME, we have grouped the data into different equivalence classes. The data type in each class has the same security level. Composite data types inherit the security levels from most restrictive class. We defined four classes: **customer data**, **account data**, **product&sales data** and **system data**.

- Customer data
  This class describes all data types that are provided by the customer role. This includes names, addresses and credit card details, to name the most important ones.

- Product&Sales data
  All the data that is related to the products and the sales process. Examples for data types are price of a product, quantity of a product, date of shipping etc.

- Account data
  Account related data refers to the introduced accounts with he addition of the PickupShop. It is needed that each role is registered with an account in the system. The account data type holds the *username* and the credentials for an account.

- System data
  In this class mainly summarizes the created queries for access to the underlying database.

The security relevance for each class is defined according to Breier's approach [2]. The approach is based on the possible damage the loss of an asset could cause. So for each asset the level of damage a loss of the asset could cause is defined. Further, for each asset the dependencies to other assets is defined. Based on this, it is possible to calculate the value of an asset. This approach is not one-to-one applicable to our case, but we can use the basic idea. We evaluated for each data class the possible impact a leak of data from this class may have in CoCoME. Keep in mind that the primary goal is to protect persons that are using CoCoME. Therefore, the customer data is the most relevant and defined as **security relevant**.
The account data allows to log in as the specific role, which may lead to leaks of the customer's personal data. So the account data is also **security relevant**. The system data mostly consists of queries. If one may gain access to the query, it is to alter the database. So this data is especially **security relevant**, because access to it may cause damage to the customer and the enterprise in the same scale.
At last, the product&sales data is not considered strictly security relevant, because in the sales process the payment process as we identify it is part of the customer data. This data becomes relevant in composite data types or if it allows tractability to customer data. Nonetheless, leak in this class may cause heavy damages to the respective enterprise, which is not in the scope of the thesis.

5.2.2.4. R4: roles

CoCoME defines six different roles. Five are defined in the CoCoME tech report [5]. These are the *Customer*, the *Cashier*, the *StoreManager*, the *Enterprise manager*, and the *Stockmanager*. The last role, the *Admin*, appears in the code. In the documentation, there is no separate description of the roles. All the responsibilities are derived from the use cases described in the documentation and/or the implementation. The key information we are looking for, are the tasks that a role performs in the context of CoCoME and which data is provided/required by the role.

- After analyzing the implementation, the *Customer* role is the role of all the customers of an enterprise, be they private customers or business customers. The role buys products, either in the stores or in the Pickup shop. The data provided by the customer role are the customer related data, It requires product related data to, for example, decide which products to buy.

- For the *Cashier* role, we rely on the defined use cases in CoCoME tech report. As shown, the role takes over the sale of products and therefore requires product &

sales data. The role provides product and sales-related data like the data that is generated when orders are placed.

- For the *StoreManager* role, we relied on the use cases. The *StoreManager* handles the tasks of a single store. The role provides and requires product& sales related data.
- After an analysis of the use cases, we are not sure what the concrete tasks are for the *EnterpriseManager* and the data requires requires or provide. There are only two uses cases that involves the *EnterpriseManager*, therefore a clear definition is not possible. Unfortunately, the code does not contain any further information. From the name it can be derived that the role is in charge of a whole enterprise.
- After analyzing the use cases, it is clear that the *StockManger* handles the stock of a single store. Therefore the role requires product&sales related data and provides the same type in the system.
- After analyzing the code we found a sixth role, the *Admin* role. This role is not mentioned in the use cases. From the name alone, we assume that this role keep a watch on the system. But use cases are missing and the implementation do not allow to define neither the tasks nor the provided/required data.

Since the hybrid cloud based variant is examined by us, all roles provide account data, because each role, in the hybrid cloud-based variant, needs an account in CoCoME to access the system.

5.2.2.5. R5: access rights

To define the access rights, we use the finer grained, high level from proposed by Evered and Bögeholz [4] in contrast to the well known read/write semantics for access control. Therefore, as described in chapter 4, it is defined for the data present in a component how which role can access it. We defined four different privilege level for the access to data, presented in the following enumeration. We used the elements from the previous requirements R2 (R2: Existence of use cases), R3 (R3: Security relevant data) and R4 (R4: roles) to derive the access rights for CoCoME. The access to data decreases with the ascending numbers.

1. **FullAccess**
   This access rights defines that the associated role has access to all data types for the respective class in the component.
2. **AccessToUsedData**
   This access right defines that the role has accessed to it used data types for the respective class in the component. Used data in this context means the data types that are required by the role to perform its defined tasks.
3. **AccessToOwnedData**
   This access right defines that the associated role has access to its , for example, own account data or customer data. This access rights ensures that roles may access data that is provided by it but not necessarily needed for their tasks.

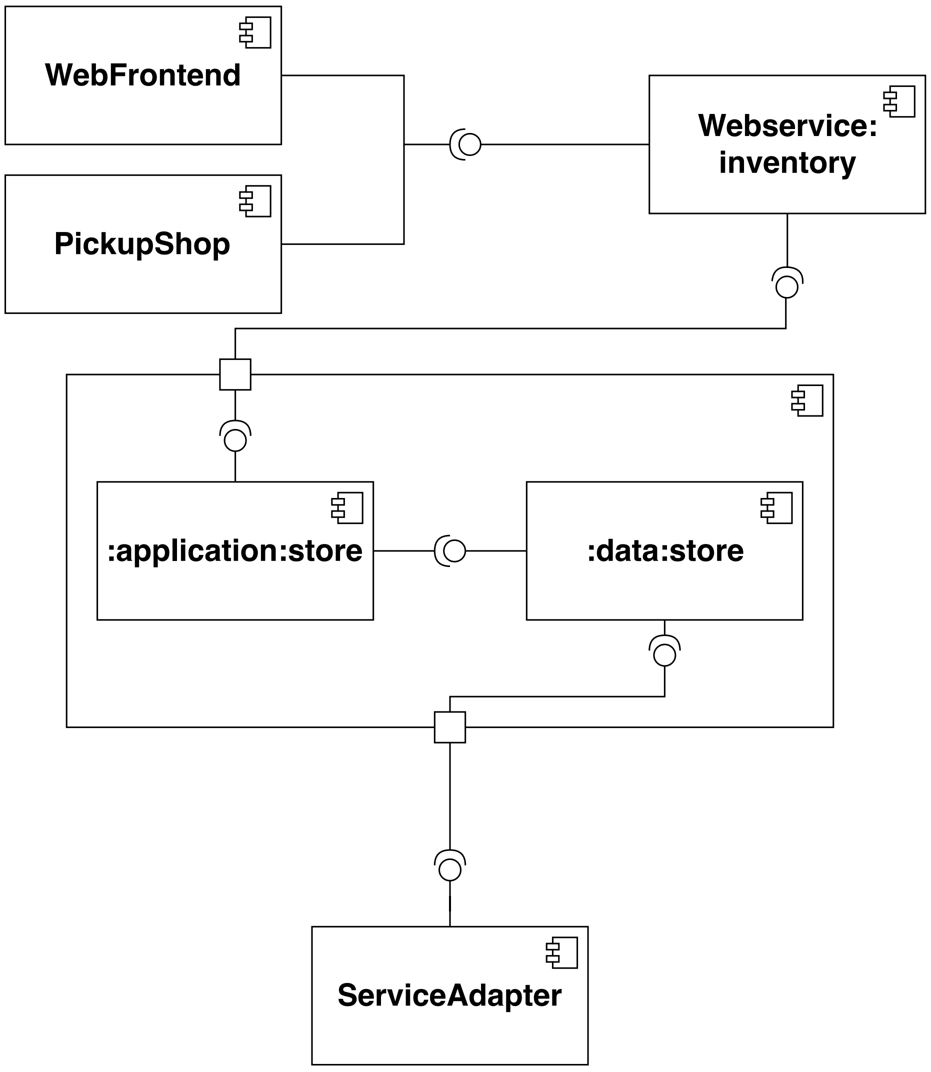


Figure 5.2.: The figure shows an simplified overview of the CoCoME. The Webservice component is omitted.

4. **Default** This access right forbids the complete access to all data in a class for this role and component.

Another part of this requirement is the identification of the present data types in each component. After analyzing the code and the CoCoME tech report, we identified data for each class of data in each component. Also we identified that no role except the *customer* may access the *PickupShop* component. A reduced system model is displayed in Figure 5.2. As already mentioned in section 5.1, it is only possible for individual users to interact with CoCoME via the components *Webfrontend* and *PickupShop*. No role except the admin has direct access to the *Tradingsystem:inventory* component in which the data is processed. Therefore, all access rights to data are cascaded for the individual roles (except the admin). This ensures that it is always visible which role receives which data or has provided which data.
For the fact that the ACM in Table 5.2.2.5 is rather large and complex, we only point out

the most important points. We omitted the *Webservice* component, as it only transmits data between the user interface and the *Tradingsystem:inventory* and therefore has no effect on the data. As stated before, only the *customer* may access the *PickupShop*, therefore no other role may access the data in this component. For the *Admin* it is not clear if the role may access data. Also, the *Admin* it the only role that may access *system* data. The *StockManager* has access to customer data due to the use cases. In

ACM	Webfrontend		PickupShop		TS:inventory data		TS:inventory application	
Customer	customer data	3	customer data	3	customer data	3	customer data	3
	account data	3	account data	3	account data	3	account data	3
	p&s data	3	p&s data	3	p&s data	3	p&s data	3
	system data	4	system data	4	system data	4	system data	4
Cashier	customer data	3	customer data	4	customer data	3	customer data	3
	account data	3	account data	4	account data	3	account data	3
	p&s data	2	p&s data	4	p&s data	2	p&s data	2
	system data	4	system data	4	system data	4	system data	4
StockManager	customer data	2	customer data	4	customer data	4	customer data	2
	account data	3	account data	4	account data	4	account data	3
	p&s data	2	p&s data	4	p&s data	4	p&s data	2
	system data	4	system data	4	system data	4	system data	4
EnterpriseManager	customer data	2	customer data	2	customer data	2	customer data	2
	account data	2	account data	2	account data	2	account data	2
	p&s data	2	p&s data	2	p&s data	2	p&s data	2
	system data	2	system data	2	system data	2	system data	2
StoreManager	customer data	2	customer data	4	customer data	2	customer data	2
	account data	3	account data	4	account data	3	account data	3
	p&s data	2	p&s data	4	p&s data	2	p&s data	2
	system data	4	system data	4	system data	4	system data	4
Admin	customer data	?	customer data	?	customer data	1	customer data	1
	account data	?	account data	?	account data	1	account data	1
	p&s data	?	p&s data	?	p&s data	1	p&s data	1
	system data	1	system data	1	system data	1	system data	1

Table 5.2.: The ACM of CoCoME. The legend for the ACM is: 1 is the access right *FullAccess*, 2 is the access right *AccessToUsedData*, 3 is the access right *AccessToOwnedData*, 4 is the access right *Default*. The abbreviation *p&s data* stands for product&sales data.

5.2.2.6. R6: Type of data processing in components

The last requirement defines the different types how data is processed in CoCoME. For each component, it is defined how the data from the different data classes is processed in this specific component. To identify the different types of processing we analyzed the code and the use cases. All in all, we defined four different classes how data is processed in CoCoME. Each class may consists of various operations.

- relational algebra
  This type describes the operations of relational algebra on a database or similar construct. For example, if all elements of a list that have a particular ID are selected from this list.
- transmission of data
  This type describes the transmission of data between components.
- alternation of data
  This type includes the most operations. It describes each operation that changes the data class. Good examples are the creation of lists or the merging two or more data classes into one.
- I/O related processing
  This type describes the user interaction with CoCoME.

After the different classes of data processing are identified, we analyzed how which data is processed in each component. The respective type(s) of data processing are assigned to the respective components. The result is shown in Table 5.3.
System data is not available in any other component other than *Tradingssystem:inventory:data*, because in this component queries are created. The *Webservice* component only transmit data to other components. The *PickupShop* and *Webfrontend* transmits the *customer* and *account* data. In these to components the user interfaces are located and customer, for example, fill their shopping cart, therefore *products&sales* data is processed with the *I/O* processing.

5.2.3. P3: Check the fulfillment of the requirements

Once the system parts for each requirement have been identified, defined or derived, a brief check is made to ensure that each requirement has been met. For each requirement it is checked whether the individual system elements are complete. It is possible that some definitions are vague or missing. Vague means that there is room for interpretation or that different definitions contradict each other.
In the following, we analyzed the fulfillment for each individual requirement.

5.2.3.1. R1: component-based systems

This requirement is fulfilled, a very detailed component for CoCoME is provided [5].

Types of data processing	Customer data	Account data	Product&sales data	System data
Webfrontend	transmit	transmit	I/O-processing transmit	non-existent
PickupShop	transmit	transmit	I/O-processing, transmit	non-existent
Tradingsystem: inventory: application	change transmit	alter transmit	alter	non-existent
Tradingsystem: inventory:data	relational algebra operations	relational algebra operations	relational algebra operations	alter
Webservice	transmit	transmit	transmit	transmit

Table 5.3.: Overview of the different types of data processing in the components. For each component, it is defined how which data class can be processed.

5.2.3.2. R2: use cases

A detailed use case diagram with a brief description of each use case is provided in the CoCoME tech report [5]. All in all, 13 use cases are defined, which cover the main aspects of CoCoME.

5.2.3.3. R3: security relevant data

In the definition of the data, a lot of data is already defined by the implementation. Nonetheless, some data mentioned in the use cases is missing. We identified in the investigated excerpt two missing data types. First, there is no connection defined between the customer and the purchased products. Secondly, the *Report* data type mentioned in the use cases is also not defined.

5.2.3.4. R4: definition of roles

For some roles the actual tasks are not clear because some use cases contradict each other. Further, for the *EnterpriseManager* there are too few use cases to clearly define the tasks. For the *Admin* role use cases are completely missing, because this role is only present in the code.

5.2.3.5. R5: definition of access rights

In the case of the access rights we cannot say in general if they are fulfilled, because the access rights are derived from the previous requirements R1-R4. If there are changes in R1-R4, the defined access rights have to be reviewed and if necessary updated. Nonetheless, in the case *Admin* the tasks for this role are not clear, therefore it was not possible to derive access rights in some cases.

5.2.3.6. R6: types of data processing in the components

This requirement is adjacent to R5: definiton of the access rights. The different types of data processing are derived from the previous requirements R1-R4. If there are changes in R1-R4, the different types of data processing have to be reviewed and if necessary updated.

5.2.4. P4: Define system extensions

In the next step, we define system extensions for CoCoME to fix all shortcomings for the requirements. In the previous step all shortcomings were summarized. In the following, we give an overview how CoCoME was extended to meet all requirements.

R1: component-based system Here, no extensions was needed, because this requirement is met.

R2: definition of use cases Also, no need to define an extensions. This requirement is also met.

R3: security relevant data As identified previously in subsection 5.2.3, two data types are missing. First, there are no connection defined between a customer and its purchased products. Secondly, the *Report* data type is only mentioned but is not defined.

- Connection between customer and purchased products
  We defined that the connection is realized by adding a list of all orders to the customer object. Each order in CoCoME includes the involved products and other information like the total price.

- Report data type
  We have defined this data type as a string that can be read by humans.

R4: definition of roles For the fourth requirement, two roles need a clearer definition: the *EnterpriseManager* and the *Admin*.In the case of the *EnterpriseManager* there are too few use cases are defined to clearly derive tasks for this role. In the case of the *Admin* there are no use cases defined. because this role only exists in the code.

- EnterpriseManager
  Due to the fact, that only one use case is defined for the *EnterpriseManager*, the actual tasks for this role are not clear. So determined that the role is in charge of a whole enterprise. For the fact that a *StockManager* manages the stock for each store, we defined the *EnterpriseManager* works on a larger scale. The role monitors the workflows within an enterprise and calculates forecasts for, for example, the CPU capacity required. Therefore, the *EnterpriseManager* provides product&sales data and requires customer data, account data and product&sales data. For the customer and account data, the role only requires meta data, like the number of registered accounts and therefore no explicit data.

- Admin
  The *Admin* has no use cases associated, so we relied on the implementation. In the implementation, the role has access to all data, so we defined the *Admin* to be the master role in the system, that has access to all data. With access to all data any small or big problems may be reviewed and fixed. Therefore the role provides and requires all data types.

R5: definition of access rights Since the previous requirements are fulfilled with the defined system extensions, in this step the ACM is reviewed and updated. The updated ACM is shown in Table 5.4. The entries that have changed since the old version are shown in bold. As before, the *Webservice* component is omitted.

ACM	Webfrontend		PickupShop		TS:inventory: data		TS:inventory: application	
Customer	customer data	3	customer data	3	customer data	3	customer data	3
	account data	3	account data	3	account data	3	account data	3
	p&s data	3	p&s data	3	p&s data	3	p&s data	3
	system data	4	system data	4	system data	4	system data	4
Cashier	customer data	3	customer data	4	customer data	3	customer data	3
	account data	3	account data	4	account data	3	account data	3
	p&s data	2	p&s data	4	p&s data	2	p&s data	2
	system data	4	system data	4	system data	4	system data	4
StockManager	**customer data**	**4**	customer data	4	customer data	4	**customer data**	**4**
	account data	3	account data	4	account data	4	account data	3
	p&s data	2	p&s data	4	p&s data	4	p&s data	2
	system data	4	system data	4	system data	4	system data	4
EnterpriseManager	**customer data**	**1**	**customer data**	**1**	**customer data**	**1**	**customer data**	**1**
	account data	**1**	**account data**	**1**	**account data**	**1**	**account data**	**1**
	p&s data	**1**	**p&s data**	**1**	**p&s data**	**1**	**p&s data**	**1**
	system data	**4**	**system data**	**4**	**system data**	**4**	**system data**	**4**
StoreManager	customer data	2	customer data	4	customer data	2	customer data	2
	account data	3	account data	4	account data	3	account data	3
	p&s data	2	p&s data	4	p&s data	2	p&s data	2
	system data	4	system data	4	system data	4	system data	4
Admin	**customer data**	**1**	**customer data**	**1**	customer data	1	customer data	1
	account data	**1**	**account data**	**1**	account data	1	account data	1
	p&s data	**1**	**p&s data**	**1**	p&s data	1	p&s data	1
	system data	1	system data	1	system data	1	system data	1

Table 5.4.: The updated Version of the ACM for CoCoME after the shortcomings are fixed. The legend for the ACM is: 1 is the access right *FullAccess*, 2 is the access right *AccessToUsedData*, 3 is the access right *AccessToOwnedData*, 4 is the access right *NoAccess*. The bold entries changed since the old version.

Figure 5.3.: GQM-plan for the evaluation of the defined access rights. The evaluation focus on the highlighted parts.

Access rights	
Specification	Aspect-oriented
	Positive
	Need-to-know
Comprehensibility	Clear
	Concise
Implementation	Fundamental
	Efficient

Table 5.5.: Classification of the criteria for good access rights.

R6: types of data processing in the components The different types of data processing are also derived from the requirements R1-R4. After reviewing the different types of data processing that were defined, there are no need to extend anything.

5.2.5. P5: Evaluation of the defined access rights

After all system extensions are done, in this step the defined access rights are evaluated. The evaluation follows a GQM-plan The GQM-plan for the evaluation of the access rights is shown in

5.2.5.1. Goal: Evaluation of the case study

The goal is to evaluate the case study. A shown in Figure 5.3 the evaluation of the case study is split into two parts. In this we will only focus on the highlighted plan, the evaluation of the access rights.

5.2.5.2. Question: Are the access rights well defined ?

Well defined access rights means in this context that the defined access rights meet the criteria defined by Evered and Bögeholz[4].The two authors defined seven different criteria. In order to ensure well defined access rights, the seven criteria should be met. The seven criteria are : Concise, clear, aspect-oriented, fundamental, positive, need-to-know and efficient. We categorized the criteria into three classes: specification, comprehensibility and implementation. The division of the individual criterion into categories is shown in Table 5.5. The criteria in the class *Specification* evaluate the properties of the defined access and the general access levels that that well defined access rights cover.
The criteria in the class*Comprehensibility* evaluates the complexity of the notation.
The criteria in the class *Implementation* evaluate the embedding of the access rights in the implementation.
It was possible to only evaluate three of the seven criteria due to various reasons. *Comprehensibility* criteria ware not possible due to time constraint. The criteria in this class are

Access rights		fulfilled?
Specification	Aspect-oriented	✓
	Positive	✓
	Need-to-know	✓
Comprehensibility	Clear	?
	Concise	?
Implementation	Fundamental	n/a
	Efficient	n/a

Table 5.6.: Summary for the evaluation of the defined access rights.

checked by conducting a survey. This was not possible in the time frame of this thesis. For the *Implementation* criteria an integration of the access rights into the implementation of CoCoME is needed. This implementation is missing, so it was also not possible to check this class.
The remaining criteria *Aspect-oriented*, *Positive* and *Need-to-know* located in the *Specification* class.
Aspect-oriented deswcribes, that the implementation and the access rights are sperate stored and define. This alloows that the implementation and the access rights can be used in different contexts. Further, both are easier to understand , if they are separated.
Positive describes, that the access to data have to explicitly given to the entities. The default level of access is *no access*. This avoid that access is implicitly granted.
Need-to-know describes, that well defined access rights only allow access to the absolute minimum of data that are used by the entities.

5.2.5.3. Metric Number of satisfied criteria

The evaluation is done in a checklist manner. For each criterion the defined access rights are evaluated whether they fulfill this criterion. The results of the metric are summarized in Table 5.6.

Aspect-oriented The access rights are stored separately from the code and even from the defined data flows. The access rights are changeable in the context of the case study. This allows that a scenario may be evaluated in different security contexts. So this criterion is met.

Positive The created case study achieves this criterion. First, granular access control rights have been defined. The access rights are differentiated in four different levels and each level represents fine grained access. We also defined a default value, which represents *no access* to data.

Need-to-know This criterion is achieved by the created case study. We split the data in four classes. For each component it is defined which role has access to which data. With this we can model, for example, that a role may access data in component A but not in component B. Further the differentiation in four levels allows, for example, to explicitly distinguish between access to data provided by that role and access to data that is not provided, but needed for the role's tasks. so this criteria is also met

Concise and clear Due to the time frame of the thesis, we could not make a qualified statement if these criteria are met.

Fundamental and Efficient Since access control is not yet part of the implementation, it was not possible to check it at all.

5.2.6. M1: Store the current state in a milestone

Before the current system state is saved in the milestone, one have to decide if the access rights are well defined. After that the milestone is created. The milestone stores for each requirement the necessary model elements.

Quality of access rights The defined access rights achieved all criteria that we were able to check. So we summarize that the defined access rights are for the moment well defined. So the procedure moves to the next step and the current system state is stored in a milestone.

Milestone For each requirement the associated system elements are stored.

- R1: The system model
  In this particular milestone, the system model from the CoCoME tech report [5] is stored.
- R2: Use case diagram, definition for each use case.
  In this particular milestone, the use case digram from the CoCoME tech report [5] is stored.
- R3: The data types and the examination, which data is security relevant.
  the four data classes ans the respective description of them are stored.
- R4: The different user roles
  The description of the tasks and the provided/required data for each role are stored. The *Admin* role is explicitly stored, because this role is not mentioned in the stored use case diagram.
- R5: The created ACM Table 5.4.
- R6: The created OpM Table 5.3.

6. Case study system

After we reached the milestone in the last chapter, we are going to define scenarios, evaluating the defined scenarios and concluding the procedure in this one.

6.1. P6: definition of scenarios

A scenario is a actual characteristics from, for example, a use case. But scenarios in general describe a actual interaction by one or more users with the system. This scenarios are later converted in data flows that are added to the system model. The scenario created by using the ACM Table 5.4 and the OpM Table 5.3. We defined two scenarios for CoCoME. The basic structure for each scenario is: First, the scenario is briefly described. Then the specific data types for the scenario are identified. We then describe the behavior of the individual components in a scenario. Finally, the resulting data flow is shown.
After the generated data flows have been added to the system model, they are evaluated based on the number of covered information flow classes.
Finally, it is checked whether the number of covered information flow classes are sufficient. Then the process is concluded.

6.1.1. Excerpt of the system

First of all, the excerpt where both scenarios are located is brifely presented. Both scenarios ar elocate din the *PickupShop* scenario from the CoCoME tech report [5]. In Figure 6.1 the excerpt of CoCoME is shown. The single roles access the system via the *Webfrontend* component. The *Webservice* component only transmits the data to the underlying *Tradingsystem:inventory* component. This component consists of two inner components. The *Tradingsystem:inventory:application* and the *Tradingsystem:inventory:data*. The *Tradingsystem:inventory:application* handles the alternation of data whereas the *Tradingsystem:inventory:data* manages the communication with the *ServiceAdapter*. The *ServiceAdapter* abstracts the underlying database.

6.1.2. Scenario: stock manager requests the report for a customer

6.1.3. Description

This scenario is derived from the use cases described in the CoCoME tech report [5], more explicit the use case 13.
In this scenario, the *StockManager* is already authenticated and then requests a report for the purchased products of a customer. To identify the customer among all customers, the

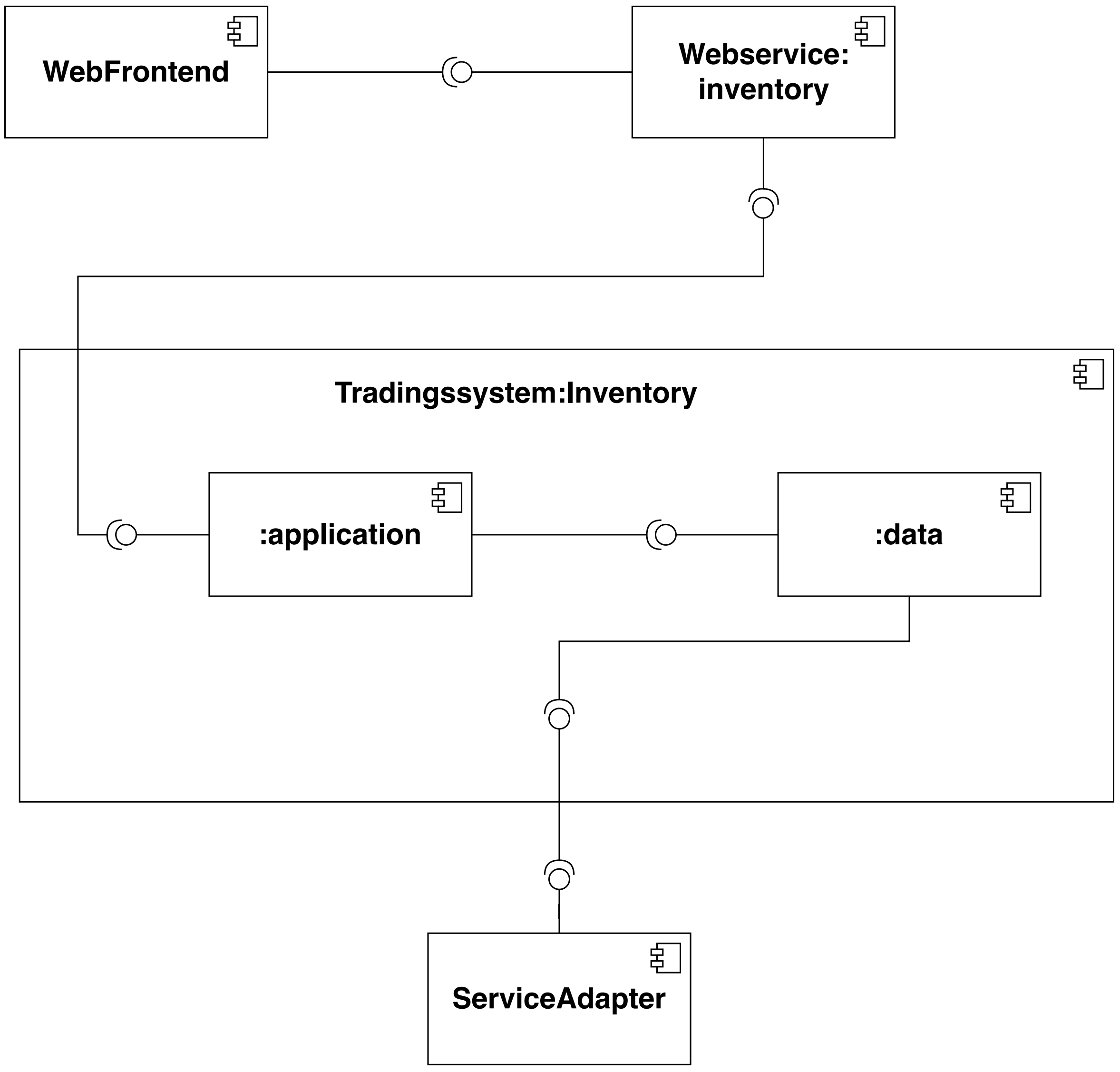


Figure 6.1.: Excerpt of CoCoME for which the described scenarios are defined.

ACM	Webfrontend	TS:inv:application:store	TS:inv:data:store
stockmanager	customer : 4	account : 3	account : 3
	account : 3	customer : 4	) customer : 4
	p&s : 2	product&sales : 2	product&sales : 2
	system : 4	system: 4	system : 4

Table 6.1.: An ACM showing the access rights for the case study system.

StockManager has access to the ID of the specific customer. The *StockManager* enters the ID in CoCoME, then the request is processed. At the end, the stock manager is presented with a full report for the customer. This report contains all purchased products of the customer.

6.1.3.1. Extract the data types, access rights and types of data processing for the scenario

In this section, we will first determine what actual data will be used in each component. Next, we obtain the corresponding parts of the two matrices for access rights (ACM) Table 5.4 and data processing (OpM) Table 5.3.
As stated in the milestone, the data is divided into four classes: customer data, account data, product&sales data and system data. In the following enumeration for each data class the used data in the scenario is described.

- account data
  No data from this class is used in this scenario.
- customer data
  The ID from the customer is part of the scenario.
- product&sales data
  In the scenario two data types are used. First, the *IOrderEntries* are used. The *IOrderEntries* are a collection of all data that is generated after an order successful passed. The second used data type is the *Report* data type, which is a human readable string.
- system data
  This class provides the data that is used to create the queries to the underlying database.

Int he next step, we extract the corresponding parts of the ACM and the OpM. The ACM for this scenario is shown in Table 6.1 and the OpM is shown in Table 6.2. We omitted the Webservice component for the fact that it only transmits the data.

6.1.3.2. Component behavior

The excerpt of the system model of CoCoME in which the scenario is located is extended with *operations*. For each component one or more operations are defined. These model

Types of data processing	customer data	p&s data	system data
Webfrontend	transmit	I/O operations, transmit	non-existent
TS:inv:application	alter, transmit	alter	non-existent
TS:inv:data	relational algebra	relational algebra	alter

Table 6.2.: A matrix showing the data processing for each component. the abbreviate p& s data stands for product and sales data.

the data processing in this component. An operation is associated with one of the data processing classes in the OpM Table 6.2. Each operation has one or more inputs and one more outputs. For each input and each output the data types are known.
First, we describe the observable behavior of the scenario across all components and the data processing for each component. All operations are then combined in a data flow.

Observable Behavior In the scenario, the *StockManager* interacts with CoCoME by requesting a report for a customer. In the following, the behavior of the system is described. The *StockManager* enters the *ID* of a customer through the *Webfrontend* into CoCoME. The *Webfrontend* processes the ID by transmitting it to the *Webservice* component, which also transmitting the *ID* to the *Tradingssystem:inventory* component. The *Tradingsystem:invetory* consists of two sub components. First, the *ID* is transmitted to the *Tradingsystem:inventory:application:store*, where it is further transmitted to the *Tradingsystem:inventory:data:store* component. In this component a *query* is created by using the *ID*. This query is then send to the *ServiceAdapter*, where the database is requested. The query first selects the respective customer for the *ID*. Then it projects all *IOrderEntries*. The *IOrderEntries* represents an order for a customer. In the *IOrderEntries*, beside other data, which occur with an order, the purchased products are included. The list of all *IOrderEntries* is then transmitted back to the *Tradingssystem:inventory:data:store* and then on to the *Tradingsystem:inventory:application:store*. In this component, the list is then processed in a *Report*. This *Report* is then transmitted via the *Webservice* back to the *Webfrontend*, where the result is shown to the *StockManager*. The resulting report contains a list of all purchased products. In addition, to each entry the date of purchase is added.

Data flow definition Once the general behavior of the scenario within the system has been described, the data flow is created. For each component, the operations and processed data that are used are identified and added to the current component. The operations are then linked in the correct order to complete the creation of the data flow.
The overview which data and which operations is shown in Table 6.3. In Table 6.3 the association between the components, the used operations and the data is shown. To give a brief explanation of how to read this table. In line 1, the *Webfrontend* only uses the operation **transmit** and data from a total of 2 classes, **customer** data and the **product&sales** data. From these classes the concrete data *ID* and *Report* are used.
The resulting data flow is shown in Figure 6.2.The data flow notation has been extended to include the corresponding component and operations for the processes. The data is still

Components	Operations	Data
Webfrontend	transmit	I: ID II: Report
Webservice	transmit	I: ID II: Report
TS:inv:data:store	rel. Algebra	IV: query
TS:inv:app:store	transmit alter data	I: ID II: List<IOrderEntries>

Table 6.3.: Overview over the used operations and the used data for the Scenario: StockManager requests a report for a customer.

on the edges. Also nothing has changed for the entities.
In this scenario a violation for the customer's privacy is displayed. According to the defined access rights tow violations are modeled. First, the *StockManager* should not have access to the *ID* of a customer. And secondly, the *Report* is in combination with the *ID* security relevant. This data flow should normally prohibited by the system.

6.1.4. Scenario: Support employee requests information for an order

This scenario was not defined on the basis of an use case. We defined this scenario for various reasons. First, we wanted to define a counterpart to the already existing scenario (subsection 6.1.2). The scenario is located in the same system part and therefore operates on the same components. The idea behind this is to provide a violation and a non-violation. An data-based privacy approach my be evaluated by checking if the violation and the non-violation is identified correctly. Due to the fact that CoCoME is a rather minimal system for the goal the system aims for, we couldn't find further use cases where multiple classes of data and/or multiple roles are involved.

6.1.4.1. Description

The fundamental setting of this scenario is that a customer has a problem with an issued order. To solve the problem, the customer authenticates himself in CoCoME and issues a ticket for the order. The support employee then request a report for the particular order from CoCoME. After the report is presented to the support employee, the scenario has ended. With the report at hand, the support employee should be able to solve the customer's issue.

6.1.4.2. Description of a new use case

We decided to add the scenario described in subsubsection 6.1.4.1 as a new use case to CoCoME. The embedding in the already present use cases can be seen in Figure 6.3. First we briefly describe the new role added to CoCoME, then the new use case is described.

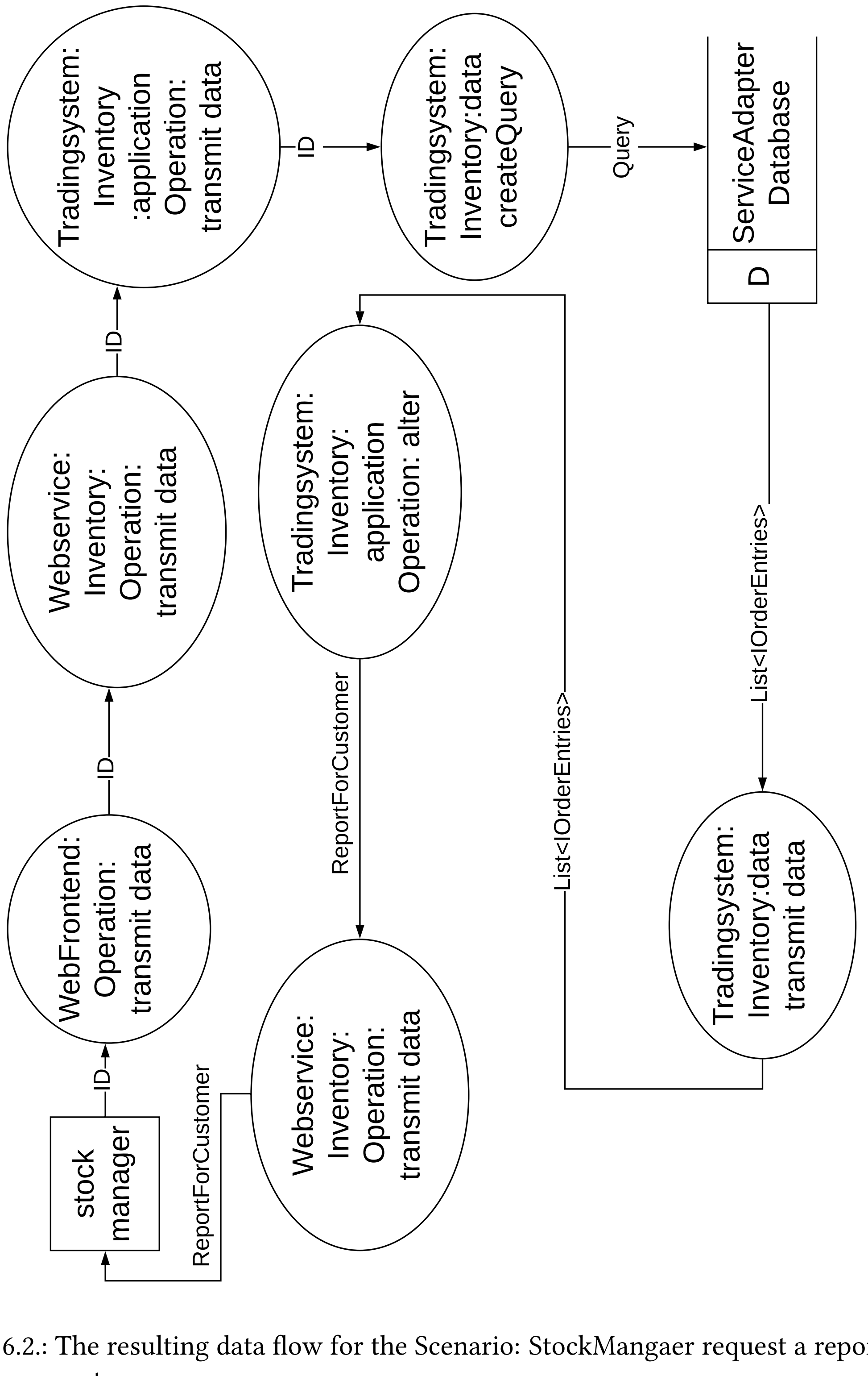

stock manager
ID
WebFrontend: Operation: transmit data
ID
Webservice: Inventory: Operation: transmit data
ID
Tradingsystem: Inventory :application Operation: transmit data
ID
Tradingsystem: Inventory:data createQuery
Query
D
ServiceAdapter Database
List<IOrderEntries>
Tradingsystem: Inventory:data transmit data
List<IOrderEntries>
Tradingsystem: Inventory: application Operation: alter
ReportForCustomer
Webservice: Inventory: Operation: transmit data
ReportForCustomer

Figure 6.2.: The resulting data flow for the Scenario: StockMangaer request a report for a customer.

Figure 6.3.: Use case diagram for CoCoME with the addition of the new use case.

ACM	Web-frontend	TS: inventory: app:store	TS: inventory data:store	Pickup Shop
suppEmp	account : 2 customer : 1 product& : 2 sales system : 4	account : 2 customer : 1 product& : 2 sales system : 4	account : 4 customer : 4 product& : 4 sales system : 4	account : 4 customer : 2 product& : 4 sales system : 4

Table 6.4.: Access right for the role *Support employee*. 1 refers to the access right *FullAccess*, 2 refers to the access right *AccessToUsedData*, 3 refers to the access right *AccessToOwnedData*, 4 refers to the access right *Default*. The abbreviate *suppEmp* refers to the role support employee.

Description the new role: Support employee The support employee role processes the tickets issued by customers. A ticket is issued if there are problems with an order. The support employee receives access to the order and checks their current status. Then he takes an appropriate action to solve the issue if possible. The actions are dependent on the actual order. They can reach from resending the order to taking no action, because the customer tries to scam the enterprise.

- **Role description**
  The support employee is a new role in the system, so we had to define the access rights for this role. It requires data beyond the data it owns itself, this includes customer and product & sales related data. The role may provide customer and product & sales related data. It may happen, for example, that an order is changed, because some products are not available and the customer decides to take a similar product. Also customer may used an invalid credit card in the order under investigation and the credit card details are changed.

- **access rights**
  From the description we derived the access rights shown in Table 6.1.4.2. To point out the important definitions. The support employee got no access to the Tradingsystem:cashdeskline, because for his tasks s/he does not need to. Also no access to system data as every role. At last no access to the customer related data in the PickupShop to verify , for example, the credit card details with the bank. We omitted the Tradingsystem:cashdeskline for space purposes

Description of use case 14

- *Brief Description* The system provides the possibility to generate a report for the current status of a customer's order.

- *Involved actors* customer, support employee

- *Precondition* the support employee is authenticated.
- *Trigger* the customer submits a ticket for a certain order.
- *Post condition* The report for the order was generated and is displayed to the support employee.
- *Standard process*
  1. The support employee enters the customers identifier and the report identifier to create the report.
  2. The report is generated and displayed
- Alternative or exceptional process
  - in step 2: the order doesn't exist
    The system sends an error message to the customer.
  - in step 3: order is ready
    the support employee sends a reminder to the customer to pick up the order.

6.1.4.3. Extract the data types, access rights and types of data processing for the scenario

In this section, we will first determine for the scenario what actual data will be used in each component. Next, we obtain the corresponding parts of the two matrices for access rights (ACM) Table 5.4 and data processing (OpM) Table 5.3.
As stated in the milestone, the data is divided into four classes: customer data, account data, product&sales data and system data. In the following enumeration for each data class the used data in the scenario is described.

- account data
  No data from this class is used in this scenario.
- customer data
  The ID from the customer is part of the scenario.
- product&sales data
  In the scenario two data types are used. First, the *IOrderEntries* are used. The *IOrderEntries* are a collection of all data that is generated after an order successful passed. The second used data type is the *Report* data type, which is a human readable string.
- system data
  In this class the data is located provides the queries to the underlying database.

Int he next step, we extract the corresponding parts of the ACM and the OpM. The ACM for this scenario is the same as defined in the new scenario and shown in Table 6.1.4.2, and the OpM is shown in Table 6.2. We omitted the Webservice component for the fact that it only transmits the data.

Types of data processing	customer data	p&s data	system data
Webfrontend	transmit	I/O operations, transmit	non-existent
TS:inv:application	alter, transmit	alter	non-existent
TS:inv:data	relational algebra	relational algebra	alter

Table 6.5.: A matrix showing the data processing for each component. The abbreviate p&s data stands for product and sales data.

6.1.4.4. Component behavior

The excerpt of CoCoME is extended with *operations*. For each component one or more operations are defined. These model the data processing in this component. An operation is associated with one of the data processing classes in the OpM Table 6.5. Each operation has one or more inputs and one more outputs. For each input and each output the data types are known.
First, we describe the observable behavior of the scenario across all components and the data processing for each component. All operations are then combined in a data flow.

Observable behavior In the scenario the *SupportEmployee* requests and receive a report for a specific order of a customer. In the following, the behavior of the system is described. The *SupportEmployee* enters the *ID* of the customer and the *ID* of the order. Then the tuple is transmitted via the *Webservice* component and the *Tradingsystem:inventory:application:store* component to the *Tradingsystem:inventory:data:store* component. In this component the tuple is utilizied to create a query that is transmitted to the *ServiceAdapter*. In this component the query is executed and the result is transmitted through the *Tradingsystem:inventory:data:store* component to the *Tradingsystem:inventory:application:store* component. There the result of the query is processed into a *Report*. This *Report* is then transmitted via the *Webservice* component to the *Webfrontend*, where it is shown to the *SupportEmployee*. The resulting report contains meta data in addition to the ordered products. This meta data includes, for example, delivery day, the used payment method, etc.

First the ID of the authenticated customer and the ID of the order are entered in the Webfrontend by the support employee. Then the tuple is transmitted through the Webservice to the Tradingsystem:inventory. The Tradingssystem:inventory consists out of two compoents. First, the Tradingssystem:inventory:application transmits the tuple to Tradingssystem:inventory:data, where the tuple stays for the time being. Then the whole database is selected. In the next step, a query is created by using the customer ID. Then the query is used to select the corresponding customer. Then order ID is used to build another query and select the corresponding order. The order and the customer data is passed to the Tradingsystem:inventory:application, where it is processed to create an report. This report contains meta data in addition to the ordered products. This meta data includes,for example , the day of delivery, the payment method used, etc. Then the report is transmitted via the Webservice component back to the Webfrontend. There the report is shown to the support employee.

Data flow definition Previously, the data was divided into equivalence classes. Now we present the concrete data to be used in this scenario and specify the corresponding classes.

- Webfrontend
  Transmit the (customer ID (customer data), order ID (product& sales related data)) tuple and the resulting report (product& sales related data).
- Tradingsystem:inventory:application
  Transmits the tuple and alters the Customer and Order object to a report and transmits it.
- Tradingsystem:inventory:data
  Transmit the Customer and Order object and takes the tuple to create two queries.

With these informations about the data processing, we are able to build the resulting data flow, which is shown in Figure 6.4.

6.2. P7: Evaluation of the scenarios

After all data flow are defined and added to the system, the second part of the evalaution for the case study is conducted in this section. The overview is shown in Figure 6.5.

6.2.1. Goal: Evaluation for the created case study

The goal is to evaluate the case study. As shown in Figure 6.5 the evaluation of the case study is split into two parts. In this we will only focus on the highlighted plan, the evaluation of the defined scenarios.

6.2.2. Question: Is the case study usable for a data-based privacy analysis?

To verify if the created case study are usable for the evaluation of a data-based privacy analysis, it is checked which information flow classes the created case study covers. We relied on the problem statement *Non-influence* [10]. Non-influence combines two sub problem statements, *Non-interference* and *Non-leakage*. Non-inference describes that no role may acquire information from a role that inherits a higher security level. In the course of a program flow, user with a high security level and user with low security level inserts data in the system and receive outputs from the system. If there is no interference in the system, inputs from high level user have no effect to the outputs of low level user. The effects of *Non-inteference* can be expressed by three information flow classes: **Illegal information flow**, **Direct information flow between roles** and **Information flow form high to low**.
Illegal information flow describes that a role can receive information for which it is not authorized.
Direct information flow describes the flow of information between two roles for which is not cleared to either receive or transmit.

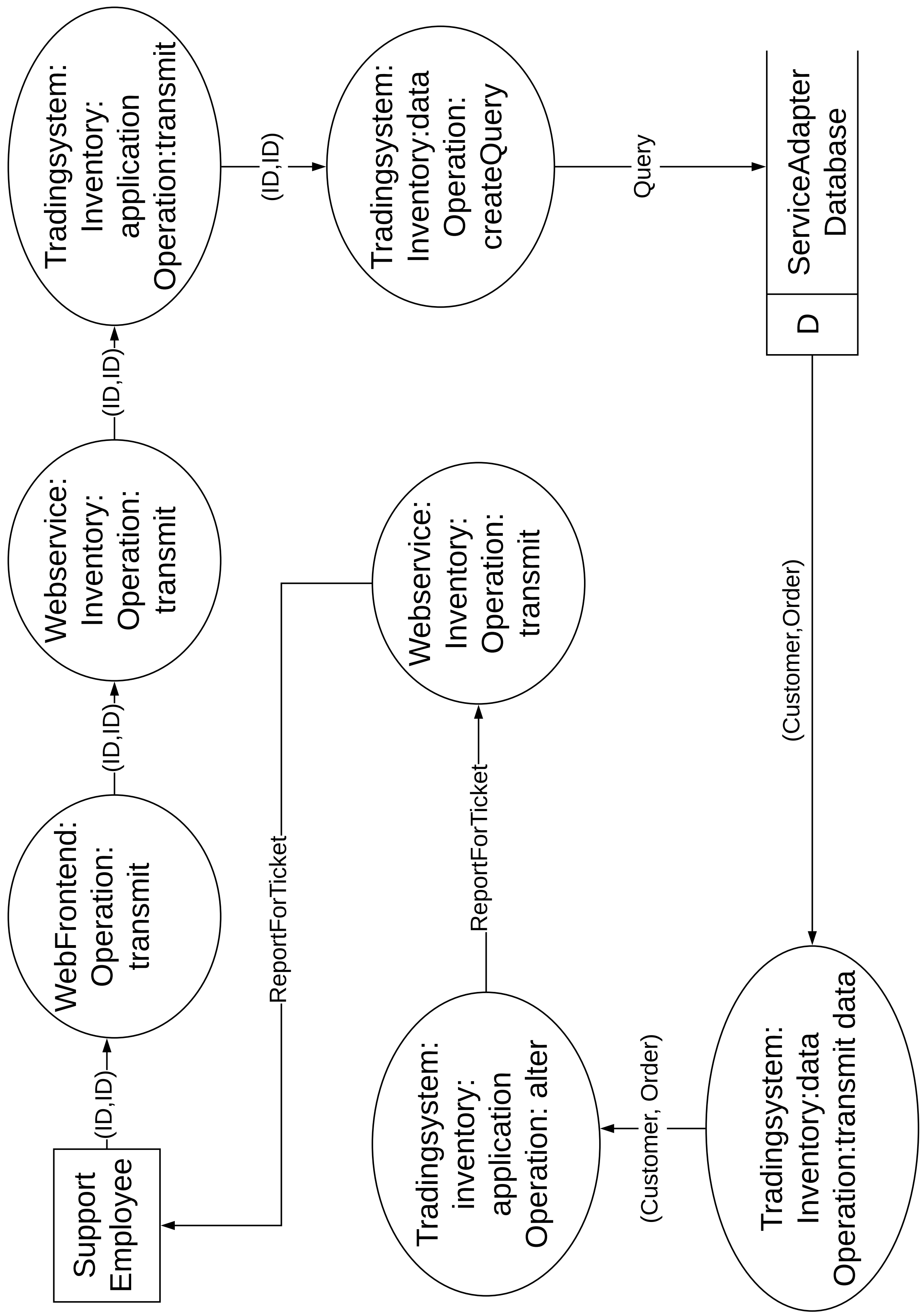

Support Employee
(ID,ID)
WebFrontend: Operation: transmit
(ID,ID)
Webservice: Inventory: Operation: transmit
(ID,ID)
Tradingsystem: Inventory: application Operation:transmit
(ID,ID)
Tradingsystem: Inventory:data Operation: createQuery
Query
D
ServiceAdapter Database
(Customer,Order)
Tradingsystem: Inventory:data Operation:transmit data
(Customer, Order)
Tradingsystem: inventory: application Operation: alter
ReportForTicket
Webservice: Inventory: Operation: transmit
ReportForTicket

Figure 6.4.: The resulting data flow for the scenario: Support employee requests information for an order.

Figure 6.5.: Overview for the evaluation for the Case study system

Data flow	fulfilled?
Illegal information flow	✓
Information flow from high to low	✓
Direct information flow between roles	✗
No observable information flow	✗

Table 6.6.: Resulting checklist for the evaluation of the case study.

Information from high to low describes flow of information, even if not intended, from a higher security level to a lower security level. *Non-leakage* describes the issue that it is not observable what specific actions are taken place by a system. This can be expressed by the information flow class **Observable information flow**.
The metric is the number of covered information flow classes in the case study. The evaluation is conducted in a checklist manner.

6.2.2.1. Number of different covered information flow classes

We evaluate the variety of covered information flow classes for the defined scenarios in the case study. We defined four information flow classes to cover *Non-influence*(*non-interference* + *non-leakage*. The covered information flow classes are: Illegal information flow, information flow from higher security levels to lower ones, observable information flow and direct information flow between roles. W

Illegal information flow The first scenario covers illegal data flow. The stock manager in this scenario has access to the *ID* of an customer. The role has no rights to have access *customer* data. Then, the stock manager request a report of this specific customer and receives a full report for this customer. The stock manager has the security level *AccessToUSedData*. The report for one customer is no necessary data for the stock manager to perform its tasks. In this scenario an illegal data flow is modeled. Therefore, the illegal data flow class is part of the created case study.

Information flow from high to low In the defined scenarios, for the role involved, data from different security levels is present. The data associated also flows to lower levels. This information flow class is also covered.

Direct information flow between roles For the fact that no scenario with more than one role is defined, this class is also not covered in the case study.

Observable information flow This information flow class is not modeled in the scenarios.

6.2.3. Conclusion

The last step of the procedure is to decide whether the procedure can be concluded. If the procedure cannot be concluded the procedure moves back to the P5. The decision is based on the covered information flow classes. After the evaluation in the access rights are already well defined. In this decision it is going to be decided if the covered information flow classes are sufficient for the objective to be achieved with the created case study.
For the created case study in chapter 5 and chapter 6, the answer is yes and no. The particular answer is heavily dependent on

Conclude the procedure The case study may be used for a data-based privacy analysis in the current state, because the defined access rights are evaluated. Some criteria were not possible to check, due to the scope of the thesis and a missing implementation. For this thesis, the access rights as well defined as it could be. Further, we covered two out of four defined information flow classes. Also, for the covered information flow classes a violation and a counterpart to the violating scenario is defined. This allows to evaluate a data-based privacy analysis (DBPA). The DBPA should recognize that one scenario is a violation and the other is not. This verifies if the DBPA works correctly.

The procedure may not be concluded Given the fact, that not all information flow classes are covered, we could say that the procedure cannot be concluded. We create qualitative data and therefore a not verified category may impact the outcome in a DBPA. The same goes for the access rights. Due to different constraint it was not possible to evaluate all criteria. A missing criteria may impact the outcome of the DBPA. Further, the case study is not created for the whole CoCoME system. This also limits the possible evaluations.

6.3. Discussion

In this section, we are going to discuss the single design decision that were made during the creation of the case study. The query is explicitly defined in the data flow diagrams. This representation was chosen, because, conceptual speaking, the changes in this process its class. With the changing of the class, the access rights may change. Therefore, the change is stored in the diagram. The second reason is, the query is explicitly defined, because of the representation of the data flow, as mentioned, differs from the described in chapter 2. The processes in the data flow store the component in which the data is processed and the operation with which the data is processed.

7. Evaluation

After we evaluated the created case study in chapter 5 and chapter 6, in this chapter the procedure (chapter 4) and the used modeling language (PCM [13]) are evaluated. The evaluation are also based on a GQM-plan section 2.5. The plan for the whole evaluation can be seen in Figure 7.1.
First, we conduct the evaluation for the applicability of the presente dprocedure, then the expressibility of the modleing language. Afterwards, we summarize the results for the created case study. To conclude the chapter, we discuss the *threats to validity* ([**TtoV**]).

7.1. Goal: Applicability of the introduced procedure

The first aspect we are evaluating is the applicability of the introduced procedure to create case studies from software systems. We evaluate the applicability to verify if its possible to create case studies that later may be used to evaluate approaches for a data-based privacy analysis. The examination if the quality of the created study is sufficient is a separate part and has to be done on a case-by-case basis.

7.1.1. Question: Is the introduced method applicable to an actual system?

To verify if the goal is achieved, we check if the introduced procedure is applicable to a software system that abstracts the selling process and warehousing of a supermarket group. The metric to answer the question is a successful application to an actual system.

7.1.1.1. Application to the CoCoME system

The system we chose to apply the method on is CoCoME. We applied the procedure not the whole CoCoME system but only to an excerpt of it. The application to the excerpt and resulting case studies is conducted in chapter 5 and chapter 6.
We successfully applied the procedure to an actual system and created a case study. Therefore, we conclude that the procedure is applicable.

7.2. Goal: Expressiveness of data-centric PCM

In this part, we evaluate the modeling language that is used for the case study. To model the case study, technically speaking, it have to be possible to add two extensions to the system model. First the data flows and ,Secondly ,the defined ACM.
We chose to use data-centric PCM as the modeling language By default it is not possible with data-centric PCM to extend models by data flows and an ACM. Therefore we went

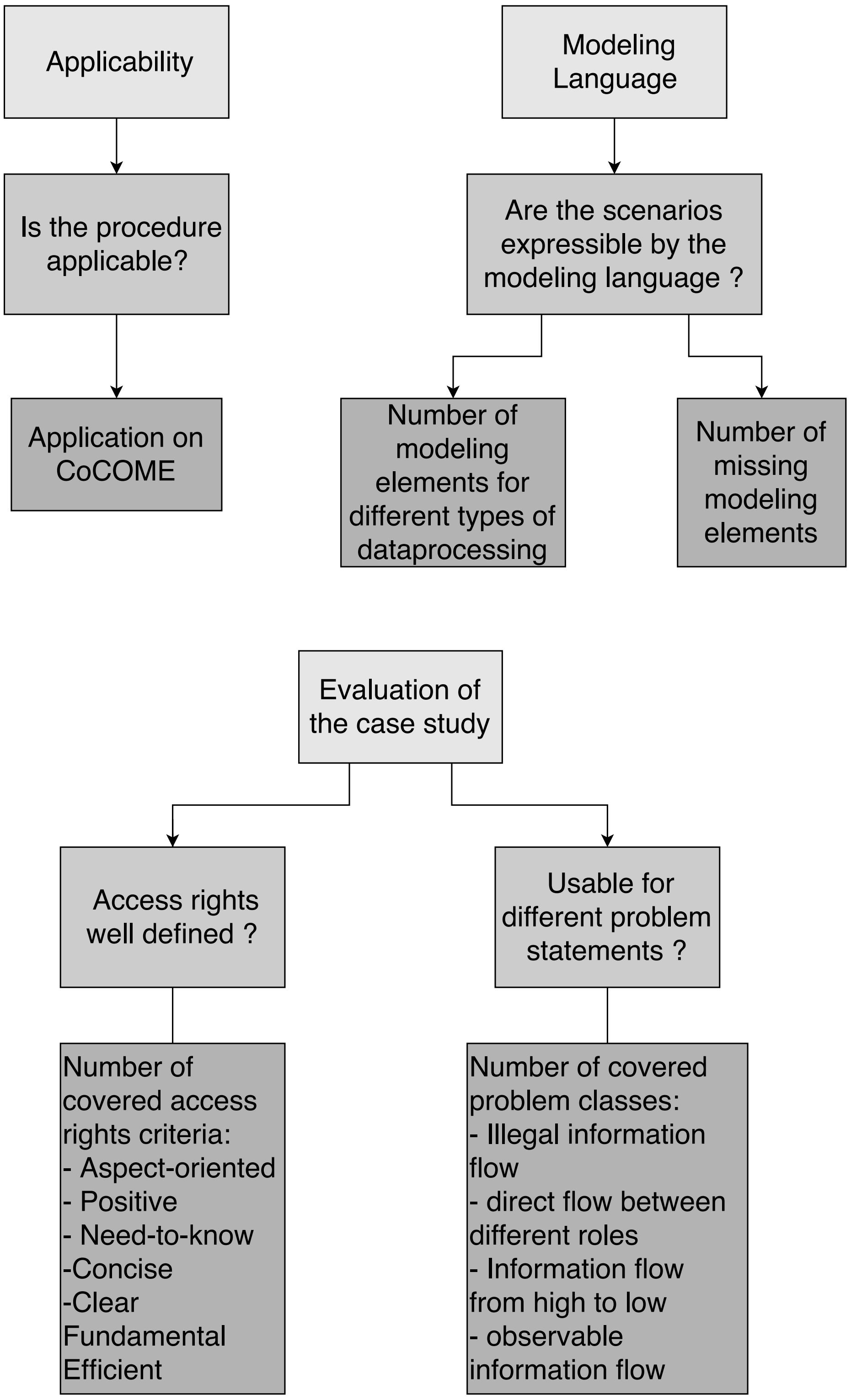

Applicability
Is the procedure applicable?
Application on CoCOME
Modeling Language
Are the scenarios expressible by the modeling language ?
Number of modeling elements for different types of dataprocessing
Number of missing modeling elements
Evaluation of the case study
Access rights well defined ?
Usable for different problem statements ?
Number of covered access rights criteria:
- Aspect-oriented
- Positive
- Need-to-know
-Concise
-Clear
Fundamental
Efficient
Number of covered problem classes:
- Illegal information flow
- direct flow between different roles
- Information flow from high to low
- observable information flow

Figure 7.1.: The GQM plan for the three parts of the evaluation. Each part is divided into

for the meta-model extension for data-centric PCM from Seifermann [16]. So, this part of the evaluation will mainly focus on the meta model extension for data-centric PCM.

7.2.1. Is the created case study expressible with data-centric PCM ?

To verify, if the case study is expressible with data-centric PCM, we ar eusijgn two metrics. First we measure which elements are available and then which elements are missing.

7.2.1.1. Number of available elements to model the different types of data processing

The main focus is to verify, if the created case study is expressible with data-centric PCM. We check if it is possible to model all defined operations in the OpM. This is also done in a checklist manner. We defined four operations for the case study in the OpM: transmission of data, alternation of data, operations for relational algebra and operations to model user interaction.

Transmission data This operation describes if components transmit data. An operation for this available in the meta model extension.

Alternation of data This is a larger type of operations. All in all, this type describes the alternation of data. This includes creation of data, merging many points in, for example, into list or set, the splitting of data, like lists, in the single data, etc. With the alternation of data it can happen that the class of data is changed and thus the applying access rights change. To describe the change of the applying access rights an operation is available in the meta model extension.

Operations relational algebra This type of data processing describes the manipulation of database or data requested from databases. The operations for this are available in the meta model extension.

I/O- operations Operations to model the user interactions are also available.

7.2.1.2. Number of missing elements for the different

Currently it is not possible to store the ACM in the same system model. It is possible to define access rights for each data in each component for each role. First, for each data a new access right has to be defined and , secondly, it is not or only with disproportionate effort possible to swap out the access rights or generating the ACM form the model. For the fact, we created our case study *aspect-oriented* (see []) the current modeling contradicts the concept. Therefore, a model element for the ACM is missing.

Meta model	possible ?
relational algebra	✓
I/O operations	✓
Transmission of data	✓
Change of access rights	✓
Alternation of data	✓
ACM in system model	✗

Table 7.1.: Summary for the evaluation for the modeling language.

Access rights		fulfilled?
Specification	Aspect-oriented	✓
	Positive	✓
	Need-to-know	✓
Comprehensibility	Clear	?
	Concise	?
Implementation	Fundamental	n/a
	Efficient	n/a

Table 7.2.: Summary for the evaluation of the defined access rights.

7.2.1.3. Summary: expressiveness of data-centric PCM

Now that the two metrics have been collected, we summarize them. The summary of the both metrics is shown in Table 7.1. As it is shown, the only flaw is that the ACM cannot be included in the system model.

7.3. Evaluation of the created case study

The evaluation of the created case study is split into two parts: the quality of the access rights and the covered information flow classes. Each part is already conducted in Here we shortly summarize the results of the single evaluations.

7.3.1. Access rights

Further details on this evaluation can be seen in Evered and Bögeholz [4]defined seven criteria to review the quality of defined access rights. All in all, the criteria can be divided in three categories: Specification, Comprehensibility and Implementation.
Specification criteria review the definition of the access rights. *Comprehensibility* criteria mainly reviews the notation and ho clear each is defined. *Implementation* criteria reviews the embedding of the access rights in the implementation.
The result of the evaluation are displayed in Table 7.2.

Data flow	fulfilled?
Illegal information flow	✓
Information flow from high to low	✓
Direct information flow between roles	✗
No observable information flow	✗

Table 7.3.: Summary for the evaluation of the covered information flow classes of the case study.

7.3.2. Covered information flow classes

Further details on this evaluation can be seen in Table 7.3. In the evaluation we examine which different information flows are covered by the created case study and may later be checked in a data-based privacy analysis. To define different information flow classes, we relied the problem statement *Non-influence* [10]. This problem statement includes four different information flow classes: illegal information flow, information flow from high to low, direct information flow between roles and observable information flow. The summary of the covered information flow classes is displayed in

7.3.3. Summary for the evaluation of the case study

We achieved to cover three out of seven criteria (43%) for good access right. The evaluation of the criteria in the *Comprehensibilty* class would have exceeded the scope of the thesis. So we cannot make a qualified statement for these criteria. The criteria associated with *Implementaation* class may be omitted in a purely conceptual case study. For instance, this may happen when a complete system is modeled but not implemented yet. We achieved all of the *Specification* criteria with our defined access rights.
All in all, we say the number of applicable criteria are dependent on the goal for that the specific case study is created.
We also achieved to cover 50% of the information flow classes. We coul not achieve to cover all classes due to time constraints of the thesis and therefore missing scenarios.

7.4. Threats to validity

In this section we discuss possible threats to the validity of the evaluation. The general description for this threats are published by Runeson and Höst [14] The possible threats are divided into four categories: internal validity, external validity, construct validity and conclusion validity.

Internal validity Internal validity describes if the evaluation supports the conclusion.

External validity External validity describes that the results can be generalized.

Internal Validity	External Validity	Construct Validity	Conclusion Validity
II, III	I	II	III

Table 7.4.: Threats to validity for the thesis.

Construct validity Construct validity describes that the measurements for the construct under investigation are correct. In particular, this means that the measurement is not influenced by other factors.

Conclusion validity Conclusion validity describes that evaluation is based on *reasonable* data, for instance statistical data, to minimize or eliminate the subjective view of the researcher.

7.4.1. Analysis of the evaluation

We analyze the three parts for the evaluation carried out and identified aspects that could pose a threat to the validity of the results. The aspects are: the procedure, the defined access rights and the covered information flow classes. In Table 7.4 a categorization for the aspects is shown.

I: Procedure The introduced procedure has only been applied to an excerpt of a system. This endangers the *external validity*. The procedure works for CoCoME but this cannot be ensured in general.

II: Access rights Three out of seven criteria were evaluated for different reasons. This could be a threat to the *Internal validity*. A case study generates qualitative data and therefore unchecked categories may backfire. So we could not say with certainty that our evaluation supports the results. Further, the

III: Information flow classes The information flow classes were defined based on one problem statement. Due to that fact, the information flow classes are a threat to the *conclusion validity* because the impact of the researcher. Other information flow classes could be defined which probably give more insights. Further, the *internal validity* is endangered. As with access rights, qualitative data is used and missing categories can alter the evaluation.

8. Conclusion and future work

As a conclusion, we shortly recapitulate each aspects presented in the previous chapters. At last, the future work is discussed.

8.1. Conclusion

The two main contributions of this thesis are a procedure for creating case studies and a case study created by using this procedure. First, The procedure allows to create case studies that later are used for evaluating data-based privacy analysis approaches. The resulting case study consists of two parts: first, the defined access rights and second, a system model extended with data flows. Then each part of the case study is evaluated. We used evaluation criteria to measure good access rights provided by Evered and Bögeholz [4] and the created data flows are evaluated based on the coverage of predefined information flow classes. Here we utilized the information flow classes that are covered by the problem statement *Non-influence* [10]. Secondly, an application to CoCoME was conducted. During the application process, we found vagueness in CoCoME. Another benefit of the procedure, beside the creation of a case study, is to detect vague definitions in the system and provide definitions for them . In CoCoME, the roles were rather well defined, but missed the last bit of precision. For instance, the role of the *StockManager* was mentioned, but there were too few system elements to derive exact tasks and the provided/required data. Also for some data used in CoCoME exact definitions were missing. After we added the definitions, scenarios were defined. From this scenarios the data flows that describe the data processing in CoCoME, were derived. Further, we define a new use case (UC14) for CoCoME. The UC14 introduces a new role, the support employee. When a user encounter problems with an order, they can issue a ticket. The support employee handles the tickets and solve the problem. At the end we evaluated the case study and discussed the findings. At last, we discussed if the procedure for creating a case study may be concluded. Finally, the applicability of the procedure and the expressiveness of the chosen modeling language were evaluated.
We discovered that the procedure is applicable for CoCoME and the meta model extension is able to express the data flows, but it is not possible to store an ACM in the same model. For the case study, we achieved to cover about 43% of the discussed access rights criteria and we covered 50% of the presented information flow classes. Note that, case studies are qualitative data and therefore the numbers does not matter that much. In the case of the access rights each missing category in the evaluation have an impact on the case study. The desired coverage of different information flow classes is dependent on the objective that is planned to achieve with the case study. Therefore, no generalized for the coverage of the information flow classes may be made.

At last, CoCoME was not the most fitting system for this thesis, but the only one available that is sufficiently documented. First of all, CoCoME is in constant development and therefore is more a proof of concept than a full system. In addition, CoCoME was a closed system before the *PickupShop* was introduced. There was only a limited number of users. Therefore the *PickupShop* is also the part of CoCoME that is relevant for a privacy analysis. Therefore we are only working on an excerpt from CoCoME.

8.2. Benefits of our work

As stated beforehand, the two contributions of this thesis are the procedure for creating case studies and an example case study created with the procedure.

Procedure The procedure was derived from the more general process described by Runeson and Höst [14]. We introduced a procedure that allows to create case studies usable for evaluating a data-based privacy analysis. In the procedure requirements for a system are defined. Further, for each of the two parts the evaluation is defined. The resulting case studies improve the process for evaluating data-based privacy analysis. With case studies created with a defined process the different evaluation of approaches may be evaluated and then compared.

Case study We applied the procedure and created a case study base don CoCoME. In this case study, we have shown how an ACM can be structured for component-based systems. The idea of the matrix was introduced by Evered and Bögeholz [4]. Also, CoCoME was extended to meet the necessary requirements for the creation of a case study. Therefore, we categorized the data, added definitions for the different roles and even added a new use case to CoCoME. Further, the system model were extended by the defined data flows. An important property of the defined data flows is that the data flows cover a violation of two information flow classes. A counterpart for the violation has also been defined. In an evaluation, this makes it possible to check a data-based approach. An approach should correctly categorize the violation and the counterpart. Also, the new definitions for CoCoME eliminate some vagueness in the system.

8.3. Future work

This section presents possible approaches for future work. The discussion of future work will be divided into the three main aspects of the thesis: the method for creating a case study, the resulting case study and its evaluation, and at last the used modeling language PCM..

8.3.1. Procedure

In the case of the procedure, we validated the applicability for an excerpt of CoCoME. The next step is to create a case study for the entire CoCoME system. Further, the approach should be applied to other systems covering areas other than CoCoME. A concrete example would be a travel system [8].

8.3.2. Case study system

For the case study, we decided to divide the future work in a short term and a long term work.

Short term work As short term work, one should define more scenarios. First, to cover all defined information flow classes. Also another possibility is to define scenarios that for each information flow class a violation and a counterpart is defined. Furthermore, a survey should be conducted to evaluate the access rights clear and concise. After the survey is done, the case study should be reviewed.

Long term work A long term work would be the addition of the access rights into the CoCoME implementation to allow an evaluation of the criteria *fundamental* and *efficient*. Further, additional information flow classes, that are not yet covered by *Non-influence* and define corresponding scenarios. At last, an evaluation for a data-based privacy approach should be conducted by using the case study.

8.3.3. Meta model extension

As future work, we propose to extend the meta model of PCM even further to allow the storage of the ACM in the same model to negate possible inconsistencies.

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A. Appendix

A.1. Git repository for the PCM models

Github URL for PCM models for the defined scenarios.

- **stock manager requests the report for a customer**
  Gihub URL: `https://github.com/julhin/DataProcessing/tree/dataprocessing_withoutAssemble`
- **Support employee requests information for an order**
  Github URL: `https://github.com/julhin/ModelsUC14`