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REPORT



Empirical Investigations of the CORAS Language for Structured Brainstorming

Experiment Material, Solutions

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Address: P.O.Box 124, Blindern
0314 Oslo NORWAY
Location: Forskningsveien 1
0373 Oslo
Telephone: +47 22 06 73 00
Fax: +47 22 06 73 50

Enterprise No.: NO 948 007 029 MVA

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Empirical Investigations of the CORAS Language for Structured Brainstorming

AUTHOR(S)

Ida Hogganvik, Ketil Stølen

CLIENT(S)

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ABSTRACT

Methods for security risk analysis are often based on structured brainstorming (e.g. what [20] calls HazOp). A structured brainstorming gathers a group of different system experts and the idea is that they will find more risks as a team than one-by-one.

The CORAS modeling language [19] has been designed to support the brainstorming and to document incident scenarios identified during these structured brainstorming sessions. The language is graphical, based upon the unified modeling language (UML) [21], and is recommended by OMG [9].

This paper reports the results from two experiments with the CORAS language and the lessons learned from these. The first experiment aimed to test the understanding of the language's internal conceptual model, while the second tested the graphical representation. The findings show that the interpretation of the conceptual model is a possible source for misunderstandings in a security analysis and we point out the ways to avoid this. The graphical icons in the CORAS language make model "navigation" faster, but the models are not necessarily understood more correctly than those without graphical icons.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Security risk analysis	Sikkerhetsanalyse
GROUP 2	Modeling language	Modelleringspråk
SELECTED BY AUTHOR	Empirical experiments	Empiriske eksperimenter
	Usability	Brukskvalitet

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1 Introduction

The participants in a structured brainstorming are system experts with different expertise. The idea is that the experts see the system from different viewpoints and therefore in collaboration will identify more risks than through individual expert judgments. The participants may have little or no previous experience with security risk analysis and therefore they need a common, intuitive way of documenting the security risk scenarios they identify. In the following we call security risk analysis just *security analysis*. The CORAS language [19] is a graphical modeling language that has been developed to support brainstorming and help document the results. The CORAS language was delivered within the EU project “CORAS” [3, 10, 12, 14-16] which gathered well known risk analysis techniques into one common methodology for security analysis. The CORAS language is built on UML [21] as a UML profile and is recommended by the international standardization consortium OMG [9].

The aim of this study is to investigate the usability of the CORAS language. We will look at both the conceptual model, on which the abstract syntax is based, and the external graphical representation.

The underlying conceptual model incorporates terminology from several relevant standards [1, 2, 4-8]. The abstract syntax of the CORAS language is based on this conceptual model for security analysis. Clearly, this model must be intuitive for the CORAS language to be successful during brainstorming sessions.

The external representation of the CORAS language is recognized by its special graphical icons that symbolizes the different terms in the conceptual model. The icons are believed to make the models easier to read and understand. Often graphical icons are seen as merely “decoration” just to make the models look nicer, but we believe that for people that are unfamiliar with system modeling, these icons help understanding the models.

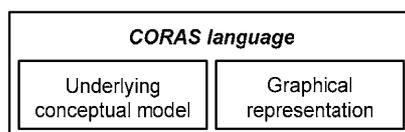


Figure 1 Components in the CORAS language

We report the results from two student experiments that have been conducted to investigate the issues discussed above. The first tested the understanding of the underlying conceptual model and showed that the interpretation of security analysis terms is influenced by how they are commonly used in daily language. The second experiment tested the use of graphical icons and the effect on the understandability of models. The icons were found to increase the speed of model navigation (i.e. identification of different elements), but not the correctness of model interpretation.

The paper is structured as follows: Section 2 provides an introduction to structured brainstorming and the CORAS language. Section 3 describes the design of the two experiments and Section 4 reports the results from statistical analyses. In Section 5 we

discuss these results and possible interpretations, Section 6 reports lessons learned and Section 7 concludes this report.

2 Structured brainstorming and the CORAS language

A structured brainstorming is a methodical assessment of a system where people with different roles and competence participate. Through discussion they identify risks and suggest treatments under the guidance of an analysis leader. The participants in a structured brainstorming need to have a clear understanding of the terminology the techniques is based on. Terms like frequency, probability, vulnerability and asset are commonly used, but the individual interpretation may differ depending on the background and experience of the person in question. Several of the concepts are commonly used in everyday language, but not with one unique context independent interpretation.

2.1 Structured brainstorming

The participants in a structured brainstorming are potentially anyone with an interest in the target system. The participants may be customer support personnel, system administrator, system developer, company security responsible or other roles. They receive no special training in advance, only an introduction in the beginning of the brainstorming session. We believe that if an analyst is not clear in what terms to use, and how to explain them, participants may be left confused and will not contribute optimally to the analysis. With this assumption in mind, we wanted to explore how people with software background and nearly no experience with security analysis interpret the most common concepts and relationships in the CORAS conceptual model.

2.2 The underlying conceptual model for the CORAS language

The most important terms of the CORAS conceptual model are: risk, unwanted incident, threat, vulnerability, treatment, consequence, frequency, asset, probability and stakeholder (**Figure 2**). The associations between the elements have cardinalities that say how many instances of one element can be related to one instance of the other. Example: “a stakeholder has at least one and maximum infinite assets; and an asset belongs to only one stakeholder”.

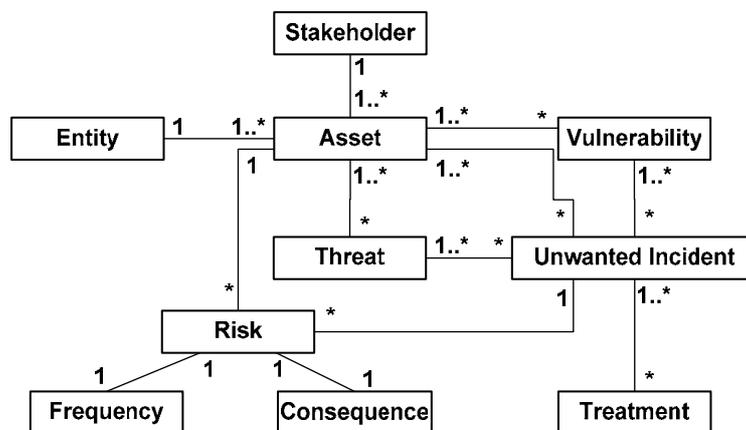


Figure 2 The CORAS conceptual model of security analysis terms

Originally **Figure 2** was not designed to be “stand-alone” model with a unique association line for every possible relation between the risk analysis terms. The

understanding of the figure also relies on a textual description. We explain **Figure 2** as follows: the system or part of a system, assessed during a security analysis is called the **target of evaluation**. Everyone with interests in the target is **stakeholders** of the system. System users, system maintainers and system developers are typical stakeholders. Different stakeholders often value the system differently; a system user who is dependent on the system will put a high value on it, while other stakeholders might not value the system equally high. The same **entity** may be assigned different values by different stakeholders. We refer to these entities with their values as assets. An **asset** is something to which a stakeholder directly assigns value and, hence, for which the stakeholder requires protection. An asset is therefore uniquely linked to a single stakeholder. A stakeholder wants to protect his/her assets from losing value. Examples of assets are customer information, source code, company routines, critical system services etc. Target system stakeholders and their assets are normally identified early in the security analysis process. Figure 1 includes four important security analysis concepts related to asset: vulnerability, unwanted incident, threat and risk. A **vulnerability** is a weakness or lack, making an asset vulnerable to harmful actions. One may understand a vulnerability as something that is missing, e.g. if a company network lacks a firewall then this may be a vulnerability with respect to some assets in the network. An **unwanted incident** is an event that may harm the asset and something we want to prevent. An unwanted incident is the result of a threat exploiting a vulnerability. If the company network is an asset, then an unwanted incident is unauthorized access to the network by intruders. A **threat** is someone or something that wants to destroy, remove or interfere with the asset and a risk is the chance of this happening. With respect to the already mentioned company network a threat may be a person who knows or discovers the vulnerability and wants to exploit it. First the company does not recognize the situation as a potential risk because nobody outside the company is aware of the security hole, but when an employee is fired, they suddenly realize that there is a risk for unauthorized network access by people familiar with the company infrastructure. The risk is characterized by a **risk value** (e.g. low, medium, high or other scales) which is based upon the estimated **frequency** for it to happen and its **consequence** in loss of asset value. If a risk is estimated to occur two times a year and the consequence is a loss of 200000 dollars each time, the risk value could be “high” which means the risk should be treated. The **treatment** is applied either to the unwanted incident, the threat or the asset’s vulnerability and the desired effect is reduced frequency and/or consequence, i.e. a reduced risk value.

2.3 Stereotyping with graphical icons in the CORAS language

A security risk scenario will typically illustrate how unwanted incidents relate to assets and treatments, it illustrates the threats and how they through various threat scenarios can harm the assets. A security risk scenario shows associations and relationships that are infeasible to describe with text only. To make the scenarios easier to read, the concepts in the CORAS language are stereotyped with special icons and text-labels as illustrated in **Figure 3**. Stereotyping is a technique in UML that lets you mark normal UML elements with “labels” to emphasize that they are of a certain type, for more about this we refer to [11, 21]. Our focus is mainly on the graphical icon stereotyping and less on the stereotype name. We are not aware of other experiments with UML stereotyping, focusing on understanding, than [18]. The

results from this experiment showed that icon stereotyping makes the models easier and faster to understand. The treatment, unwanted incident and the threat scenario are all special cases of a UML use case, and the asset and threat (here: “attacker”) are UML actors. In our setting this implies that a risk scenario without icons will use normal UML symbols for use case and actor, illustrated in **Figure 4**.

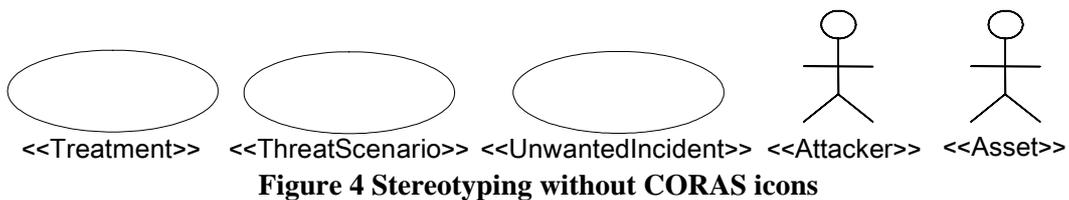
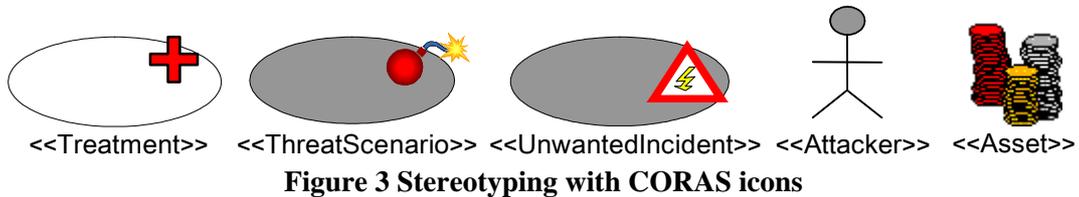
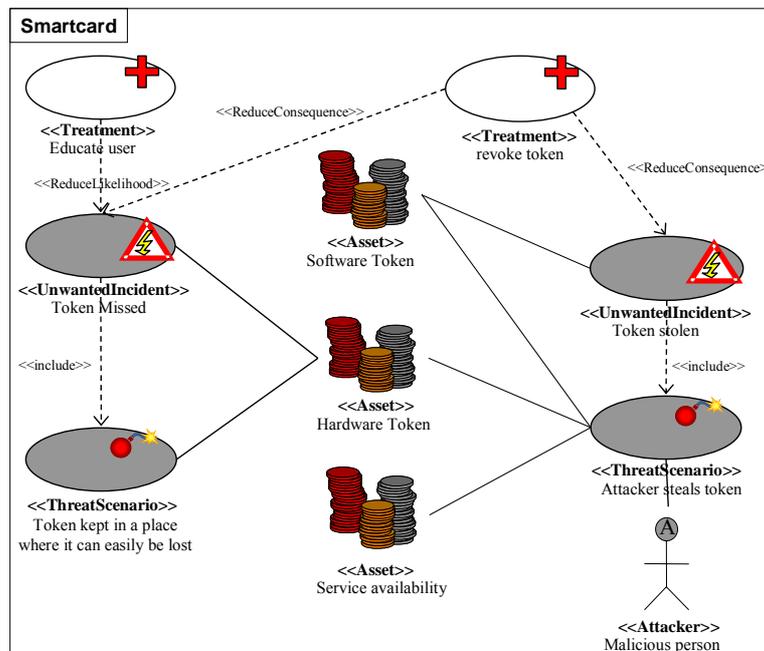


Figure 5 illustrates one of the risk scenarios that were used as material in our icon experiment. The model illustrates three assets (software token, hardware token and service availability) associated with two unwanted incidents (token stolen and token missed) and two ways this can happen (the two threat scenarios). One of the threat scenarios is initiated by an attacker (malicious person). Two treatments are identified, “educate user” will reduce the likelihood for token missed and “revoke token” will reduce the consequence of both token missed and token stolen.



3 Description of the two experiments

The experiments were conducted during the lectures in a university course at the institute for informatics, University of Oslo. The course has focus on a theoretic foundation for UML, refinement concepts in a UML context, modularity through contract-oriented specifications and model-based security analysis. The purposes of the experiments were:

- Terminology experiment: to explore the comprehension of risk terms taken from the underlying conceptual model of the CORAS language.
- Icon experiment: to investigate the effect of the graphical stereotyping used by the CORAS language.

3.1 Material for the terminology experiment

The terminology experiment material was a questionnaire with 20 short statements. Each covered the relationship between 2-4 security analysis concepts that was either correct or incorrect. In addition to judging the statement, the subjects were asked to give a short explanation for their answer. The first section of the questionnaire asked some demographic questions about the subject's background and personal perception of the topic that should help us interpret the results from the analysis. We asked if they:

- had attended the previous lesson about security analysis (attendance is voluntarily)
- feel the concepts are difficult to understand
- believe security analysis is useful
- think they understand the concepts well

To ensure that the questionnaire was completed on time, the subjects had to "tic off" an answer alternative for all the statements before writing their explanations. The questionnaire is presented in **Table 1** and had three different answer alternatives: "correct", "wrong" and "I don't know" (the original is in Norwegian):

Table 1 Terminology questionnaire

<p>1. An unwanted incident can initiate new unwanted incidents by exploiting new vulnerabilities (correct).</p> <p>2. A treatment will eliminate at least one unwanted incident (wrong).</p> <p>3. The purpose of a treatment is to reduce risk, not necessary reduce vulnerability (correct).</p> <p>4. An unwanted incident consists of consequence, frequency and a risk (wrong).</p> <p>5. A treatment is always directed towards a vulnerability (wrong).</p> <p>6. A threat is something that can initiate an unwanted incident (correct).</p> <p>7. A risk is related to an asset's vulnerability (correct).</p> <p>8. A threat can create a risk (correct).</p> <p>9. There has to exist a threat before one think of an unwanted incident as a risk (correct).</p> <p>10. A risk is something that will reduce the value of an asset (correct).</p> <p>11. A vulnerability is the same as a risk (wrong).</p> <p>12. A threat is something that has a potential to reduce the value of an asset (correct).</p> <p>13. An unwanted incident cannot consist of multiple unwanted incidents (wrong).</p> <p>14. An entity without value can also be considered as an asset (wrong).</p> <p>15. A treatment can be directed towards a threat (correct).</p> <p>16. A stakeholder is someone that wants to protect his or her assets (correct).</p> <p>17. A threat can exploit a vulnerability (correct).</p>
--

18. A successful treatment must reduce both consequence and frequency (wrong).
 19. A risk and an unwanted incident is the same (wrong).
 20. One has to know both probability and frequency to calculate the risk value (wrong).

A challenge in designing the questionnaire was which concepts to include, and which relationships to test. We selected 10 of the most common security analysis terms from CORAS' conceptual model in addition to "probability" which is commonly used to describe one kind of frequency. Some concepts are associated with more concepts than others, and this is reflected in the number of times they appear in different statements in the questionnaire (see also **Figure 8**). E.g. the term "risk" is included in more statements than "frequency" since it is associated with more concepts. The CORAS conceptual model (**Figure 2**) displays only the most common relations between its terms, but there are other possible relations which we aim to capture in our experiment illustrated in **Figure 6**.

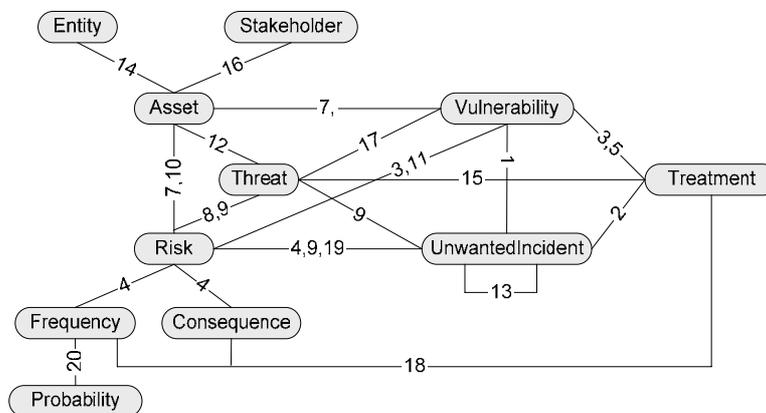


Figure 6 Relations covered by the questionnaire

3.2 Material for the icon experiment

The icon experiment material was a set of security risk scenarios modeled with the CORAS language (example in **Figure 5**) and a related questionnaire. The diagrams were taken from a report on security threat modeling project resulting from a research collaboration between Microsoft Research in Belgium and SINTEF ICT [13]. The questions focused on general understanding of notation making domain knowledge less important. Nevertheless, the models we used illustrated general security issues related to smartcard (credit card sized storage medium) and web services (software that makes itself available over the Internet using standardized XML) that could be known to some of the students.

Half of the subjects received models stereotyped with both CORAS icons and stereotype names while the other half had standard UML use case icons and stereotype names. The questions were the same for both groups. This experiment did not test stereotyping in general since we kept the stereotype name, but rather the graphical icon stereotyping.

The questionnaire was divided into three parts:

Table 2 Experiment material

	Max time	Type of task	# Models, # Questions	Max score	Variables measured
Part 1	3 min	Training task for model navigation	1 model, 7 questions	7p	Score, # questions answered
Part 2	1.5 min	Model navigation	1 model, 10 questions	10p	Score, # questions answered
Part 3	15 min	Model understanding	3 models, 11 (4+5+2) questions	11p	Score, # questions answered, time used pr. model

Part 1 and 2 had questions that tested whether the subjects were able to quickly identify specific elements like treatment, risk, threat agent etc in a model (model navigation). The questions were of the type “*How many assets are explicitly modeled in this diagram?*” Part 3 focused on how the models were understood and interpreted. An example of the type of question used here is “*Which unwanted incidents affect the asset “Web server” in this model?*” Since part 3 included three different sets of models with belonging questions, the students had to record the start time on each of the sets to make us able to analyze the time spent (in minutes) on each sets.

3.3 Execution and practical considerations

The master students attending the experiments had not been given information in advance since they were executed as exercises during the lessons. At this level of education it is natural to assume that the students know some UML.

For the terminology experiment, we faced the situation that the subjects’ previous knowledge about security analysis could vary from 0-4 hours. We believed this could influence the result and therefore we asked about this in one of the demographic questions. A short introduction to the type of task was given and the students were given 20 minutes to fill in the questionnaire.

The icon experiment took place in the same setting two weeks later. The lesson before the experiment the students had a 45 min introduction to the CORAS language. Also in a real structured brainstorming the participants will be given an introduction to the notation in advance, but then considerably shorter. The questionnaires were handed out in a randomized manner, 13 subjects received questionnaires with CORAS icons and 12 received the one with standard UML use case icons.

3.4 Analysis models

The two experiments measured different variables, and had therefore different analysis models. In the terminology experiment we measured score for each statement looking for particular easy or difficult concept-relationships.

The icon experiment measured both score and time used per question /number of questions accomplished. The two groups of subjects were compared to see whether the one with CORAS icons had a higher score than the group without. In the same manner we analyzed whether one group managed to complete more questions than the other group or used less time pr. model-question-set. Since the sample set was expected to be relatively small and possible not normally distributed, we chose to use a one-tailed, non-parametric Mann-Whitney test with alpha level = 0.05.

4 Results from the two experiments

4.1 Descriptive statistics from the terminology experiment

We had 31 subjects in the experiment. The shaded numbers in the table indicates statements that obtained a high percentage of either “correct answers”, “incorrect answers” or “I don’t know answers”.

Table 3 Descriptive statistics of the statements

Statement (terms used)	Correct answers		Incorrect answers		"I don't know" answers	
	#	%	#	%	#	%
1 (unwanted incident, vulnerability)	23	74.2	3	9.7	5	16.1
2 (treatment, unwanted incident)	12	38.7	16	51.6	3	9.7
3 (treatment, risk, vulnerability)	20	64.5	9	29.0	2	6.5
4 (unwanted incident, consequence, frequency, risk)	9	29.0	19	61.3	3	9.7
5 (treatment, vulnerability)	14	45.2	9	29.0	8	25.8
6 (threat, unwanted incident)	25	80.6	3	9.7	3	9.7
7 (risk, asset, vulnerability)	23	74.2	4	12.9	4	12.9
8 (threat, risk)	19	61.3	8	25.8	4	12.9
9 (threat, unwanted incident, risk)	13	32.3	10	41.9	8	25.8
10 (risk, asset)	13	41.9	18	58.1	0	0.0
11 (vulnerability, risk)	25	80.6	4	12.9	2	6.5
12 (threat, asset)	25	80.6	6	19.4	0	0.0
13 (unwanted incident)	22	71.0	3	9.7	6	19.4
14 (entity, asset)	16	51.6	9	29.0	6	19.4
15 (treatment, threat)	19	61.3	8	25.8	4	12.9
16 (stakeholder, asset)	29	93.5	1	3.2	1	3.2
17 (threat, vulnerability)	28	90.3	0	0.0	3	9.7
18 (treatment, consequence, frequency)	16	51.6	11	35.5	4	12.9
19 (risk, unwanted incident)	23	74.2	4	12.9	4	12.9
20 (probability, frequency)	5	16.1	20	64.5	6	19.4

The distribution of data is also illustrated using histogram in **Figure 7**.

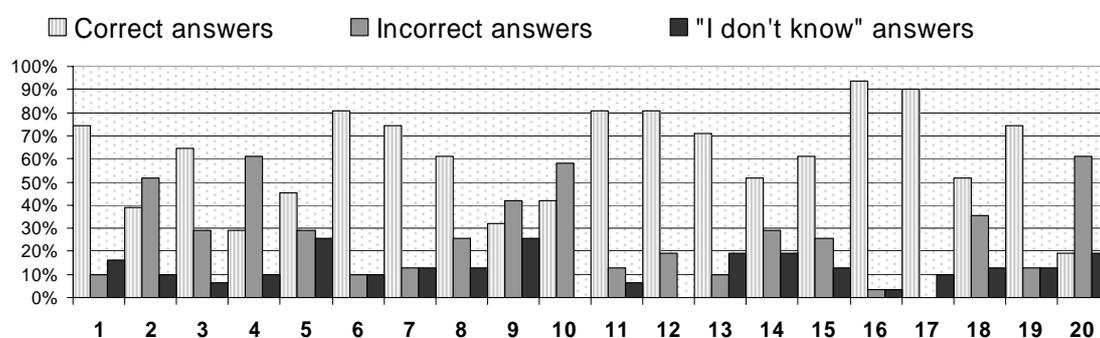


Figure 7 Histogram of data from terminology experiment

Table 2 shows how many of the subjects that had attended the previous lesson about security analysis and how they scored.

Table 2 Lesson attendance and score

Attended previous lesson about security analysis				
	#	Correct answers	Incorrect answers	"I don't know"
"yes"	18	60.8%	26.1%	13.1%
"no"	11	60.5%	28.6%	10.9%
n/a	2			

Not all concepts are used equally many times in the statements, **Figure 8** illustrates how often a concept is used, the most tested term is "risk" (40% of the statements contain this term) while the least tested term is "probability" (5% of the statements). Statements that contained the term "risk" received in average 57.3% correct answers, while for "probability" the result was 16.% correct answers. This shows that one have to take into consideration how often a terms is used in the questionnaire when comparing the level of correct answers.

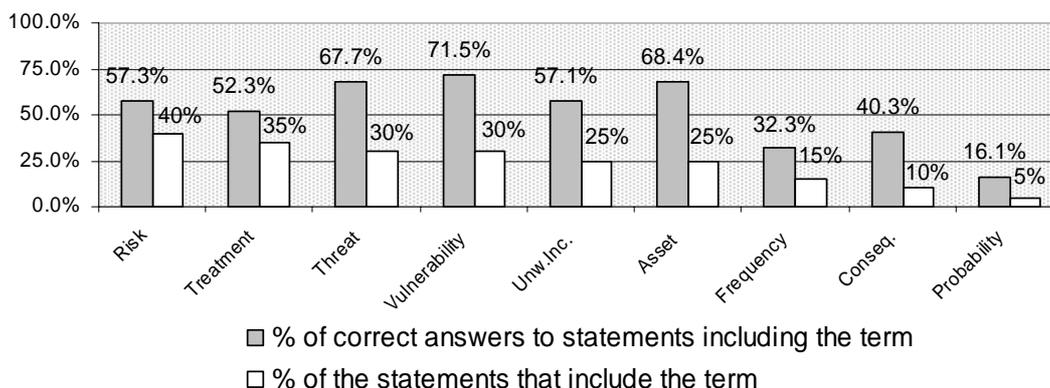


Figure 8 Usage of terms and correct answers

4.2 Descriptive statistics for the icon experiment

We had 25 subjects. 13 of them received questionnaires with CORAS icons, 12 got questionnaires with standard UML use case icons. **Table 4** contains descriptive statistics from the icon experiment. The results are grouped according to which part of the questionnaire they represent. **Score** denotes how many points the students scored, **# Answers** are the number of answers the students managed to complete within time and **Time used** is the minutes used pr set of questions in part 3. We report mean and standard deviation for each of the groups (with and without icons).

Table 4 Descriptive statistics from icon experiment

		CORAS icons		UML icons	
		mean	st.dev	mean	st.dev
Part 1	Score	4.5	1.38	4.77	1.09
Part 2	Score	2.88	0.91	2.58	0.95
	#Answers	4.75	1.54	3.69	1.18
Part 3	Score set 1	3.04	0.96	3.38	0.92
	Score set 2	3.62	0.68	3.7	1
	Score set 3	0.63	0.8	0.27	0.6
	Score all sets	7.29	1.41	7.36	1.82
	Time used set 1	5.58	1.44	6	1.53
	Time used set 2	5.3	1.34	6.7	1.25
	Time used set 3	2.71	0.95	-*	-*
Total	Score	14.67	2.11	14.7	2.51

*only one subject finished

4.3 Statistical tests for the icon experiment

The results from the Mann-Whitney test is presented in **Table 5**, the critical value in column five is taken from [22]. Both for #Answers (part 2) and Time used set 2 (part3) the results showed a significant difference between the two groups.

Table 5 Mann-Whitney test

		n1	n2	critical value	u
Part 1	Score	12	13	<=47	71.5
Part 2	Score	12	13	<=47	67.5
	# Answers	12	13	<=47	46
Part 3	Score set 1	12	13	<=47	62
	Score set 2	12	13	<=47	70.5
	Score set 3	12	13	<=47	56.5
	Score all sets	12	13	<=47	77.5
	Time used set 1	12	13	<=47	71
	Time used set 2	10	10	<=27	21.5
	Time used set 3	7	1	-	-
Total	Score	12	13	<=47	76

$\alpha = 0.05$

5 Discussion

This section discusses both experiments, first the terminology experiment, then the icon experiment.

5.1 Terminology experiment

The results from our terminology experiment show that most of the concepts and relationships from the CORAS' conceptual model are well understood. The easiest statements seem to be the ones which include terms used in the daily language, like *stakeholder*, *asset*, *threat* and *vulnerability*.

Figure 6 illustrates the relationships that we tested; and in the following we discuss those that obtained high percentages of correct (**Figure 9**), incorrect (**Figure 10**) or “I don't know” answers (**Figure 11**). In the remaining we refer to the statements using their number: #3 means statement 3 in the questionnaire (in the figures the “#” is not used).

The results show that terms that are quite common in everyday language, seem to be best understood and not so easily mixed up with other concepts (**Figure 9**). The terms that stand out are threat, vulnerability, asset and stakeholder. The single most intuitive relation is the asset-stakeholder relationship (#16). A large majority of the subjects (93.5%) believe “a stakeholder is someone that wants to protect his or her assets” is correct. 90.3% of the subjects agreed in “a threat can exploit a vulnerability” (#17). The relation between asset and threat (#12) obtains over 80% correct answers and over two third agree in “a risk is related to an asset's vulnerability” (#7).

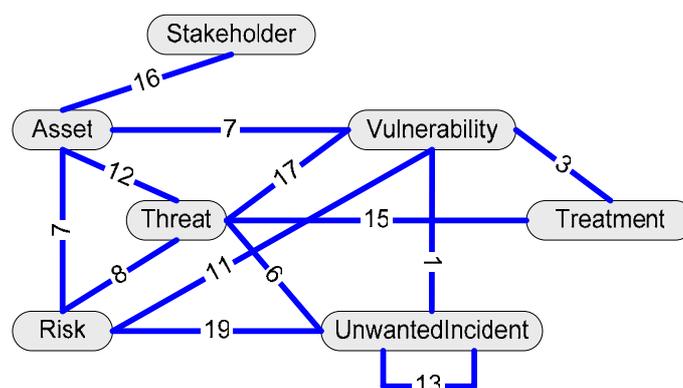


Figure 9 Well understood relations

Our impression is that the subjects find it easier to deal with concrete concepts, i.e. an unwanted incident is something real, than the more abstract term “risk”. As an example the statement “a threat is something that can initiate an unwanted incident” (#6) obtained a high level of correct answers (80.6%), but in a similar statement (#8), where we substituted unwanted incident with risk, we received considerably less correct answers (61.3%).

The subjects seem to be unaware of the fact that the purpose of a treatment often is to *reduce* frequency or consequence. More than half of the subjects (51.6 %) believe a treatment always will *eliminate* at least one unwanted incident (#2, **Figure 10**).

In the CORAS conceptual model a risk is **always** associated with an unwanted incident, a frequency value, a consequence value and an asset which represent concrete scenarios, values or entities, but “risk” in itself is rather a composition of them. This means that risk in a way is an abstract concept, something that seems troublesome for the subjects. The terms “unwanted incident” and “risk” are often confused, 71 % of the subjects were wrong or uncertain on whether a risk includes an unwanted incident or vice versa (#4). **Figure 8** shows that statements that include the term *unwanted incident* in average only get 52.3% correct answers and this should be considered when revising the model.

In statement #10: “a risk is something that will reduce the value of an asset”, more than half of the subjects disagreed (58.1%). They disagreed in the use of “will” in the statement, claiming that a risk with frequency near zero “*may reduce...*”, not “*will reduce...*”. We agree in their argumentation and will reformulate the statement in further work with the conceptual model.

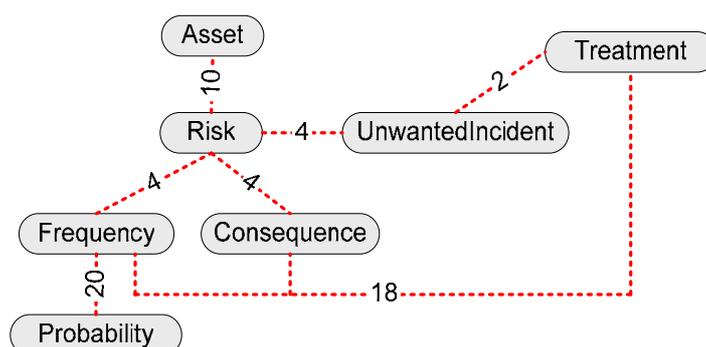


Figure 10 Misunderstood relations

The single most difficult statement in the questionnaire was “one has to know both probability and frequency to calculate the risk value” (#20). A risk value is a function of a consequence and a frequency measure, and some may have answered “I don’t know” because they did not know what a risk value is. On the other hand it should be possible to answer this statement just by knowing that probability and frequency are two measures for the same thing and therefore knowing only one of these is sufficient to calculate risk value. A large group (83.9%) either gave incorrect answer or did not know the answer on this statement. Neither frequency nor probability is particularly common in the everyday language and this is probably why we get a high percentage of incorrect or uncertain answers. It is possible that just by avoiding these exact terms and rather ask “how often?” or “how many out of 100?” is enough to reduce the uncertainty among the participants in a structured brainstorming.

More than half of the subjects (54.8%) either think a treatment will always be directed towards a vulnerability or they are uncertain on the answer (#5). The subjects had not understood that a treatment can also be applied to an unwanted incident or a threat.

According to CORAS' conceptual model an unwanted incident is always associated with one or more threats, but a threat is not necessary associated with an unwanted incident. The statement "There has to exist a threat before one think of an unwanted incident as a risk" (#9) confused the subjects. A majority either disagreed (41.9%) with this interpretation or were uncertain (25.8%), and they did not accept this as an intuitive explanation for the relation between threat, unwanted incident and risk. We believe that some of this confusion arises from a misunderstanding that an unwanted incident in itself is a threat (comments made by the subjects in the questionnaire).

It was unclear how an entity relates to an asset (#14) and the subjects were inconsistent in their answers. The reason may be that "entity" is a term that almost does not exist in the daily language and we think this created more uncertainty than the actual relationship to asset.

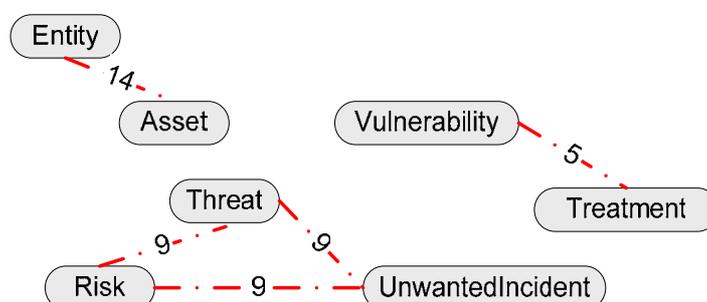


Figure 11 Relations creating uncertainty (answer="I don't know")

There were not identified correlations between data from the initial demographic questions and score. Surprisingly enough, attendance to the previous lesson did not affect the overall score on the questionnaire. This indicates that many security analysis concepts are already known to people, but often with another interpretation.

5.2 Icon experiment

What we can see from the icon experiment is that stereotyping with CORAS icons does not affect the "correctness" of the answers, but the subjects managed to answer more questions than the group without CORAS icons. Both model sets kept the stereotype name; otherwise it would be impossible to distinguish the UML icons. If all the subjects had read the text under the icons there had not been any difference between the two groups, but looking at the results it is possible to assume that the stereotype name is ignored. We did ten statistical tests of the data from the icon experiment (not including the test on *time used for set 3* since the number of subjects was too small). For two of the tests we obtained a statistical significant difference between the two groups of subjects at an alpha level of 0.05.

Part 1 and 2 had questions that aimed to investigate whether the subjects were able to differentiate between the elements in the model. They were asked to count the number of different security analysis concepts, some were in fact represented in the models and some were not. Part 1 was a training task with no time pressure; therefore the differences between the groups are insignificant both with respect to correctness and number of answers. Part 2 was similar to part 1 but with a much less time available

and here we obtained a significant difference in the number of questions answered between the CORAS icon subjects and the other group. The subjects with CORAS icons manage to answer in average 4.75 questions, while the result for the group without CORAS icons is 3.69. There was insignificant difference with respect to the correctness of the answers, the group with CORAS icons scored in average 2.88 points while the others scored 2.58 points.

Part 3 of the questionnaire had a different style than the previous parts. The section focused more on interpretation of models, and less on navigation. We used three models with belonging sets of questions (Set 1, Set 2 and Set 3). All sets were measured for score and time used pr set. The results show that there was no significant difference between the groups in Set 1. We see this set as a training set since the type of questions was different from the previous ones and therefore both groups used some time to get used to the questions. For Set 2 we obtained a significant difference with respect to the time used. The group with CORAS icons used less time to complete the questions (average: 5.3 min) than the group using standard UML use case icons (average: 6.7 min). But also here there were no difference in score between the two groups. It was not possible to statistically analyze the difference between the two groups in Set 3 since only eight finished it. 7 from the CORAS icon group finished in contrast to only one using UML icons, which can indicate that the CORAS icon group performed better also in this set.

[18] reports the results from a similar experiment investigating the understanding of stereotyped UML class diagrams. The experiment tested icon-stereotyping vs. normal class stereotyping (roughly sketched in **Figure 12**). They substituted traditional stereotyped classes (Alt.1) with special stereotype icons (Alt.2) and found this to improve both the speed of navigation and the correctness of model interpretation.

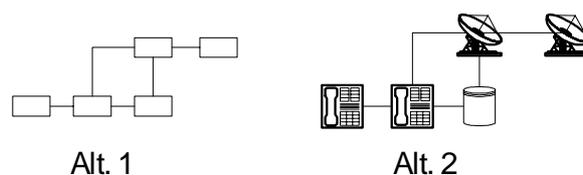


Figure 12 Class diagram with and without icons

According to their findings we should expect to find an improvement in both areas but we only found the difference in the navigation speed. A possible reason is that many of the security risk concepts do not have obvious graphical representations and that our icons may be ambiguous. Also the interpretation of a model may depend on other factors than icons like naming of elements, modeling style and familiarity with the system or domain that is modeled. At this point our results support the belief that icons affect how fast the subjects navigate through the model to identify different elements, but less on how they interpret the model.

5.3 Threats to validity for the experiments

Experiments will always have some threats with respect to the validity of its results. In the following we explain the ones we have identified.

5.3.1 The terminology experiment

- The questionnaire design: developing a good questionnaire using natural language is difficult. There is always possible to write text that is interpreted different from its intention. Even though our questionnaire was both pilot tested and reviewed, we found some weaknesses after the experiment. We believe statement 11 “a vulnerability is the same as a risk” failed to express what we really intended to check. We wanted to investigate whether a vulnerability automatically is considered as a risk, or do the subjects recognize the need for identification of unwanted incidents also. Unfortunately it was probably quite easy to guess that the two terms they were not identical and mark “Incorrect”. The same goes also for statement 19 “ a risk and an unwanted incident is the same” where the intention was to investigate whether the subjects were aware of that unwanted incident is a part of a risk, not if the subjects see the difference between two words.
- Data interpretation: since one of the alternative answers for each statement was “I don’t know”, we choose to interpret missing answers as “I don’t know” This gave us some data points that are not directly filled in by subjects, but since there were no reasons for not answering, neither short time nor fear of getting a low score on the test we decided that this was legitimate.
- Time pressure: we know that the 20 minutes given to complete the terminology questionnaire was sufficient time, but still some did not answer all statements.

5.3.2 The icon experiment

- Domain knowledge and questionnaire design: the students were not tested in their understanding of the specific domain modeled and the questions dealt with the CORAS language notation only. The models were not too technical detailed, but taken from a real security analysis and therefore representative for its type.
- Familiarity with material: the students had seen the CORAS icons before and were more used to them than the other icons. This is a problem, even if we used identical models, kept the stereotype name in both and replaced the CORAS icons with two standard UML icons the students with CORAS models had a small advantage. Still we believe this was too small to make a real difference, in most cases the group without CORAS icons had equal or higher mean score than the other group.
- Time pressure: it was important to have some time pressure to investigate fast model navigation. The questionnaire also contained extra tasks in the end to make sure that no subjects finished before time and thereby could disturb the other subjects.

5.3.3 General

- Norwegian experiment material: the findings reported in this paper are based on experiments with Norwegian students. Even though the experiment material was mainly in Norwegian and used Norwegian subjects we assume that our findings are not limited to apply only for Norwegians. The conceptual model is developed in an international project and all the concepts have precise translations into Norwegian.
- Student as subjects: Using students as subjects will always be criticized, but we believe that students are well suited for this explorative study. There are no other requirements than being familiar with a part of the system assessed in order to

participate in or understand the documentation from a security analysis. These experiments did not require knowledge about a particular system; we only tested terminology and modeling notation. In our opinion, unless a company already conducts security analyses using this type of terminology, the concepts tested here will be just as unfamiliar for industrial employees as for students. Many of the students were 6-9 months from graduating with a master degree in informatics, and many will become employees in companies that conduct this type of security analyses. They are comparable to technical experts in an analysis.

- Selection of subjects: The participants in our experiments were volunteers and not picked out according to background or experience. Like in a real security analysis we do not require the participants to know terminology or notation in advance.
- The “student-teacher”-setting: both the experiments were completely anonymous and the students did not have to worry about grades which could potentially influence their behavior.

6 Lessons learned

While the original model needs a textual explanation in order to be understood correctly, we aim to develop a new model that needs a minimum of extra explanation. The results from the terminology experiment have taught us that some parts of the conceptual model are not as intuitive as desired. On the basis of these results we propose a set of changes to the original model (see **Figure 13**):

- To avoid confusion about frequency, probability and consequence we have included probability as a specialization of frequency.
- In order to emphasize that a risk consists of a frequency value, consequence value and an unwanted incident, these terms have been grouped together in a logical manner that illustrates how they are components of a risk. The black diamond symbolizes that if a risk is eliminated this will also remove the frequency and consequence values (composition). The white diamond means that the unwanted incident is a part of the risk, but if the risk is eliminated the unwanted incident may still exist in other risks (aggregation).
- The direct relation between treatment and unwanted incident has been removed and instead we have connected treatment to risk. By doing this we specify that a treatment is directed towards a risk, but not whether it targets a vulnerability, a threat, an unwanted incident or a combination of these.
- The association between asset and risk was a major source for misunderstandings. Nevertheless we have decided to keep the relation because we believe it is important. The subjects seem to think of an unwanted incident in the way we use the term risk, and by removing the direct association between asset and unwanted incident we hope that this misunderstanding will be less common.
- We chose to remove “entity” from the model. The term was often misunderstood (48.9% incorrect or uncertain answers) and it is not natural to speak of general entities in a structured brainstorming, only entities assigned value which then are called assets.
- The association between asset and vulnerability has been changed from a regular relation to become a part of the asset in the sense that an asset *can* have a vulnerability.
- In the original conceptual model it is not explicitly modeled that “a threat exploits a vulnerability to initiate an unwanted incident”. This is an intuitive relation that achieved a high percentage of correct answers and we feel it is correct to make it clearer than it was in the original model.
- The new model tries to emphasize that an unwanted incident is a part of a risk and therefore one or more threats are always associated with the risk through its unwanted incident.
- We have chosen to highlight concepts grouped together in the form of compositions and aggregations, i.e. vulnerability is tightly connected to asset and risk is a concept that includes three other concepts.

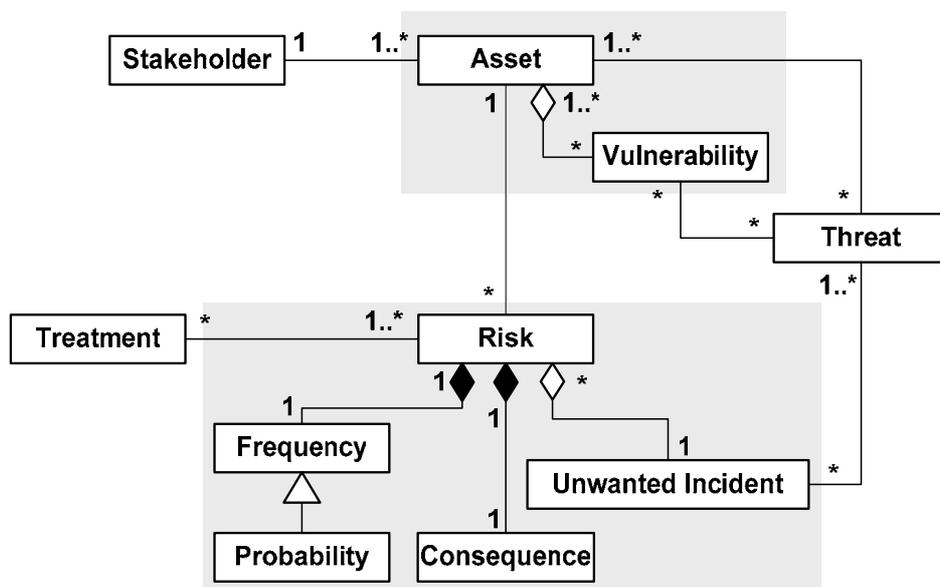


Figure 13 The revised conceptual model

7 Conclusions and recommendations

A structured brainstorming within security analysis gathers system experts with the aim of identifying risks and treatments for the system. The participants need to have a common understanding of concepts like asset, stakeholder and threat, in addition to more traditional security analysis terms. If the analysis leader asks them to identify unwanted incidents for the system, it is important that the participants understand that this is different from risks or threats. They need to understand a security risk scenario quickly and interpret it in the same way. The CORAS language for structured brainstorming is specially developed to support structured brainstorming and document the results. The language is based on a conceptual model, consisting of security analysis specific terms. The suitability of its notation and its underlying conceptual model is very important for the usability of the language. We aimed to investigate this in two experiments, one focusing on the terminology in the underlying conceptual model and the other on the use of graphical icons. We used students as subjects and the results from this study will be used as input in further experiments with professionals to see if we obtain similar results.

The results from the terminology experiment showed that few subjects had problems with relations like stakeholder and asset or threat and vulnerability. These terms are part of the daily language and most people have an intuitive understanding of them. Concepts like frequency, consequence and probability created more confusion and a large majority was not aware that probability is kind of frequency. These results show the importance of using terms that are intuitive and do not conflict with the daily language.

Even though the CORAS language is a UML profile, it uses special graphical icons to symbolize selected security analysis terms. The results from the icon experiment showed that stereotyping with CORAS icons vs. UML icons improves the speed of navigation, i.e. identification of specific model elements. The results showed a statistical significant difference in the number of questions completed in favor of the group using CORAS icons. The icons did not affect the correctness of interpretation of models.

The conclusion from our icon experiment is that using CORAS' graphical icons helps the participants in a structured brainstorming session to identify the same model elements faster than if one does not use CORAS icons. When it comes to correctly understand the models we believe it is necessary to look at other aspects as well as graphical icons.

Future Work

The future goal of our work is to develop a modeling language that supports and documents structured brainstorming, whose usability and suitability is thoroughly supported by empirical and analytical evidence. The assessment of the CORAS language has provided us with information that will be used as input for design of this new language. In addition to more student experiments, we have planned an analytical assessment of the CORAS language, based on the quality framework of [17]. Through industrial field studies in the SECURIS project we aim to test our hypotheses and

gather experience from real users. The language will be tested in SINTEF ICT's usability laboratory using subjects that are representative for real users. The results from these investigations will help us identify the requirements for a language that in the best possible ways supports and documents brainstorming sessions in security analysis.

Acknowledgements

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Appendix A – Icon Experiment Material

The material used for the icons experiment was made in two versions, one with CORAS icons and one with standard UML icons, in the following we present both versions. The material is divided into three parts, Part 1 and 2 have one set of questions each and Part 3 has 4 sets. The fourth set of questions is a “fill-in” task, included to make sure that the subjects do not finish too early.

A.1 Material with CORAS icons

Part 1

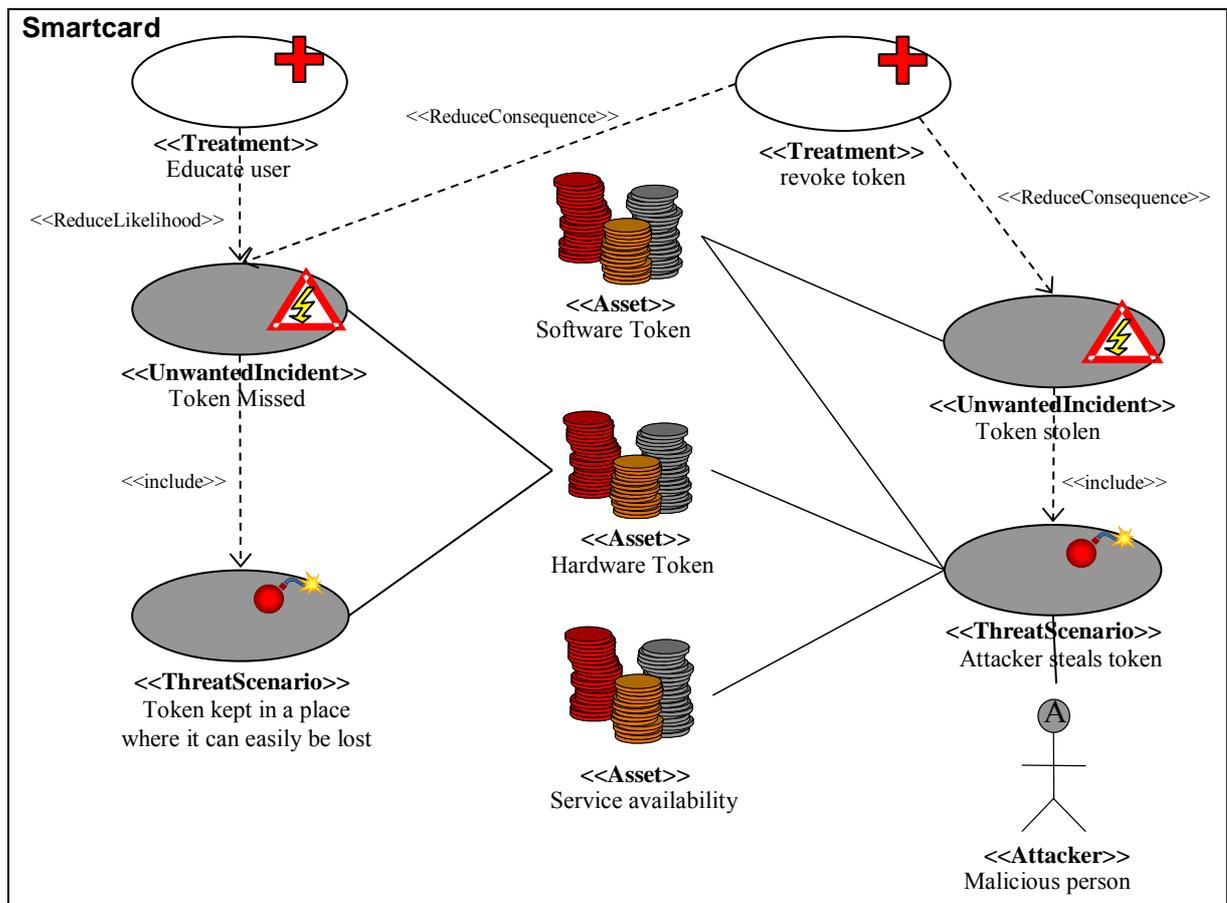


Figure 14 Smartcard

Set 1 – Smartcard

- How many assets are explicitly modeled in the diagram above?
- How many unwanted incidents are explicitly modeled in the diagram above?
- How many threats are explicitly modeled in the diagram above?
- How many risks are explicitly modeled in the diagram above?
- How many threat scenarios are explicitly modeled in the diagram above?
- How many treatments are explicitly modeled in the diagram above?

G. How many vulnerabilities are explicitly modeled in the diagram above?

Part 2

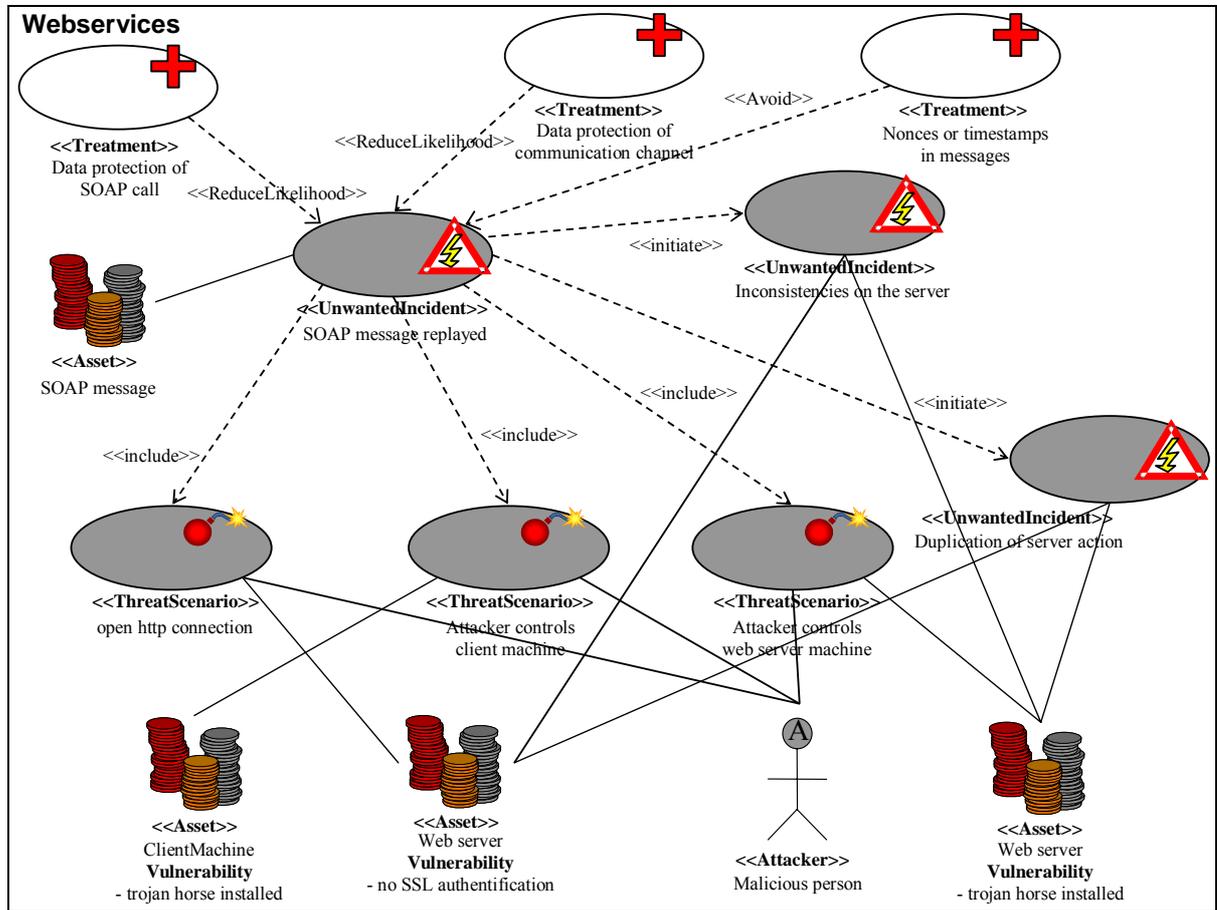


Figure 15 Web services

Set 1 – Web services

- A. How many threat scenarios are explicitly modeled in the diagram above?
- B. How many unwanted incidents are explicitly modeled in the diagram above?
- C. How many risks are explicitly modeled in the diagram above?
- D. How many types of icons are used in the diagram above?
- E. Which assets are affected by the unwanted incident "SOAP message replayed"?
- F. How many assets are explicitly modeled in the diagram above?
- G. How many vulnerabilities are explicitly modeled in the diagram above?
- H. Which threat scenarios affect the asset "Web server"?
- I. How many threats are explicitly modeled in the diagram above?
- J. How many treatments are explicitly modeled in the diagram above?

Part 3

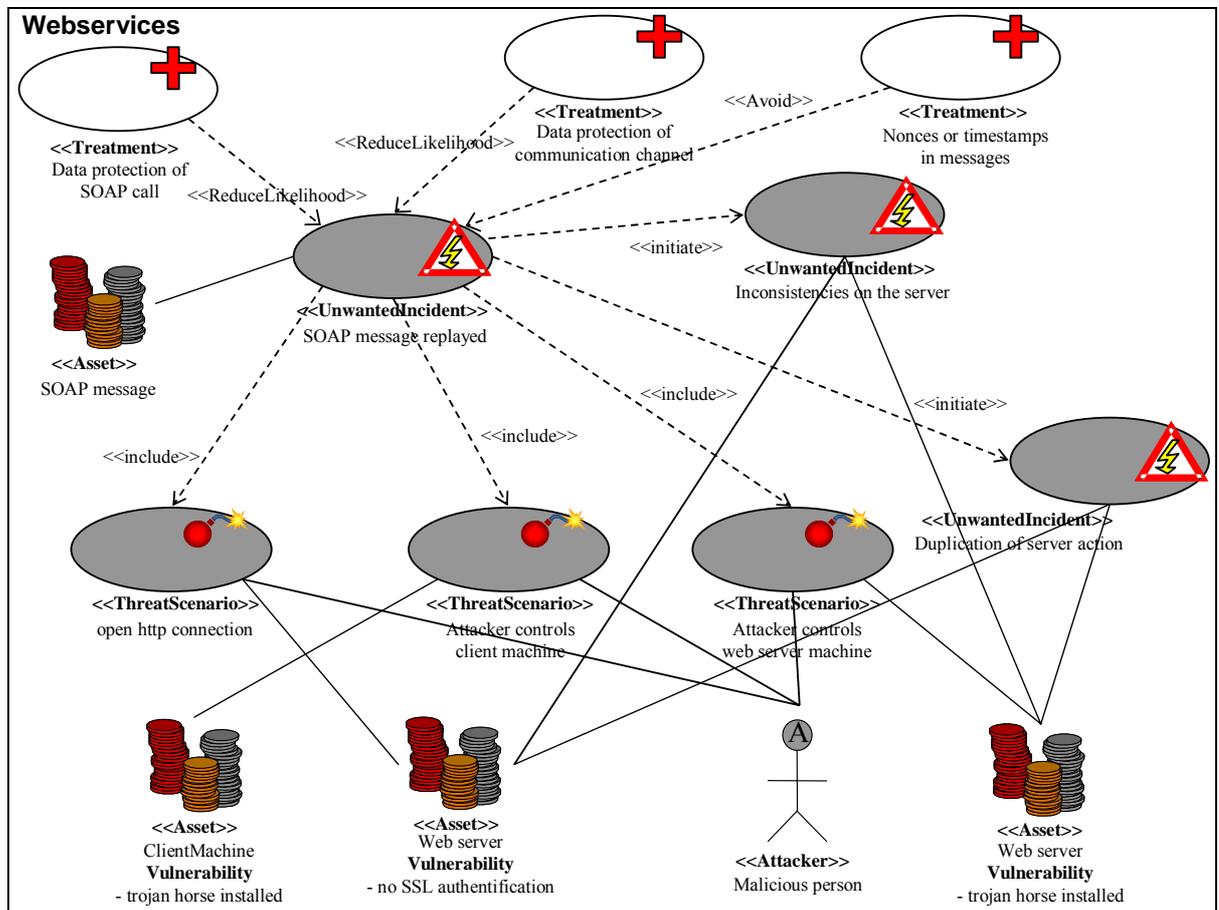


Figure 16 Web services

Set 1 – Web services

- Please record the current time (hh:mm)
- What does a stapled arrow tagged with <<include>> mean?(use an example from the diagram above)
- What does a solid line mean? (use an example from the diagram above)
- Below each icon there is some text, what is the difference between the text put in angel brackets (<<text>>) and the other text?
- How should one read the relation between "Nonces or timestamps in messages" and "SOAP message replayed"?

Set 2 – Web services

- Please record the current time (hh:mm)
- Which unwanted incident(s) affects the asset "Web server" in

- C. Figure 16?
- D. Which unwanted incident(s) affects the asset "Client machine" in
- E. Figure 16?
- F. Which unwanted incidents, assets and threats are associated with the threat scenario "Attacker controls web server machine" in
- G. Figure 16?
- H. What is the effect of the treatment "Nonces or timestamps in messages" applied against the unwanted incident "SOAP message replayed" in
- I. Figure 16?
- J. How should one read the relation between "SOAP message replayed" and "Inconsistencies on the server" in
- K. Figure 16?

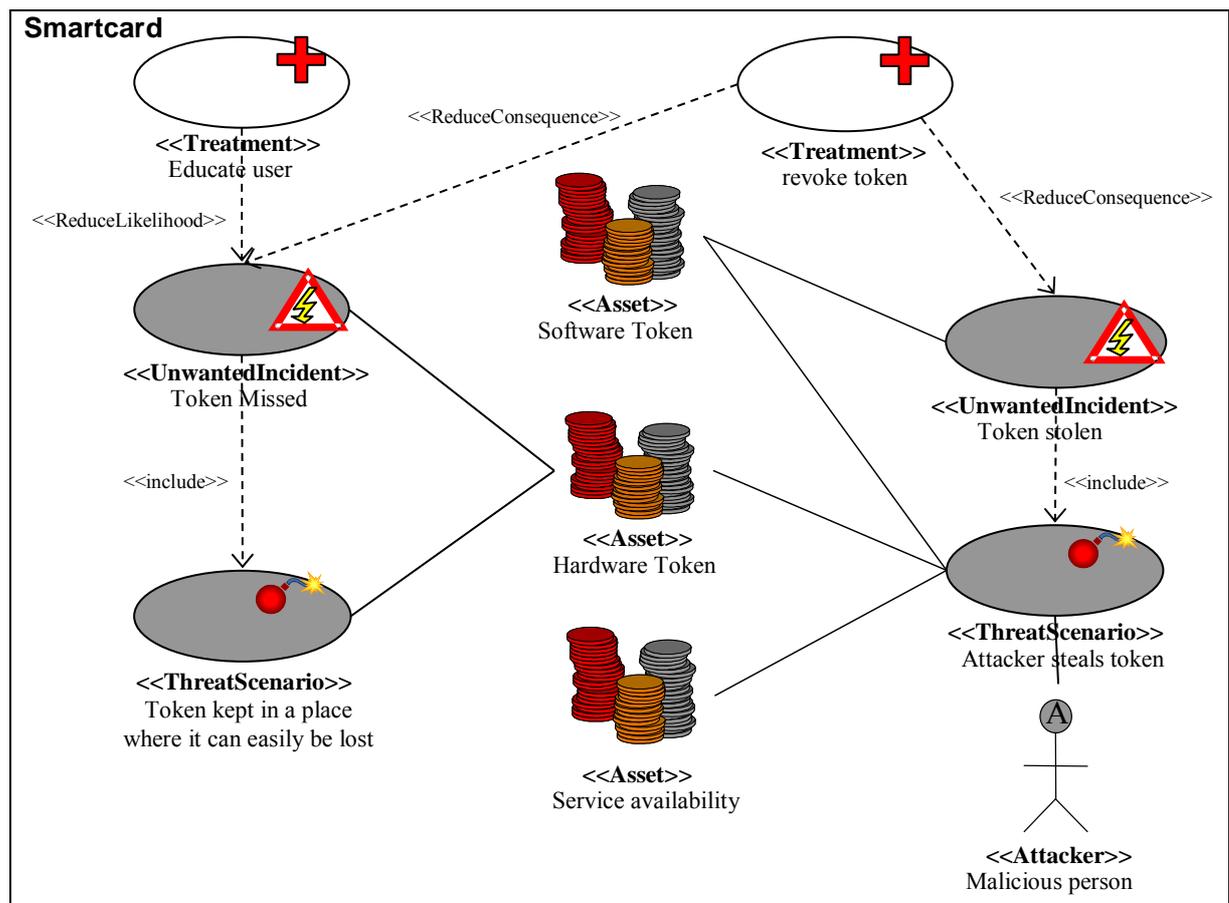


Figure 17 Smartcard

Set 3 – Smartcard

- A. Please record the current time (hh:mm)
- B. Can you explain the relation between: "Token missed", "Token kept in a place where it can be lost" and "Hardware token"?
- C. If one removed the relation between "Hardware token" and "Token missed", how would this affect your explanation to B?

Set 4 - General

- A. Please record the current time (hh:mm)
- B. Explain why you think the icons you have seen in the diagrams have been selected.
- C. How would you have modeled the situation where to unwanted incidents exploits to separate vulnerabilities of one and the same asset?(draw a suggestion)

A.2 Material without CORAS icons

Part 1

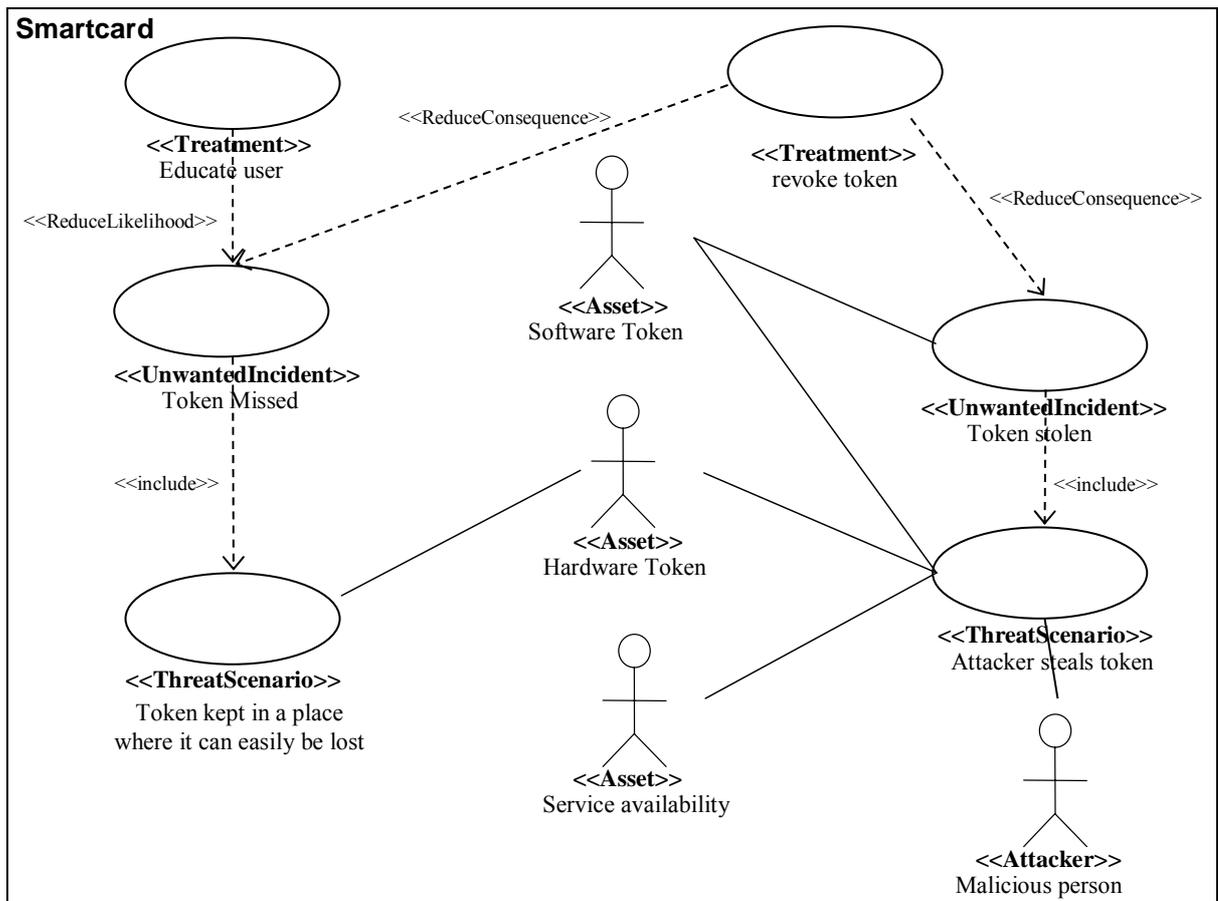


Figure 18 Smartcard

Set 1 – Smartcard

- A. How many assets are explicitly modeled in the diagram above?
- B. How many unwanted incidents are explicitly modeled in the diagram above?
- C. How many threats are explicitly modeled in the diagram above?
- D. How many risks are explicitly modeled in the diagram above?
- E. How many threat scenarios are explicitly modeled in the diagram above?
- F. How many treatments are explicitly modeled in the diagram above?
- G. How many vulnerabilities are explicitly modeled in the diagram above?

Part 2

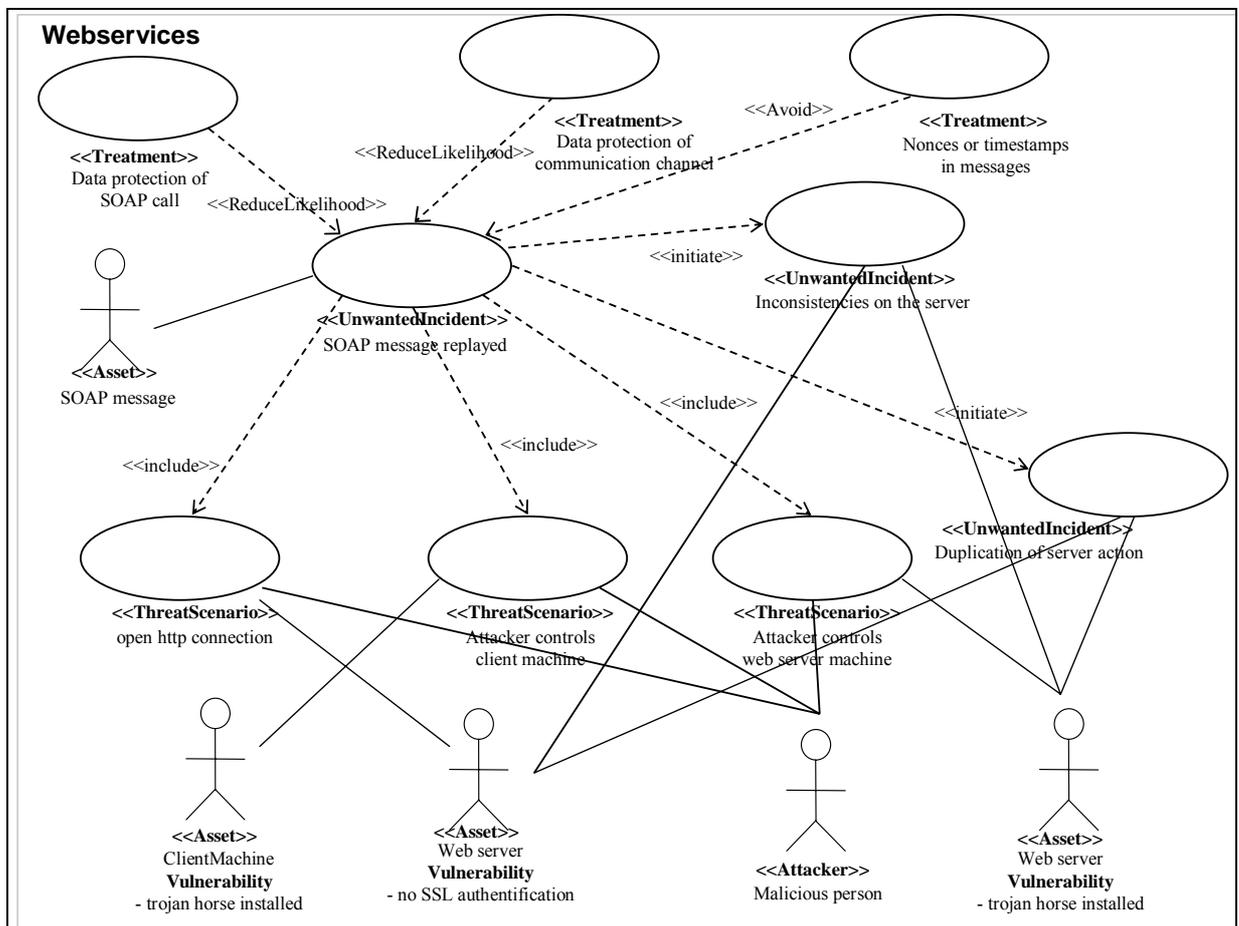


Figure 19 Web services

Set 1 – Web services

- A. How many threat scenarios are explicitly modeled in the diagram above?
- B. How many unwanted incidents are explicitly modeled in the diagram above?
- C. How many risks are explicitly modeled in the diagram above?

- D. How many types of elements are used in the diagram above?
- E. Which assets are affected by the unwanted incident "SOAP message replayed"?
- F. How many assets are explicitly modeled in the diagram above?
- G. How many vulnerabilities are explicitly modeled in the diagram above?
- H. Which threat scenarios affect the asset "Web server"?
- I. How many threats are explicitly modeled in the diagram above?
- J. How many treatments are explicitly modeled in the diagram above?

Part 3

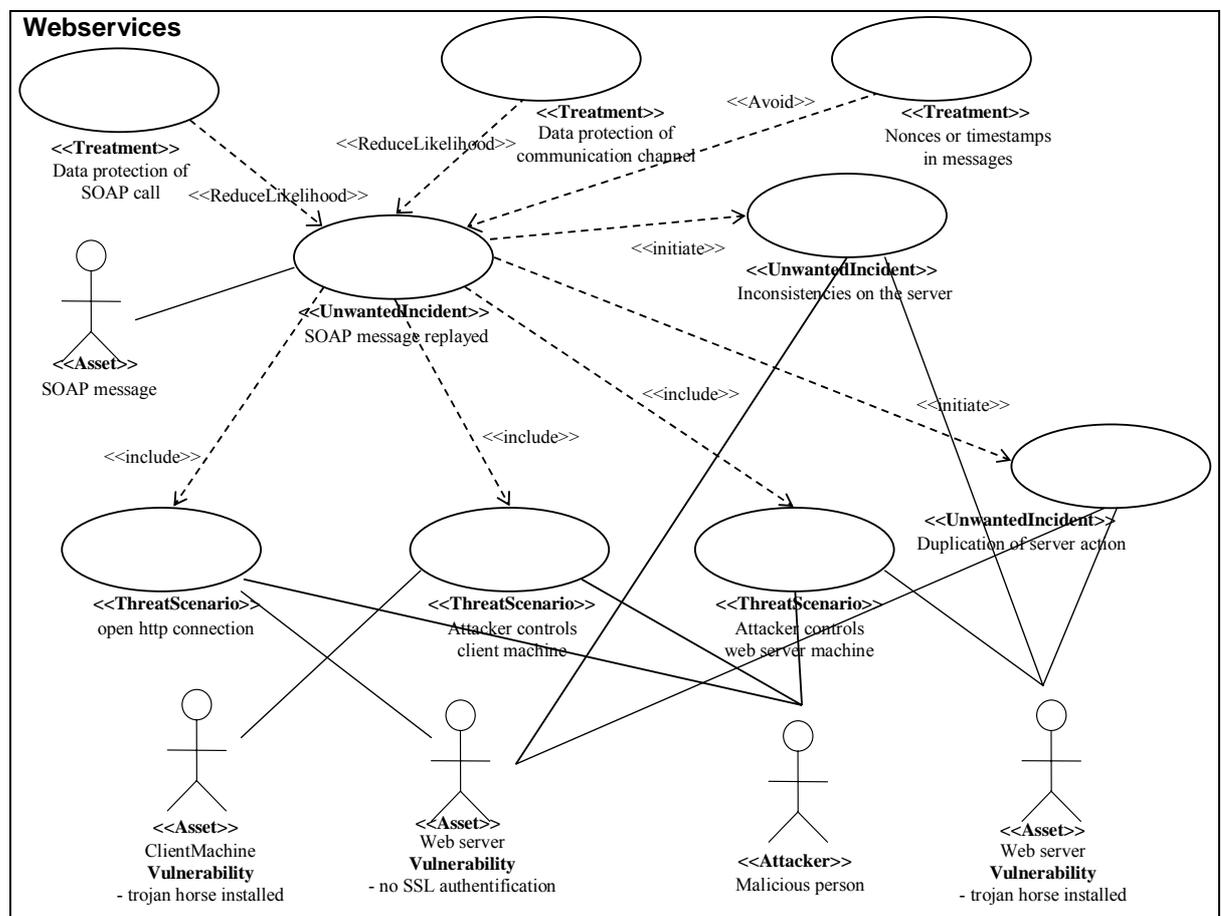


Figure 20 Web services

Set 1 – Web services

- A. Please record the current time (hh:mm)
- B. What does a stapled arrow tagged with <<include>> mean?(use an example from the diagram above)
- C. What does a solid line mean? (use an example from the diagram above)

- D. *Below each icon there is some text, what is the difference between the text put in angel brackets (<<text>>) and the other text?*
- E. *How should one read the relation between "Nonces or timestamps in messages" and "SOAP message replayed"?*

Set 2 – Web services

- A. *Please record the current time (hh:mm)*
- B. *Which unwanted incident(s) affects the asset "Web server" in Figure 20?*
- C. *Which unwanted incident(s) affects the asset "Client machine" in Figure 20?*
- D. *Which unwanted incidents, assets and threats are associated with the threat scenario "Attacker controls web server machine" in Figure 20?*
- E. *What is the effect of the treatment "Nonces or timestamps in messages" applied against the unwanted incident "SOAP message replayed" in Figure 20?*
- F. *How should one read the relation between "SOAP message replayed" and "Inconsistencies on the server" in Figure 20?*

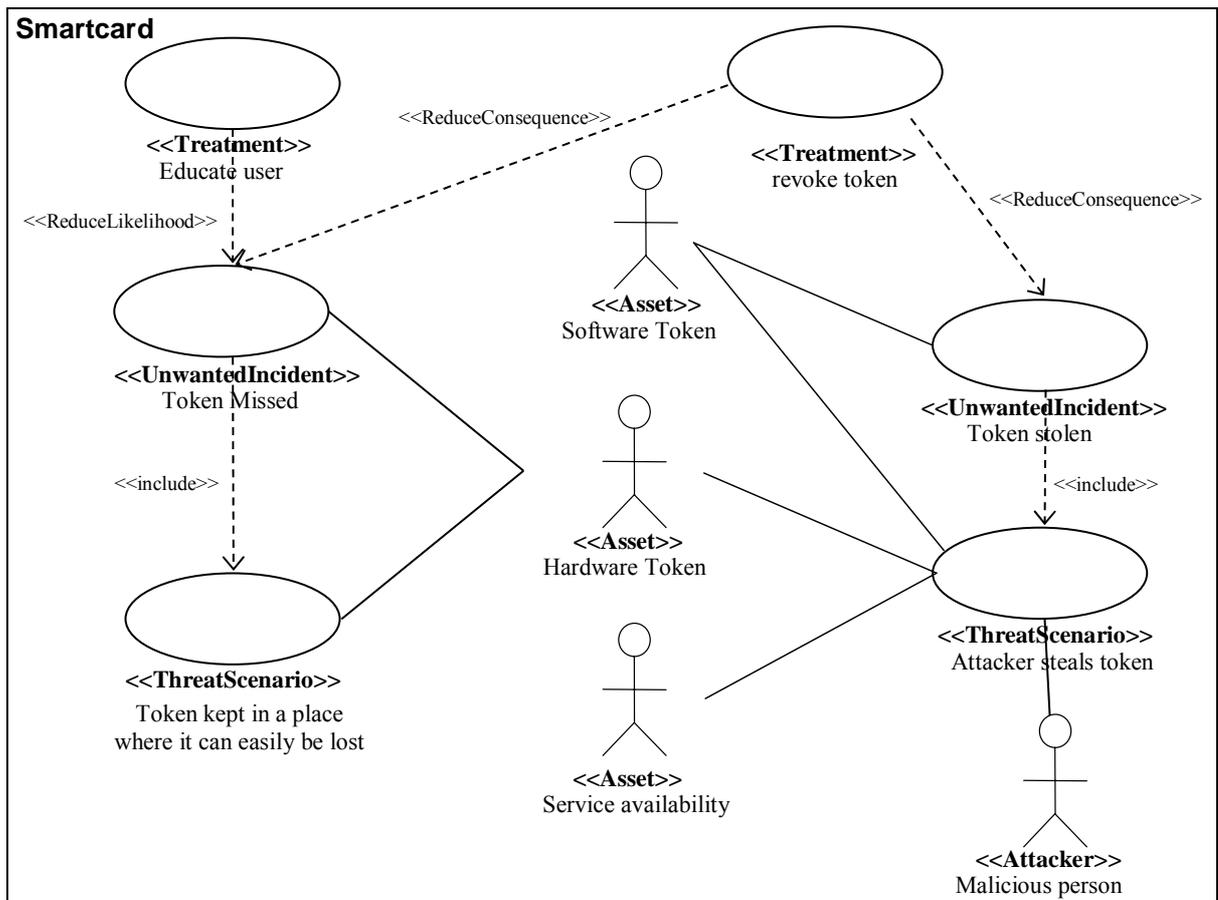


Figure 21 Smartcard

Set 3 – Smartcard

- Please record the current time (hh:mm)
- Can you explain the relation between: "Token missed", "Token kept in a place where it can be lost" and "Hardware token"?
- If one removed the relation between "Hardware token" and "Token missed", how would this affect your explanation to B?

Set 4 – General

- Please record the current time (hh:mm)
- How would you have modeled the situation where to unwanted incidents exploits to separate vulnerabilities of one and the same asset?(draw a suggestion)

Appendix B Suggested Solutions for the Icon Experiment

Part 1

Set 1 – Smartcard

- A. 3
- B. 2
- C. 1
- D. 0, risks are not explicitly modeled in this type of diagram
- E. 2
- F. 2
- G. 0
- H. "Hardware token" 2 stk.

Part 2

Set 1 – Webservice3

- A. 3
- B. 0, risks are not explicitly modeled in this type of diagram
- C. 5
- D. All
- E. 3
- F. 3
- G. "Open http connection" and "Attacker controls web server machines"
- H. 1
- I. 3

Part 3

Set 1 - Web services

- A. -
- B. An "include"- relation between an unwanted incident and a threat scenario means that the arrow from the unwanted incident points at the threat scenario(s) that is (are) included.
- C. There is some sort of relation between them. An unwanted incident and a threat scenario may be related to an asset or a threat is an actor in a threat scenario.

- D. The stereotype name in angle brackets (<< >>) has its origin from UML and denotes the type of element. The other text is the name or description of the element.
- E. “If you apply nonces or timestamps in the messages you will avoid the problem with replay of SOAP messages”.
- F. Yes all 3, (but it is possible to look upon these as “indirect” threat scenarios since they are included in the “predecessor” of this unwanted incident).

Set 2 – Web services

- A. -
- B. All three (NB: “Web server” is modeled twice to emphasize that two different threat scenarios exploit two different vulnerabilities on the same asset. If both vulnerabilities had been modeled on the same asset-icon it would have been impossible to know which vulnerability is associated with each of the threat scenarios)
- C. “Soap message replayed”
- D. All three unwanted incidents, two assets (“Web server”, “Soap Message”), one threat.
- E. By applying this treatment one avoids the unwanted incident.
- F. The first initiates, or leads to the other.

Set 3 – Smartcard

- A. -
- B. The threat scenario "Token kept in.." is a part of the unwanted incident "Token missed" and affect the asset "Hardware token".
- C. Unchanged interpretation since the threat scenario is included in the unwanted incident.

Set 4 - General

- A. –
- B. –
- C. –