Constructing the Organisational Learning Model for the Utility Asset Management

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Abstract: Under the evolving environment, a utility company is required to improve the operation and maintenance of its physical assets usually in the forms of an asset management program. In the past, conventional financial techniques were used to quantify the asset's values and make decision relating to the asset accordingly. However, most of the time, the data and information required for the analysis are incomplete and even unavailable. This is due to the fact that it is not explicitly clear which data and information are required at the beginning of the asset's life cycle. This paper proposes an organisational learning model for the utility companies with respect to the asset management activities. CommonKADS is utilised as a tool to capture the knowledge associated with managing the assets from the learning processes of the utility company. A case study of substations operating in the distribution network in Thailand is presented. The results show that by applying the proposed methodologies, the learning processes within the utility companies can be categorised and explained by five major learning steps of breakdown, corrective, preventive, predictive, and proactive maintenances.

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1. Introduction

Under the evolving environment, utility companies are required, by business nature, to eliminate low value, high cost practices, and develop ones which can lower future costs in order to survive in this new environment. The effective management of assets plays an increasingly important role in optimising business profitability (Roda and Garetti, 2014). Typically, these main costs of the utility companies are associated with the installation, the operation and maintenance, and the decommissioning (Vetter et al, 2000). However, the costs associated with the installation and the decommissioning are fixed and primarily included in the planning stage. Hence, to meet the new challenge the utility companies need to improve the operation and maintenance of its assets by reducing these variable costs while continually maintaining the similar quality of services. And there will be better returns for shareholders and better asset management means better customer service and satisfaction (Sinha, 2007).

This usually comes in the forms of an asset management program. The key features of this asset management program are to control costs, reduce risks and improve the utility operation within a constrained operational budget. The crucial themes and concept include cost, service delivery, planning, maintenance, and risks (Mahmood et al, 2014). This is in contrary to the traditional view and method of the utility companies where it is believed that spending and system performance are directly linked (Glover, 2000). Basically, the four succession stages are acquire, deploy, operate and maintain, and retire (El-Akruti and Dwight, 2013). All activities involved in the asset management program can range from the replacement and the refurbishment of the assets to the management of the business and operational risks (Galusha, 2001). This is because under changing environment, both reliability and financial aspects are equally important. Since the utility companies concern with the short and long-term hypothetical replacement costs, these costs need to be declared and included in the asset management plan, as well as explained to the shareholders. Moreover, with some business constraints placed on the utility companies, new replacement may not be a practical solution (Lai, 2001). As a consequence, life extension beyond the designed asset life is also necessary, and plays an important role in the asset management program.

In asset life extension, the main business risks depend on the engineering design of the assets, the operational and maintenance practices, and the business requirements (Schuman and Brent, 2005)(Ostergaard and Jensen, 001). Regarding the life extension of the major equipment, the life-cycle assessment and replacement of the auxiliary parts of the major equipment must also be conducted. This method is usually known as 'Reliability Centred Maintenance' (RCM) which ensures the correct maintenance activities on where and when as well as indicating the design deficiencies (Beehler, 1997).

Moreover, the marginal cost is also another important consideration in the asset management's perspective. This is especially in the case where any major equipment has no operational margin. In this case, the utility companies typically have to decide whether the replacement or the refurbishment is an appropriate solution. Hence, it shows that asset management highly involves intensive knowledge and a lot of data and information. To efficiently manage the assets, the knowledge workers' collective experience in the operation and maintenance is required and plays a key role in the process.

In the past, the conventional methods to develop the asset management program have been based on the assumption that the data and information required is available and complete. However, practically, this is not always the case, and most of the time they are incomplete and unstructured. This is due to the fact that at the beginning of the asset's life cycle (first installation) nobody knows which data and information would be of important and required for the analysis (for example, in the 20 years' time). Hence, instead of rely solely on the incomplete and unstructured data, this paper proposes to develop the asset management program by modelling the learning curve of the workers who have been operating and doing the maintenance on the asset since its first installation. This learning curve provides and makes experiences of the workers in asset's operation and maintenance activities explicit, which in turn could be used as rule based or reasoning guidelines in the asset management program.

This paper is organised as follow; section 2 briefly reviews Knowledge Engineering, and discusses the usefulness of it and learning organisation theory in the development of an effective asset management program. Section 3 presents a typical learning model of the utility companies within an asset management context. Section 4 shows that Knowledge Engineering approach discussed in section 2 can assist the utility companies to capture, analyse and model this organisational learning process systematically. Case study and conclusion are then given in sections 5 and 6 respectively.

2. Knowledge Engineering and Learning Organisation

This section discusses a methodology proposed in this paper to assist in the development of the utility asset management program. The knowledge engineering methodology is applied to capture, analyse and model the knowledge from the learning process within the utility asset management context. In short, knowledge engineering is a newly emerging discipline influenced by an advance in the development of the information technology. Knowledge engineering provides the scientific methodology to analyse and engineer knowledge. In particular, the widely used methodology is CommonKADS which stands for a knowledge analysis and data structuring program (Schreiber et al, 2000).

Generally, learning process of the utility company starts from the beginning of the initial operation of its first substation. After that, this "how-to-do" knowledge occurs, and it is learned on the daily basis at all levels (i.e. individual, team, system and organisation). From the asset management's perspective, this includes the knowledge on "how-to" assemble and de-assemble equipment, schedule resources, diagnose faults and events, monitor incidents, and assess risks during operation and maintenance as well as adapting to business changes (Lai, 2001). Normally, this learning process is collectively gained over a period of time, and the knowledge can be lost with the workers when they leave an organisation.

As mention previously, data and information collected in all processes play an important role in the operation and maintenance of the assets (Galusha, 2001). By translating this information and data into useful knowledge, the asset management program can then be effectively developed. Knowledge engineering can assist the utility company in maintaining and making use of this otherwise lost knowledge systematically. It provides methodologies to design and construct knowledge systems. In other words, it provides heuristic approach to capture, analyse, model and utilise expert's knowledge within the organisation. Hence, together with knowledge engineering methodology (CommonKADS), the learning organisation theory is also utilised and applied in this paper. The organisational learning is defined as a continuous process of creating, acquiring and transferring knowledge accompanied by a modification of behaviour to reflect new knowledge and insights, and to produce a higher level asset (Garvin, 2000).

Eventually, IT-based knowledge management system can be designed, constructed and implemented. To implement this structured knowledge-based system, it requires some effective design techniques and tools provided by the knowledge engineering methodologies. These are for example, CommonKADS which is the EU de facto standard methodology for supporting design and implementation of knowledge system (Schreiber et al, 2000). CommonKADS or KADS has widely been applied in power business such as knowledge management for planning, operation and maintenance, pricing negotiation, asset management and regulatory issues.

3. Organisational Learning Model for Operating and Maintenance

From the asset management's perspective, the organisational learning processes of a utility company in operation and maintenance can be categorised and modelled as shown in Figure 1.

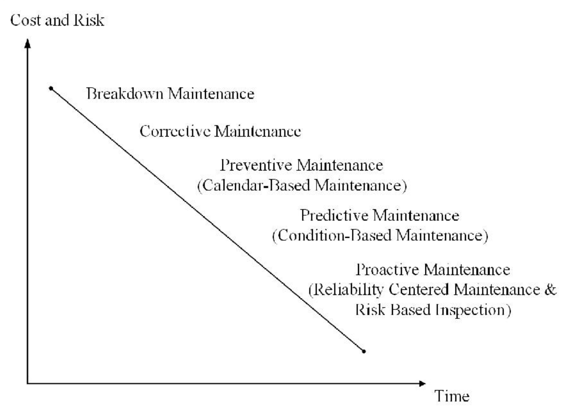

Figure 1. Utility's Learning Curve in Operation and Maintenance

Figure 1 shows the organisational learning model (learning curve) of the utility company in the operation and maintenance activities. This learning model is based on experience collectively gained over a period of time. Hence, it requires a step-by-step development from breakdown to proactive maintenance. In the breakdown maintenance scheme, equipment is de-assemble and assemble to get the basic knowledge. Corrective maintenance scheme represents knowledge on 'how-to' repair equipment when failures occur. In preventive maintenance scheme, most activities involve resource scheduling to avoid unplanned outages. Predictive maintenance scheme indicates the abilities of the knowledge workers to foresee the future faults and events based on present condition of the equipment. Finally, with more knowledge gained over an operating period, the proactive maintenance indicates abilities of the knowledge workers to assess the asset life time as well as its' parts which consequently assists the utilities in the decision making on the replacement or the refurbishment.

As shown in Figure 1, associated costs and risks reduce over time indicating better maintenance strategy. This is partly because more knowledge has been gained over a period of time. More detailed explanation of this proposed learning curve of the utility company is given in the following section where an application of knowledge engineering is also given.

4. Knowledge Engineering for Asset Management

The organisational learning model or the learning curve of the utility asset management comprises of maintenance schemes, and represents an organisation knowledge gained and developed through experience over a period of time. To capture, utilise and model this knowledge systematically, a knowledge engineering methodology is proposed in five steps of the asset operation and maintenance.

CommonKADS, which is one of widely used methodologies, is utilised as a tool to capture the knowledge associated with managing the assets from the learning processes of the utility company. CommonKADS offers some inference or useful templates to create knowledge framework (Schreiber et al, 2000). These include for example, templates for planning, diagnose, scheduling, monitoring and assessment. These templates provide useful guideline for interview, analyse, model and utilise knowledge of the substation operation and maintenance from the experts.

The following sub-sections demonstrate an appropriate template to capture the relevant knowledge.

4.1 Breakdown Maintenance

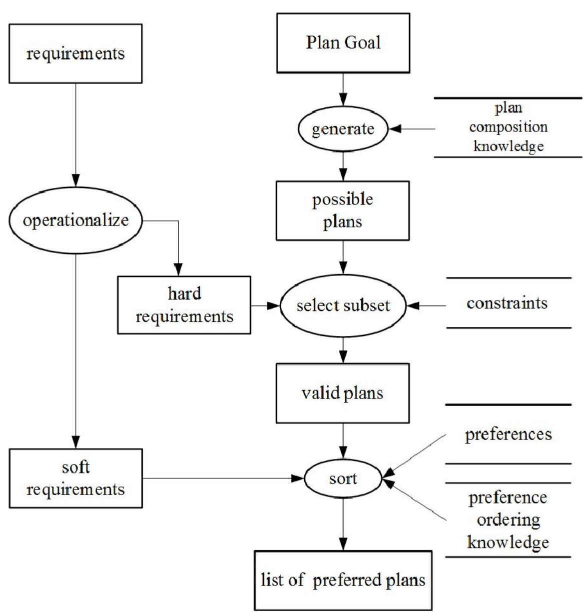

Figure 2. Planning Template

In the beginning, the knowledge from manufacturers and instruction manual books are thoroughly studied. Then, new knowledge on 'how-to operate' and 'how-to maintain' assets in real workplace situation is developed with regard to cost and risk associated with it. In this step technical supervisors are always required on hand to assist in some critical tasks. The working procedures in operation and maintenance are explicitly developed for knowledge sharing and dissemination among knowledge workers. This can also be called 'routine planning knowledge, and hence, the "planning template" is utilised.

Figure 2 shows the planning inference template selected to capture the knowledge in the breakdown maintenance scheme. The planning template in Figure 2 shows that both hard and soft requirements from the operation and management's perspective should also be included in the knowledge elicitation. Moreover, working constraints and preference ordering of the knowledge workers from their real experience need to be taken into account. Then, the working instructions can be developed for knowledge sharing and dissemination.

4.2 Corrective Maintenance

In the early period of the operation, the operators and maintenance workers collaboratively learn to diagnose the utility's asset, processes and failures. Experience and knowledge in failures and events are collectively gained by the workers. This allows the workers to develop the knowledge on 'how-to identify' the faults in each particular failure and/or event as well as costs and risks associated with it. This can also be called 'diagnosis knowledge'. Note that this knowledge is extended and enhanced from the breakdown maintenance. Hence, to capture this 'how-to-repair' knowledge the diagnosis inference template is selected.

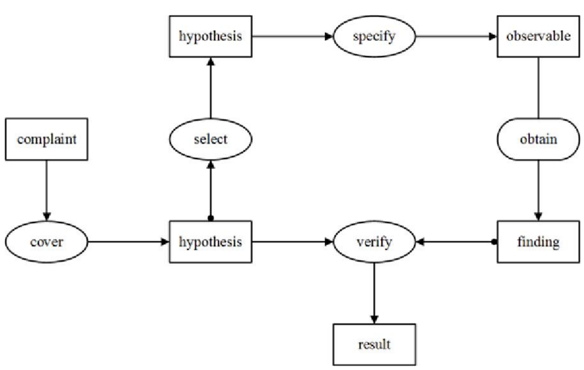

Figure 3. Diagnosis Template

Figure 3 shows the diagnosis inference template which is selected to capture the knowledge in the corrective maintenance. During the diagnosis, essential information is identified and extracted by the experts from the data acquisition system or reports of the problems encountered. Then, faults and events are analysed using hypothesis and test methods. Note here that, the expert's hypothesis and verification rationale are the main knowledge and reasoning issues in this expert interview.

4.3 Preventive Maintenance

With the knowledge gained in the previous step, the operators and maintenance workers can then attempt to schedule the activities and their existing local resources. This is to minimise costs in order to prevent unplanned outage from faults and unpleasant events. This involves the development of their resource's scheduling and optimisation techniques. This is also called 'Preventive Maintenance' or 'Calendar-Based Maintenance' scheme. Note that the opportunity costs and/or the availability are also taken into account in the scheduling. Heuristic-based techniques can be implemented to optimise the maintenance scheduling problems. Hence, the scheduling inference template is selected to capture this type of knowledge.

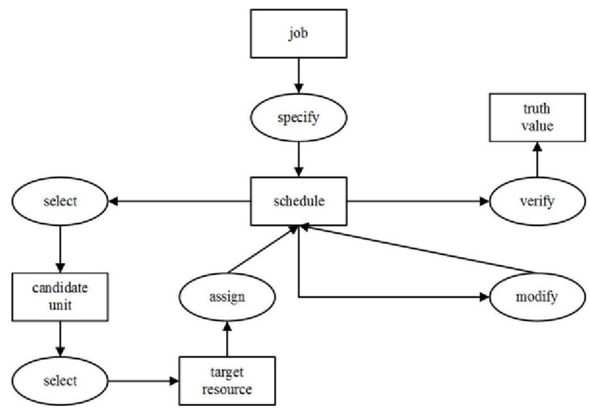

Figure 4. Scheduling Template

Figure 4 shows the scheduling inference template selected to capture the knowledge in the preventive maintenance scheme. As shown in Figure 4, it starts by identifying the preventive maintenance job. Then, the initial schedule is developed using the practical rules of the organisation in the selection and assignment of its units and resources. The important issue in this scheme is that the knowledge acquisition should address on the organisation experience/knowledge in modification and verification of the preventive maintenance. Moreover, it also covers some operational routines such as equipment test, exercise, visual inspection and adjustment.

4.4 Predictive Maintenance

With more knowledge gained over a period of time, this helps the workers to be able to detect some incidents or some conditions. In another word, this is ability to predict the likelihood of faults and events. With the ability to predict the potential future failure, this allows the appropriate operation and maintenance actions to be conducted immediately when a discrepancy conditions are found. This ability is called 'Predictive Maintenance' or 'Condition-

Based Maintenance'. As a consequence, the monitoring inference template is selected.

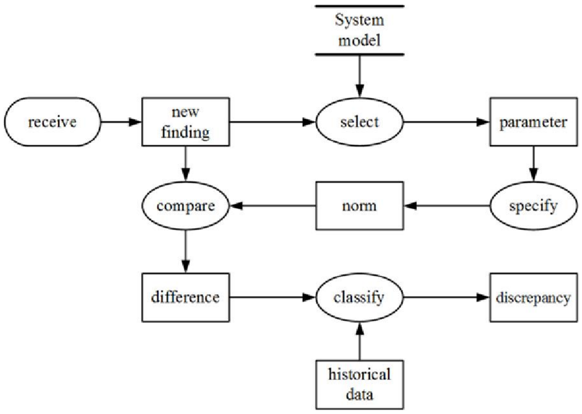

Figure 5. Monitoring Template

Figure 5 shows the monitoring inference template selected to capture the knowledge in the predictive maintenance scheme. With the ability to predict the potential future failure, this allows the appropriate operation and maintenance actions to be conducted immediately when a discrepancy conditions are found. As shown in Figure 5, field knowledge, especially new findings (information, parameters, process system models, normal condition of each parameter, comparison method between new findings and norm values, trends), must also be acquired. Note that the asset's parameters monitored can be either operating or inspecting parameters from the information relating to the utility's assets and/or infrastructure.

4.5 Proactive Maintenance

This maintenance scheme is based on historical records of equipment failures and its design information. This knowledge assists in the assessment of the equipment life time and its part's life-cycle, and also in the decision making process of the organisation to refurbish or replace some equipment proactively before its expected life time. Risk factors are also abstracted by the experts for each asset category. To categorise the types of the asset risks, knowledge on equipment design, failure history records, operation and maintenance practices, environment, disaster, health, and/or safety is necessary. This maintenance scheme is called 'Proactive Maintenance'. To reduce the risks by refurbishment and replacement, the methods such as 'Risk Based Inspection' and 'Reliability Centred Maintenance' can be utilised within this maintenance scheme. Hence, to capture this type of knowledge the assessment inference template is selected.

Figure 6 shows the assessment inference template selected to capture the knowledge in the proactive maintenance scheme. Based on the guideline provided by the assessment template (Figure 6), the scope of the asset management or case inference role can be initially classified by operation and maintenance experience. Moreover, risk factors are also abstracted by the experts for each asset category. To categorise the types of the asset risks, knowledge on equipment design, failure history records, operation and maintenance practices, environment, disaster, health, and/or safety is necessary (El-Akruti and Dwight, 2013). All possible norms and other specific norms for each risk factor must be specified. It is important that the experts are elicited on their heuristic techniques or practical assessment methods to evaluate the asset risks, life-cycle and marginal costs.

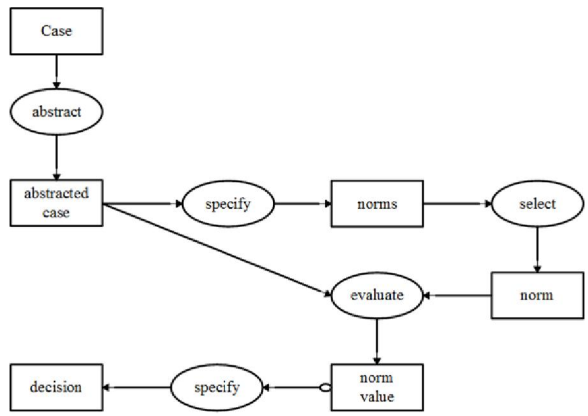

Figure 6. Assessment Template

According to the results of the asset evaluation, the asset management decisions could be to maintain or modify the current practices, refurbish or replace some equipment in order to minimise business risks or eventually develop asset management plan. Note here that it is more convenient to conduct the asset risk assessment and management activities during the turnaround period. If some risks are found but not urgent, the condition monitoring system should be implemented on the asset for the normal operation.

Eventually, to utilise the knowledge captured by these templates, an IT-based knowledge management system is realised in order to share and disseminate the asset management best practice. This is conducted by using and configuring a commercial software tool, called Microsoft Share Point. More detailed explanation of this software tool can be found in (Kemp et al, 2001).

With the proposed modelling methodology explained above, the cost and risk of a utility's asset can be modelled. Useful knowledge is translated into rationale for decision making activities regarding costs and risks. It can be seen from Figure 1 that the costs and risks of a utility's asset reduce over time with regard to actions taken.

5. Case Study

Here, a substation operating within the distribution network in Thailand is used as a case study to confirm the applicability and benefits of using the CommonKADS and learning organisation theory to capture and model the organisational learning processes systematically.

5.1 General Description of the Substations

In this paper, the group of substations operating within the distribution system in Thailand are used as a case study. This distribution system is owned and operated by one of the three utilities in Thailand. This distribution utility covers approximately 510,000 square kilometres of service areas. Its portfolio of physical assets includes network systems and more than 400 substations. The performance of these physical assets directly affects the reliability of the power system as well as its revenues. Hence maintenance activities of these assets are of important. More specifically, the knowledge workers who have been operating and doing the maintenance activities on the power circuit breaker which is one of the most important equipment in the utility's asset portfolio are chosen for the knowledge elicitation.

According to the financial plan of this substation, the substation's life was initially designed for 25 operational years, but now the average asset age is approximately 20 years. For operation and maintenance, the fiscal operational budget is approximately 5% of the total asset value per year. For the substation availability, the requirement is set such that the number of unplanned outage should be less than 2 times per year. Lastly, the major inspection or turnaround for each equipment should be done regularly to better suit the condition of the assets.

5.2 Research Methodology

A knowledge engineering exercise was conducted on the experienced workers who have been operating and doing the maintenance activities of the power circuit breakers within the selected substation. The Community of Practice (CoP) in the power circuit breaker was recruited for the interview purpose. This CoP comprises of engineers and technicians from different sections. The knowledge elicitation was completed by using structured interview on CommonKADS's planning, diagnosis, monitor and assessment templates.

5.3 Results and Analysis

With the knowledge engineering approach proposed in this paper, the asset management program of the chosen distribution utility's substation has successfully been developed. The tacit knowledge, typically embedded within each domain expert, could be gathered and made more explicit in the organisational wide context. This results in the knowledge being well structured and more manageable. To make use of the knowledge framework by constructing the IT-based knowledge system, the captured knowledge models were put into Knowledge Management software called Microsoft Share Point (Kemp et al, 2001). This software is selected because it provides decision support and e-learning environment.

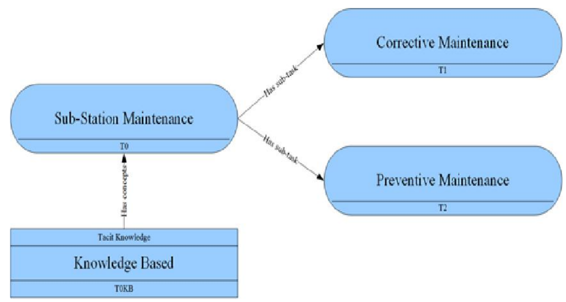

Figure 7. Task to Sub Task Knowledge Of Utility Asset Management

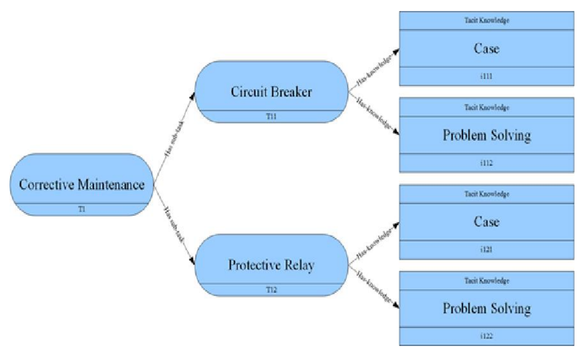

Figure 8. Corrective Maintenance of the Power Circuit Breaker

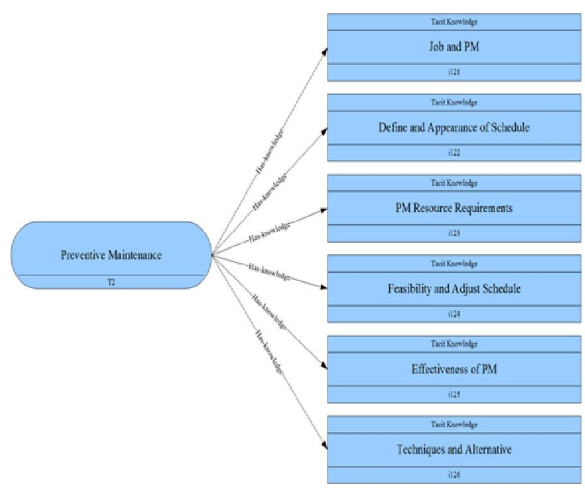

Figure 9. Preventive Maintenance of the Power Circuit Breaker

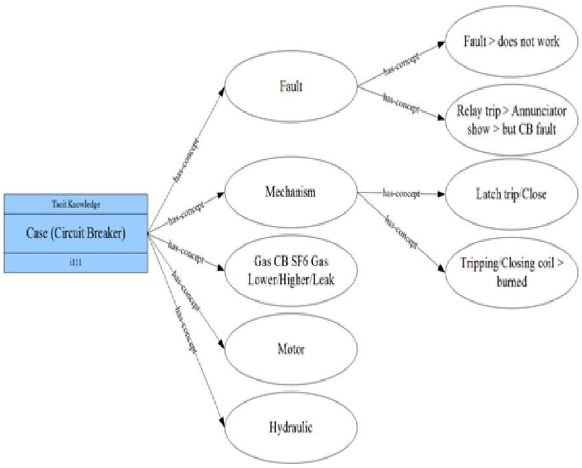

Figure 10. Inference to Domain Knowledge of Utility Asset Management

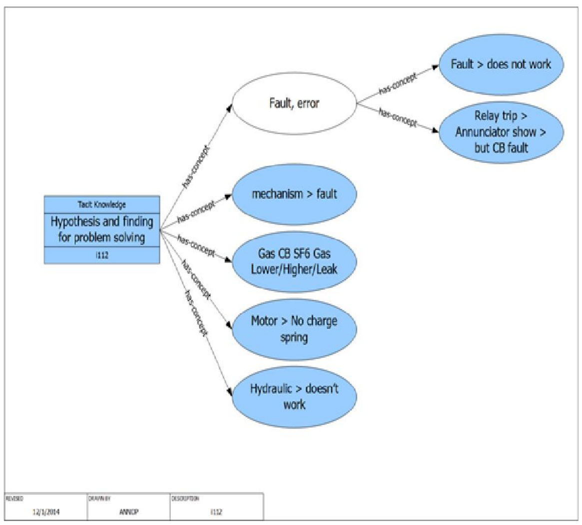

Figure 11. Inference to Domain Knowledge of Utility Asset Management

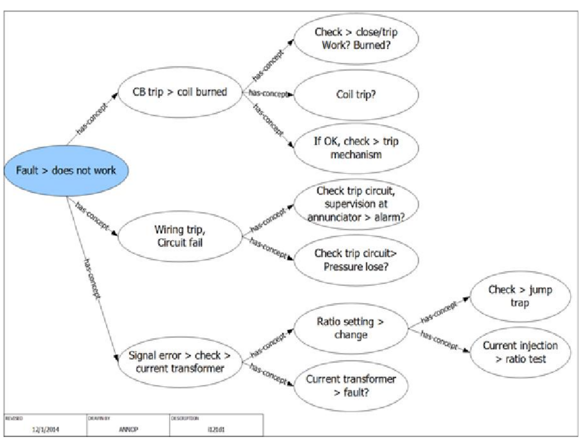

Figure 12. Domain Knowledge of Utility Asset Management

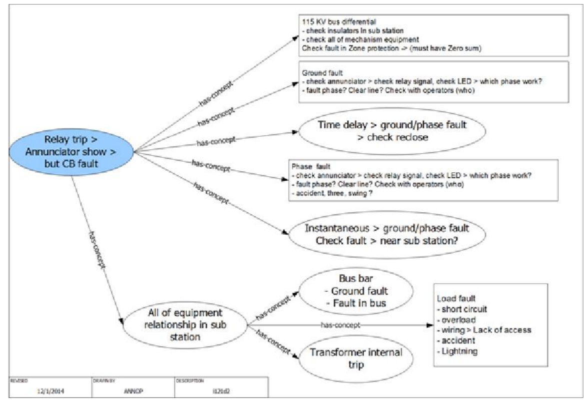

Figure 13. Domain Knowledge of Utility Asset Management

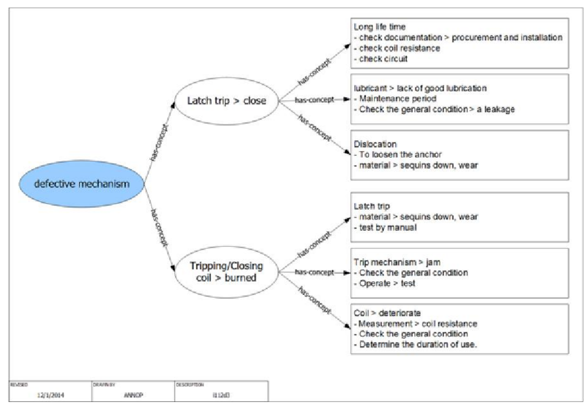

Figure 14. Domain Knowledge of Utility Asset Management

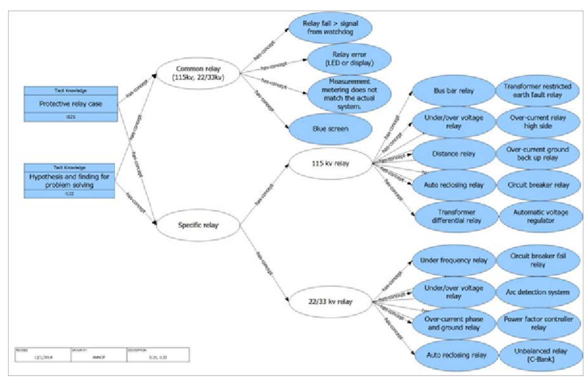

Figure 15. Domain Knowledge of Utility Asset Management

The organisational learning model for the utility asset management, in the paper on the power circuit breaker, can be systematically constructed and shown in Figure 7 - 15.

Figure 7 – 15 shows the captured knowledge in the operation and maintenance of the power circuit breaker in the substation. This knowledge is analysed and modelled according to the learning curve proposed in Figure 1. Interestingly prior to the knowledge elicitation session, the knowledge

workers could not classified their experiences which in turn makes it difficult to transfer this operation and maintenance knowledge to other within the organisation. However, with the knowledge engineering methodology utilised, the organisational learning model in the operation and maintenance can then be constructed and used to develop the utility asset management program.

The results of the research presented in this paper shows that the Knowledge Engineering methodology provides a structure to observe, capture, analyse and utilise the knowledge in the operation and maintenance activities systematically. This assists the utility companies in overcoming the most encountered problem of data/information overload but not effectively usable when it is needed. Moreover, the results demonstrate that Knowledge Engineering is another useful heuristic approach for modelling the asset management knowledge. This knowledge model can be useful for the development of a qualitative decision support system as well as the asset management best practices in the future.

Similar knowledge/experience model for the remaining maintenance actions of the organisational learning model are also constructed, but not shown in this paper due to limitation on numbers of pages. Collectively these knowledge models or the organisational learning model of the power circuit breaker can be utilised as rule based or reasoning framework in the utility asset management.

6. Conclusion

Knowledge engineering is another effective approach in the development of an asset management plan. It is essential to capture heuristics from the substation's community of practices. By using structured interview, CommonKADS inference templates can be applied to capture domain knowledge, especially operation and maintenance, and consequently construct a knowledge framework. From the utility's perspective, the asset management program requires the knowledge gained over a period of time through organisational learning experience with respect to breakdown, corrective, preventive, predictive, and proactive maintenances.

This paper shows that by applying the knowledge engineering and management methodologies, the learning processes within the utility companies can be categorised and explained by five major learning steps with respects to operation and maintenance experiences. The asset management framework applied in this paper requires the knowledge gained over a period of time through organisational learning experience with respect to corrective, preventive, predictive, and proactive operation and maintenances of utility's assets. This paper shows that by applying the Knowledge Engineering and Management methodologies, the rule based and/or reasoning guidelines for decision making activities on the utility's assets can be categorised and modelled with respects to operation and maintenance experiences. Moreover, the knowledge and experience capture method developed in this research can be embedded into day-to-day operation of workers.

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