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A Case of Quality Prediction of Architecture Knowledge Sharing through Model Mapping

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Abstract
In this report, we introduce the AK sharing activity with a query-based scenario, and the motivation for the prediction of AK sharing quality prediction. In the end, a concrete case of quality prediction of AK sharing through model mapping was presented with assumptions.

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1 Introduction

Software architecture is considered of paramount importance to the software development life cycle [1]. It is a key artifact for the early analysis of the system, as it facilitates stakeholder communication and understanding, and drives both system construction and evolution. Various authors [9][10][11][12][13] and the IEEE [4] have proposed their own AK models to document AK concepts and their relationships. Some of these concepts and relationships are different, while others are largely overlapping. These discrepancies between the AK domain models can hamper the effective sharing of AK between these organizations, which in turn results into misunderstandings among stakeholders, expensive system evolution, and limited reusability of architectural artifacts [14].

1.1 Query-based AK-sharing scenario

In our perspective, we envision AK sharing in a heterogeneous AK repository setting, in which different repositories are part of the architectural knowledge GRID. Each repository contains one AK model and its instances. A user can retrieve AK from all involved AK repositories transparently without being conscious of the underlying model differences. To quantify the quality, we use this specific user scenario, which is a key activity for knowledge sharing. The query is a precise request for information, typically keywords combined with Boolean operators and other modifiers.

The query-based scenario is shown in Figure 1. A user who understands only AK model \( T \) queries the repository of AK model \( S \) using concepts from AK model \( T \) as query keywords. The conceptual difference between AK model \( S \) and \( T \) poses a problem for AK sharing. The concepts from model \( T \) queried does not exist (or exists, but has a different meaning) in model \( S \). Thus, the repository of model \( S \) cannot return any data. Using concept mappings from model \( S \) to \( T \), the repository of model \( S \) could partially return data to the user.

![Figure 1 Query-based scenario for AK sharing](image)

2 Motivation

The quality of AK sharing is not only dependant on the models and mappings involved, but also on the actual instances of these models. Only with these instances the real cost and AK sharing quality can be determined. However, creating these instances requires considerable effort, as human intervention is required. Even more troublesome is the fact that most of this effort needs to be redone when due to further insight domain models or mappings are changed. Hence, we would like to predict the cost and quality of AK sharing in advance before effort is spend on creating instances. This report contributes such a prediction model for both the direct and indirect mapping approaches.

3 Assumptions

By assigning more practical assumptions, we can come up with better prediction model, with which the prediction of set distribution is closer to the real case. In this report, we make assumptions as follows:

- All instances in a AK repository are evenly distributed over the AK concepts;
- We use a perfect instance mapping tool for the instance mapping by which all instances will be mapped into correct concept smartly;
4 Prediction Rules

4.1 Calculation rules for prediction of set distribution

The AK instances are mapped based on concept mapping relationships between AK models, and AK model mapping is composed of a set of concept mapping relationships. With assumptions of Simple Mapping Quality Prediction Model, the prediction of sets distribution ($D_{IM}$, $D'_{IM}$ and $D'_{IM\cup IM}$) can be calculated using set distribution prediction of all individual concept mapping relationships in a instances even distribution way. To be concise and to differentiate from set distribution concept, the set distribution of individual concept mapping relationship is renamed concept mapping set distribution. The calculation rules for the prediction of concept mapping set distribution based on different concept mapping relationships are presented after the introduction of several mathematical symbols:

- $x_S$ and $x_T$ are concepts from two AK models $S$ and $T$. A concept mapping relationship from $x_S$ to $x_T$ is normalized as a triple $<x_S, m, x_T>$, in which $m$ is the mapping relationship from concept $x_S$ to $x_T$ or mapping rules applicable from $x_S$ to $x_T$. The concept mapping relationships includes equivalentClass, subClassOf, superClassOf (inverseOf subClassOf), disjointWith and noMatchingPair which can be represented by RDF [16]/OWL [17] constructors and deduced by RDF/OWL reasoners. For easy introduction of ontology mapping representation using RDF/OWL constructors, other mapping relationships like partOf, compositionOf are not included.

- $|x|$ is the number of concept $x$. In triple $<x_S, m, x_T>$,
  (1) if $m\neq$noMatchingPair, then $|x_S|=1$ and $|x_T|\geq 1$, which means that the concept mapping relationship can be 1 to 1 or 1 to multiple;
  (2) if $m=$noMatchingPair, then $|x_S|=1$ and $|x_T|=0$, which means that there is no mapping concept for $x_S$;

- $D'( <x_S, m, x_T>)$ is the prediction of concept mapping set distribution of individual concept mapping relationship represented by triple $<x_S, m, x_T>$, and its real value $D( <x_S, m, x_T>)$ is the percentage of the number of instances mapped from concept $x_S$ to $x_T$ to the instances number of $x_S$ as shown in Figure 2, in which both $x_S$ and $x_T$ are sets. With the assumption of even instances distribution over concepts in SMQPM, we can assume that the instance number of all concepts is 1 (i.e. $|x_S|=1$) for easy calculation, thus for the prediction $D'( <x_S, m, x_T>)$, we can get:
  (1) $0 \leq D'( <x_S, m, x_T>) \leq 1$;
  (2) $D'( <x_S, m, x_T>)=0$, if $m=$noMatchingPair;
  (3) $D'( <x_S, m, x_T>)=1$, if $m\neq$noMatchingPair and all instances of concept $x_S$ can be mapped as instance of concepts $x_T$;

![Figure 2 Concept mapping set distribution calculation with mapping relationship from $x_S$ to $x_T$](image)

The calculation rules for the prediction of concept mapping set distribution $D'( <x_S, m, x_T>)$ based on different concept mapping relationships are presented as follows, and note that besides $D'( <x_S, m, x_T>)$, side-effect concept mapping set distribution caused by concept mapping relationship $<x_S, m, x_T>$ can take place, which will be described in different calculation rules in details.

4.1.1 equivalentClass

RI: equivalentClass concept mapping relationship

![Figure 3 equivalentClass concept mapping relationship from $x_S$ to $x_T$](image)
• Concept mapping set distribution
  Calculation: \( D'(\langle x_S, m, x_T \rangle) = 1 \)
  Reason: since \( x_S \equiv x_T \), any instance of \( x_S \) is instance of \( x_T \), i.e. \( |x_S \rightarrow x_T| = |x_S| \).

• Side-effect concept mapping set distribution
  Condition: \( y_T \) is a concept in model \( T \), and is a direct subClassOf \( x_T \), and all concepts as \( y_T \) are disjointWith each other.
  Calculation: \( D'(\langle x_S, m, y_T \rangle) = 1/(N(y_T) + 1) \), in which \( N(y_T) \) is the number of concepts as \( y_T \).
  Reason: With the assumption of even distribution of instances with SMQPM, all instance of \( x_T \) will be distributed evenly in its direct subclasses (as \( y_T \)) plus 1 dummy subclass, which represents the concept of instances not covered by all the explicit direct subclasses as shown in Figure 4. All concepts as \( y_T \) are disjointWith each other, so there is no instances intersection between set of instances of different \( y_T \). With \( |x_S \rightarrow x_T| = |x_S| \), \( |x_S \rightarrow y_T| = |x_S \rightarrow x_T| \ast 1/(N(y_T) + 1) = |x_S| \ast 1/(N(y_T) + 1) \).

Figure 4 Instances mapping of internal subClassOf relationship with 1 subclass case

4.1.2 subClassOf
R2: subClassOf with disjointWith concept mapping relationship

![Figure 5 subClassOf concept mapping relationship from xS to xT with xS disjointWith yT](image)

• Concept mapping set distribution
  Calculation: \( D'(\langle x_S, m, x_T \rangle) = 1 \)
  Reason: the same reason as that for concept mapping set distribution in R2.

• Side-effect concept mapping set distribution
  Condition: \( y_T \) is a concept in model \( T \), and is a direct subClassOf \( x_T \), and \( x_S \) disjointWith \( y_T \).
  Calculation: \( D'(\langle x_S, m, y_T \rangle) = 0 \)
  Reason: \( x_S \) disjointWith \( y_T \), so there is no instances intersection between set of instances of \( x_S \) and \( y_T \), \( |x_S \rightarrow y_T| = 0 \).

R3: subClassOf without disjointWith concept mapping relationship

![Figure 6 subClassOf concept mapping relationship from xS to xT without xS disjointWith yT](image)

• Concept mapping set distribution
  Calculation: \( D'(\langle x_S, m, x_T \rangle) = 1 \)
  Reason: the same reason as that for concept mapping set distribution in R2.

• Side-effect concept mapping set distribution
Condition: \( y_T \) is a concept in model \( T \), and is a direct \( \text{subClassOf} \) \( x_T \), and \( x_S \) is not \( \text{disjointWith} \) \( y_T \), which is a default concept mapping relationship between \( x_S \) and \( y_T \) if no mapping relationship defined between them. All concepts as \( y_T \) are \( \text{disjointWith} \) each other.

Calculation: \( D'(<x_S,m,y_T>) = 1/(N(y_T)+1) \)

Reason: the same reason as that for side-effect concept mapping set distribution in R1.

4.1.3 superClassOf

R4: superClassOf concept mapping relationship

\[
\begin{array}{c}
\text{X}_S \quad \text{subClassOf} \quad \text{X}_T \\
\quad \text{Y}_T
\end{array}
\]

Figure 7 superClassOf concept mapping relationship from \( x_S \) to \( x_T \)

- Concept mapping set distribution
  Calculation: \( D'(<x_S,m,x_T>) = 1/(N(x_T)+1) \)
  Reason: in this mapping relationship, \( x_T \) subClassOf \( x_S \), so the same reason as that for side-effect concept mapping set distribution in R1.

- Side-effect concept mapping set distribution
  Condition: \( y_T \) is a concept in model \( T \), and is a direct \( \text{subClassOf} \) \( x_T \), and \( x_S \) is not \( \text{disjointWith} \) \( y_T \), which is a default concept mapping relationship between \( x_S \) and \( y_T \) if no mapping relationship defined between them. All concepts as \( x_T \) are \( \text{disjointWith} \) each other, and all concepts as \( y_T \) are \( \text{disjointWith} \) each other.
  Calculation: \( D'(<x_S,m,y_T>) = 1/(N(y_T)+1) \)
  Reason: the same reason as that for side-effect concept mapping set distribution in R1. With \( |x_S \rightarrow x_T| = |x_S| \cdot 1/(N(x_T)+1) \), \( |x_S \rightarrow y_T| = |x_S \rightarrow x_T| \cdot 1/(N(y_T)+1) = |x_S| \cdot 1/(N(y_T)+1) \).

4.1.4 noMatchingPair

R5: noMatchingPair concept mapping relationship

\[
\begin{array}{c}
\text{X}_S \quad \text{noMatchingPair} \quad \mathbf{X}
\end{array}
\]

Figure 8 noMatchingPair concept mapping relationship from \( x_S \)

- Concept mapping set distribution
  Calculation: \( D'(<x_S,m,x_T>) = 0 \)
  Reason: since \( x_S \) noMatchingPair \( x_T \), any instance of \( x_S \) is not instance of \( x_T \), i.e. \( |x_S \rightarrow x_T| = 0 \).

4.2 Prediction of sets distribution for precision and recall

In this section, the calculation expression for the prediction of sets distribution (i.e. \( D'_DM \), \( D'_IM \), and \( D'_DM \cap IM \)) are presented based on calculation rules defined in section 0.

4.2.1 \( D'_DM \) calculation

By the definition in section 3.4.2, \( D'_DM = |DM|/|S| \). With the assumption of even instances distribution over concepts in SMQPM and the instance number of all concepts is 1 (i.e. \( |x_S|=1 \) defined in section 0, the value of \( |S| \) is the number of concepts in AK model \( S \), and \( |DM| \) can be calculated by summary of concept mapping set distribution and side-effect concept mapping set distribution from concepts of model \( S \) to \( T \). The concept mapping relationship from one concept \( x_S \) to concepts in model \( T \) can be 1 to 1 or 1 to multiple, so we use \( n \) to represent the set of concepts mapped from \( x_S \). Detailed calculation expressions are shown below, in which \( n \) is the number of mapping relationships (direct or indirect caused calculation rules) from \( x_S \) to \( T \), and \( NoC(S) \) is the number of concepts in AK model \( S \):
\[ D'(\langle x_S, m, x_T \rangle) = \sum_{j=1}^{n} D'(\langle x_S, m, x_T^j \rangle) (x_T = \{x_T^1, ..., x_T^n\} \subset T); \]

\[ D'_{DM} = \frac{|DM|}{|S|} = \frac{\sum_{i=1}^{NoC(S)} D'(\langle x_S^i, m, x_T^i \rangle)}{NoC(S)} \]

### 4.2.2 \( D'_{IM} \) calculation

\( D'_{IM} \) is prediction of set distribution based on concept mapping from \( S \) to \( T \) with indirect mapping, in which twice concept mapping relationships from concept of model \( S \) to \( C \), and from mapped concepts in model \( C \) to \( T \) will occur. \( D'_{IM} \) can be calculated in the same way as \( D'_{DM} \) does. The only difference is that we use \( D'_{C}(\langle x_S, m, x_T \rangle) \) to represent the prediction of set distribution of individual concept mapping relationship based on twice mapping relationships represented by triples \( \langle x_S, m, x_T \rangle \) and \( \langle x', m, x'' \rangle \), in which \( x \) represents the set of concepts in central model \( C \) mapped from \( x_S \), and \( x' \) represents the set of concepts mapped from \( x_T \). For distinguishability from other kinds of concept mapping set distribution, \( D'_{C}(\langle x_S, m, x_T \rangle) \) is named combined concept mapping set distribution, and its calculation can be described in two steps. In the first step, the concept mapping set distribution for each \( x_S \) (concept mapped from \( x_S \) to \( C \)) is calculated by summary of product of concept mapping set distribution and side-effect concept mapping set distribution from \( x_S \) to \( x_C \) and \( x_T \) to \( T \). In the second step, the concept mapping set distribution for \( x_S \) is calculated by summary of the concept mapping set distribution for each \( x_C \) mapped from \( x_S \). Detailed calculation expressions are shown below, in which \( n \) is the number of mapping relationships (direct or indirect caused calculation rules) from \( x_S \) to \( C \), and \( I(j) \) is a function of parameter \( j \) representing the number of mapping relationships (direct or indirect caused calculation rules) from \( x_C^j \) to \( T \):

\[ D'_{IM}(\langle x_S, m, x_T \rangle) = \sum_{j=1}^{n} \left( \sum_{k=1}^{I(j)} D'_{C}(\langle x_S, m, x_C^j \rangle) \times D'_{C}(\langle x_C^j, m, x_T^k \rangle) \right) \]

\( x_e = \{x_C^1, ..., x_C^n\} \subset C \),

\( x_T = \{x_T^1, ..., x_T^n\} \subset T \),

\[ D'_{IM} = \frac{|IM|}{|S|} = \frac{\sum_{i=1}^{NoC(S)} D'_{C}(\langle x_S^i, m, x_T^i \rangle)}{NoC(S)} \]

### 4.2.3 \( D'_{DM\cap IM} \) calculation

\( D'_{DM\cap IM} \) is prediction of set distribution of the instances that belong to both the \( DM \) and \( IM \) sets, and it can be calculated in the nearly same way as \( D'_{IM} \) does. The only difference is that the combined concept mapping set distribution in \( D'_{IM} \), whose concept mapping relationship (caused indirectly by twice concept mappings) does not belong to direct concept mapping relationships from \( S \) to \( T \), should be filtered out because this kind of combined concept mapping set distribution is not relevant to the concept mapping set distribution in \( D'_{IM} \). We use \( D'_{C}(\langle x_S, m, x_T \rangle) \) to represent relevant concept mapping set distribution in \( D'_{IM} \), and its calculations expression is the same as calculation expression of \( D'_{C}(\langle x_S, m, x_T \rangle) \) except for an additional parameter \( r (r=1 \text{ when } \text{combined concept mapping set distribution} \text{ is relevant, and } r=0 \text{ when it is not}) \). Detailed calculation expressions are shown below, in which other parameters except for \( r \) are the same meaning as in section 4.3.2:

\[ D'_{C}(\langle x_S, m, x_T \rangle) = \sum_{j=1}^{n} \left( \sum_{k=1}^{I(j)} D'_{C}(\langle x_S, m, x_C^j \rangle) \times D'_{C}(\langle x_C^j, m, x_T^k \rangle) \times r \right) \]

\( x_e = \{x_C^1, ..., x_C^n\} \subset C \),

\( x_T = \{x_T^1, ..., x_T^n\} \subset T \),

\[ D'_{DM\cap IM} = \frac{|DM \cap IM|}{|S|} = \frac{\sum_{i=1}^{NoC(S)} D'_{C}(\langle x_S^i, m, x_T^i \rangle)}{NoC(S)} \].
5 Cases of Quality Prediction of AK Sharing

5.1 LOFAR model
The domain model proposed for the AK documentation for the LOFAR projects, which are due to the long development of more than 10 years, and architectural decisions need to be shared and used over 25 years. The concept mapping between Astron domain model and refined Griffin core model is specified in Figure 9.

5.2 Central model
The refined Griffin core model [15] as shown in Figure 10 is taken as the central model for AK model mapping.
5.3 Kruchten’s ontology

Kruchten’s ontology proposed in [9] for documenting mainly Architectural Design Decision, and the concept mapping between Kruchten’s ontology and refined Griffin core model is specified in Figure 11. The exceptional concept mappings are: Structural Decision, Behavioral Decision, and Ban Decision are subClassOf Existence Decision, Constraint, Design Rule, and Guideline are subClassOf Property Decision, Organization, Process, Technology, and Tool are subClassOf Executive Decision. The Design Decision is sameAs Architectural Design Decision or Alternative based on the value of State. The concept of Risk, Requirement, Plan, and Design Element are not the concepts from Kruchten’s ontology, but the concepts traceable from Kruchten’s ontology, and we map them onto the concepts in the refined Griffin core model as well.

![Figure 11 Concepts in Kruchten’s ontology](image)

5.4 Mapping relationships with prediction

5.4.1 D’_{DM} Prediction of set distribution with direct mapping from model S to T

Table 1 Direct mapping relationships from LOFAR domain model to Kruchten’s ontology with $D'(<x_S,m,x_T>)$

<table>
<thead>
<tr>
<th>Concept of LOFAR domain model</th>
<th>Relationship/Rule</th>
<th>Concept of Kruchten’s ontology</th>
<th>$D'(&lt;x_S,m,x_T&gt;)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author</td>
<td>noMatchingPair</td>
<td>Design Element</td>
<td>0</td>
</tr>
<tr>
<td>Artifact</td>
<td>superClassOf</td>
<td>Design Element</td>
<td>1/3</td>
</tr>
<tr>
<td>Artifact Fragment</td>
<td>superClassOf</td>
<td>Implementation Element</td>
<td>1/3</td>
</tr>
<tr>
<td>Artifact Fragment</td>
<td>superClassOf</td>
<td>Design Element</td>
<td>1/3</td>
</tr>
<tr>
<td>Artifact Fragment</td>
<td>superClassOf</td>
<td>Implementation Element</td>
<td>1/3</td>
</tr>
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<td>Requirement</td>
<td>1/7</td>
</tr>
<tr>
<td>Concern</td>
<td>superClassOf</td>
<td>Risk</td>
<td>1/7</td>
</tr>
<tr>
<td>Concern</td>
<td>superClassOf</td>
<td>Defect</td>
<td>1/7</td>
</tr>
<tr>
<td>Concern</td>
<td>superClassOf</td>
<td>Plan</td>
<td>1/7</td>
</tr>
<tr>
<td>Concern</td>
<td>superClassOf</td>
<td>Cost</td>
<td>1/7</td>
</tr>
<tr>
<td>Concern</td>
<td>superClassOf</td>
<td>Scope</td>
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</tr>
<tr>
<td>Risk</td>
<td>equivalentClass</td>
<td>Risk</td>
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<td>superClassOf</td>
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<td>Existence Decision</td>
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<td>R3</td>
<td>Property Decision</td>
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<td>R3</td>
<td>Executive Decision</td>
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<tr>
<td>Decision</td>
<td>R4</td>
<td>Structural Decision</td>
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<td>----</td>
<td>---------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Decision</td>
<td>R4</td>
<td>Behavioral Decision</td>
<td>1/4*1/4</td>
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<tr>
<td>Decision</td>
<td>R4</td>
<td>Ban Decision</td>
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<td>Process</td>
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<tr>
<td>Decision</td>
<td>R4</td>
<td>Technology</td>
<td>1/4*1/5</td>
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</tbody>
</table>

**Non-C (S)**

\[
D'_{DM} = \frac{\sum_{i=1}^{NoC(S)} D'(<x_s^i, m, x_t^i>)}{NoC(S)}
\]

\[
D'_{DM} = \frac{(1/3+1/3+1/3+1/7+1/7+1/7+1/7+1/7+1/7+1/1+1/1+1/1+1/1+1)}{11} = 0.835
\]
### 5.4.2 D'IM Prediction of set distribution with indirect mapping from S to T through central model C

#### Table 2 Direct mapping relationships from LOFAR domain model to Core model with $D'(x_S,m,x_T)$ value

<table>
<thead>
<tr>
<th>Concept of LOFAR domain model</th>
<th>Relationship/Rule</th>
<th>Concept of Core model</th>
<th>$D'(x_S,m,x_T)$</th>
</tr>
</thead>
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<td>subClassOf</td>
<td>Stakeholder</td>
<td>1</td>
</tr>
<tr>
<td>Artifact</td>
<td>equivalentClass</td>
<td>Artifact</td>
<td>1</td>
</tr>
<tr>
<td>Artifact Fragment</td>
<td>subClassOf</td>
<td>Artifact</td>
<td>1</td>
</tr>
<tr>
<td>Concern</td>
<td>equivalentClass</td>
<td>Concern</td>
<td>1</td>
</tr>
<tr>
<td>Requirement</td>
<td>subClassOf</td>
<td>Concern</td>
<td>1</td>
</tr>
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<td>R3</td>
<td>Decision Topic</td>
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<td>Risk</td>
<td>subClassOf</td>
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<tr>
<td>Risk</td>
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<td>Decision Topic</td>
<td>1/2</td>
</tr>
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#### Table 3 Direct mapping relationships from Core model to Kruchten’s ontology with $D'(x_C,m,x_T)$ value

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Table 4 Indirect mapping relationships from LOAR domain model to Kruchten’s ontology through Core model with combined concept mapping set distribution \( D_{C}(<x_{S},m,x_{T}>) \) value
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5.4.3 $D'_{DM\cap IM}$ Prediction of set distribution of intersection of sets $DM$ and $IM$

$$D'_{DM\cap IM} = \frac{\sum_{i=1}^{NoC(S)} D_{r.c}(<x^i_s, m, x^i_t>)}{NoC(S)} = \frac{1/3+1/3+1/3+1/3+1/7+1/7+1/7+1/7+1/7+1/7+1/7+1/7+1/7+1/7+1/7+1/7+1/7+1/7+1/7+1/7}{11} = 0.680;$$

6 Future Work

We outline the following points as future work:

- More AK models should be covered and AK repositories should be included for the validation of mapping quality prediction models.
- Tool support for AK model mapping and the quality and cost prediction calculation needs to be implemented to automate and provide flexibility to these tasks.
- The relationships [9] between AK instances are lost in the currently proposed AK sharing scenarios, which result in traceability problems. For example, a relationship exists between AK instances of concept “Alternative” and concept “Decision Topic” in that some “Alternative” is proposed for some “Decision Topic” in a software architecture design. A solution that retains the relationships between AK instances for AK sharing needs to be investigated.

7 Reference