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DEVELOPMENT OF AN ACTIVITY-BASED LESSONS LEARNED PROCESS MODEL AND A TOOL TO SUPPORT SCHEDULING DECISIONS IN CONSTRUCTION FIRMS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
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BY

ANIL YILMAZ

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FOR
THE DEGREE OF MASTER OF SCIENCE
IN
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Approval of the thesis:

DEVELOPMENT OF AN ACTIVITY-BASED LESSONS LEARNED PROCESS MODEL AND A TOOL TO SUPPORT SCHEDULING DECISIONS IN CONSTRUCTION FIRMS

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ABSTRACT

DEVELOPMENT OF AN ACTIVITY-BASED LESSONS LEARNED PROCESS MODEL AND A TOOL TO SUPPORT SCHEDULING DECISIONS IN CONSTRUCTION FIRMS

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November 2021, 126 pages

The construction industry still suffers from reaching critical objectives of projects like duration and budget. To deal with this situation researchers and practitioners realized the importance of knowledge management in the construction industry and put their increasing attention on it over the years. Especially, knowledge management utilization in planning and scheduling parts of construction management has made significant efforts to improve to meet projects objectives adequately. However, project knowledge capture and reuse in different projects have remained a major challenge for the construction industry. For this purpose, this study aims to introduce an activity-based lessons learned process model to integrate previous projects' lessons learned into scheduling to enhance consistency and accuracy in forthcoming projects' schedules. In this respect, the process model has been developed according to the requirements in literature review and needs analysis with construction industry experts. Then, the developed process model was evaluated by construction management professionals. A tool (ConSALL) corresponding to the process model has been implemented. A case project is demonstrated on the tool (ConSALL) and verified by experts from the construction industry. Findings show that the developed process model and the tool (ConSALL) have the potential to integrate lessons learned into the construction schedules to increase efficiency in durations estimation in future projects.

Keywords: Activity-Based, Construction Industry, Construction Schedule, Knowledge Management

ÖZ

İNŞAAT FİRMALARINDA İŞ ÇİZELGELEME KARARLARINI DESTEKLEMEK İÇİN AKTİVİTE TEMELLİ ÖĞRENİLEN DERSLER SÜREÇ MODELİ VE ARACININ GELİŞTİRİLMESİ

Yılmaz, Anıl
Yüksek Lisans, İnşaat Mühendisliği
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Kasım 2021, 126 sayfa

İnşaat sektörü proje süresi ve bütçesi gibi projelerin kritik hedeflerine ulaşma konusunda hala sıkıntı yaşamaktadır. Bu durumla başa çıkmak için araştırmacılar veya uygulayıcılar inşaat endüstrisinde bilgi yönetiminin önemini fark ettiler ve yıllar boyunca ilgilerini artan şekilde bu konuya verdiler. Özellikle bilgi yönetiminin inşaat planlama ve iş programı çizelgeleme bölümlerinde yararlanılması ile proje hedeflerini karşılamak konusunda önemli çabalar sarf edilmiştir. Bununla birlikte, proje bilgisinin elde edilmesi ve farklı projelerde yeniden kullanılması, inşaat sektörü için büyük bir zorluk olmaya devam etmektedir. Bu amaçla, bu çalışma geçmiş projelerin öğrenilmiş derslerinin iş programı çizelgesine entegrasyonu ile ilerleyen projelerin iş programı çizelgelemesinin doğruluk ve tutarlılığını arttırmak için aktivite temelli öğrenilen dersler süreç modelini tanıtmayı amaçlamaktadır. Bu doğrultuda, literatür taraması ve inşaat sektörü uzmanları ile yapılan ihtiyaçlar analizindeki gereksinimlere göre süreç modeli geliştirilmiştir. Ardından geliştirilen süreç modeli inşaat yönetimi profesyonelleri tarafından değerlendirilmiştir. Süreç modeline karşılık gelen bir araç (ConSALL) ortaya koyulmuştur. Bir vaka projesi araç üzerinde (ConSALL) gösterilmiş ve inşaat sektöründen uzmanlar tarafından doğrulanmıştır. Bulgular, geliştirilen süreç modelinin ve aracın (ConSALL) öğrenilen derslerin inşaat iş programı çizelgesine entegre edilmesi ile gelecekteki projelerde süre tahmininde verimliliğin artırılması hususunda bir potansiyele sahip olduğunu göstermektedir.

Anahtar Kelimeler: Aktivite Temelli, Bilgi Yönetimi, İnşaat Endüstrisi, İnşaat İş Programı Çizelgeleme

Dedicated to my wife and lovely family

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LIST OF ABBREVIATIONS

ALLPMS	Activity-Based Lessons Learned Process Model for Scheduling
ANN	Artificial Neural Networks
BIM	Building Information Modeling
ConSALL	Construction Industry Scheduling with Activity-Based Lessons Learned
CPM	Critical Path Method
DB	Database
DIKW	Data-Information-Knowledge-Wisdom Hierarchy
GDP	Gross Domestic Product
IT	Information Technology
LL	Lessons Learned
PFP	Partial Factor Productivity
TFP	Total Factor Productivity

CHAPTER 1

INTRODUCTION

As the importance of knowledge as a source of competitive advantage has been realized with globalization, knowledge management emerged as a critical task for companies to put them one step further in the competitive environment. Knowledge management is particularly important for project-based industries such as construction as processes should be in place for learning from projects and using lessons learned from previous projects in forthcoming projects. Learning from projects enabled by effective knowledge management brings continuous improvement for companies (Williams, 2008). On the other hand, utilization of knowledge management in the construction industry is rather difficult and complicated. The consequences of being a project-based industry include a massive amount of information that is accumulated throughout the project lifecycle, but this information may not be transferred effectively to other projects due to the one-off nature of construction projects. Therefore, if knowledge management strategies are not employed, companies may not take advantage of previous project knowledge in forthcoming projects (Özyurt, 2018; Woo et al., 2004), and may face similar problems due to poor capturing, storing, disseminating and reusing of knowledge. High staff turnover and people who do not share critical information within the company may hinder learning which signifies the importance of knowledge management in the construction industry (Haghgooie, 2012; Williams, 2008).

Planning and scheduling are critical parts of project management and important tasks for construction companies. Construction companies should execute and monitor the work schedule effectively throughout the project, and capturing and storing schedule-related tacit and explicit knowledge may bring advantages for project planning by enabling previous knowledge reuse in future projects. In the literature, it is stated that 70% of construction projects face project delays and cost overrun. Even, 14% of the construction projects exceed the project contract sum (Willmott Dixon, 2010; Dallasega et al., 2021). It implies that most of the projects deviate from the initial planning phase due to several reasons among which is insufficient planning (Ahankoob et al., 2012). In general, the quality of a schedule is dependent on the background and experience level of the planner, so a schedule prepared by a planner who does not have sufficient experience may lead to misleading project goals, accelerating cost and time overruns in construction projects (Faghihi et al., 2015). To deal with this situation companies should take advantage of previous project knowledge, in other words, lessons learned from previous planning practices. Capturing activity-level and project-level lessons learned from previous projects and utilizing them during the scheduling of current projects may improve planning process.

In this thesis, it is argued that activity-related lessons learned, both qualitative and quantitative information, should be captured, stored in a structured way so that they can be retrieved and reused for the creation of more accurate and consistent schedules in future projects. Based on this argument, the objective of this research is to develop an activity-based lessons learned process model for scheduling (ALLPMS) and demonstrate its utilization by a web-based application. Within the context of this process model first, it is aimed to capture and store both activity-based lessons learned information and activity schedule information from previous projects with the help of a taxonomy. Second, it is aimed to retrieve the schedule information to prepare a more accurate and consistent schedule and estimate durations in future projects.

The thesis is organized as follows: Chapter 2 presents "Literature Review" on "knowledge", "knowledge management", "learning from knowledge-lessons" and "project scheduling" for the project-based industries, mainly focusing on the construction industry. Chapter 3 introduces the "Research Objectives and Methodology" of the thesis. In Chapter 4, "Need Analysis" is depicted, which has been carried out with construction industry professionals/experts to find out the requirements and expectations of experts related to managing knowledge during scheduling in the construction industry. In Chapter 5, the activity-based lessons learned process model for scheduling (ALLPMS) is given. Within the context of this chapter, the main features of the model determined for information entry and retrieval according to expert evaluations are presented. In Chapter 6, the web application of the activity-based lessons learned process model for scheduling, named ConSALL, is introduced and implemented with a case project. Then, results are verified with two domain experts. Eventually, Chapter 7 concludes the thesis with major findings, limitations of the research, recommendations and suggestions for future studies.

CHAPTER 2

LITERATURE REVIEW

In this Chapter, findings of an extensive literature review conducted on “knowledge”, “learning from knowledge-lessons” and “project scheduling” are given. Particularly, knowledge management in the construction industry is discussed as well as its applications. The concept of “Lessons Learned” is presented by putting an emphasis on challenges and advantages of lessons learned applications, examples of lessons learned practices and strategies to implement lessons learned in the construction industry. In the final part of this chapter, how lessons learned can be implemented in project scheduling is elaborated.

2.1 Definition of Knowledge

It is obvious that as globalization increases and becomes dominant all around the world, thanks to the Internet, a huge amount of information is spread and transferred easily and quickly between different countries, geographic areas, companies and so on. Therefore, it is very important to deal with not only the financial capital and strength of the organizations but also with the creation of knowledge-based culture and climate in organizations to create a competitive advantage in business. Today, Gross Domestic Product (GDP) is mostly determined by knowledge analytics. In other words, quality and quantity of the knowledge that is obtained after the process of acquisition, storage, monitoring and evaluation in the production process have a significant effect on the determination of position in sectors of the economy, so the key factor of the success is mainly about how to manage the knowledge (Olubunmi, 2015). To understand the concept of knowledge management in each aspect, first knowledge should be investigated in general with its sub-categories, definition of knowledge, and types of knowledge.

There are plenty of definitions about what knowledge is in the literature. In literature, generally, the data-information-knowledge-wisdom hierarchy (DIKW) is used in knowledge definition. According to Ackoff (1989), wisdom is located at the top of the hierarchy and goes down as follows; understanding, knowledge, information and lastly, at the bottom, data. The categories that are located at the upper parts comprise the categories that are located at the lower parts. In this aspect, for example, information is obtained or transformed from data by analysis in many perspectives.

Also, Rowley (2007) describes Ackoff's DIKW hierarchy definition as the transformation process from data (an entity at a lower level in the hierarchy) to wisdom (an entity at a higher level in the hierarchy), as seen in Figure 1. Through this pattern, it is implicitly stated that information is obtained or created by using data, knowledge is obtained or created by using information, wisdom is obtained or created by using knowledge.

Figure 1:The DIKW Hierarchy (Rowley, 2007)

On the other hand, Davenport and Prusak (1998) describe knowledge as "a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating, and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organizations, it often becomes embedded not only in documents or repositories but also in organizational routines, processes, practices and norms.” As understood in the explanation mentioned above, the emphasis is that knowledge has no certain rules or logical processes, so it is neither data nor information, it includes both data and information inside.

2.1.1 Types of Knowledge

When the literature is examined about how researchers define the types of knowledge, most of the researchers in their studies divide the knowledge into two divisions: Tacit knowledge and explicit knowledge (Kivrak et al., 2008; Polanyi, 1967; Ozorhon et al., 2005). The first separation of knowledge in terms of explicit and tacit is proposed in the article “the Tacit Dimension” by Polanyi (1967) (as cited in Kivrak et al., 2008)).

Explicit knowledge is expressed as electronic data or paper-based documents stored in computers or in related authorities so that companies or entities could get the knowledge easily (Ozorhon et al., 2005). Additionally, Lin et al. (2006) stated that explicit knowledge including words and numbers later can be retrieved, stored, transferred, so it is easy to manage knowledge. As an example, reports, articles, contracts, e-mails between different parties, specifications, design codes, textbooks, visual documents like photos can be categorized as explicit knowledge in the organizations (Lin et al., 2006; Kivrak et al., 2008).

Contrary to explicit knowledge, Polany (1967) (as cited in Kivrak et al., 2008) express tacit knowledge as highly individual and specific to the context. That’s why, it is not totally possible to make it in a structured way, formalize or codify due to keeping the knowledge inside the humans’ mind. In another study, Özorhon et al. (2005) express tacit knowledge as a secret inside the person’s beliefs, feelings, norms, and it can only be stored if tacit knowledge is transferred into explicit knowledge. In the construction industry, the know-how of skilled staff can be categorized as tacit knowledge, and it can be shared and transferred via face-to-face communication, lesson learned, practices between communities (Carrillo & Chinowsky, 2006).

Several studies in the literature reveal that tacit knowledge has a crucial effect on companies and organizations. This is because know-how and experiences inside the human mind play an important role to benefit from tacit knowledge for future projects. In the project-based companies, know-how or expertise experiences of staff are exposed to shifting different companies, projects and so on. However, companies still do not benefit from this tacit knowledge that would be highly important for competitive advantage (Koskinen et al., 2003; Easterby-Smith & Lyles 2011). There is still no certain and effective way of transferring tacit knowledge into explicit knowledge. Due to the different characteristics of tacit and explicit knowledge, as can be noticed easily, there would be a remaining part while transferring tacit knowledge into explicit, but this condition should not prevent us from emphasizing transformation (Eken, 2017). So, companies or organizations should try to apply different approaches to keep all information inside the organization. One of the ways is mostly related to information systems and knowledge networks (Eken, 2017).

2.2 Knowledge Management

As mentioned in previous parts, with the effect of globalization, organizations, companies or different entities started to realize the crucial impact of knowledge in the competitive environment. Organizations and companies also realized that the features like service quality, responsiveness, variety in product, customer-oriented management put them one step forward in the competitive environment. This concern pushed them to look for an answer to that specific question: How could they manage the knowledge explicitly? The organizations or companies that tried to come up with a solution to this question generated value to their organizations or companies (Wiig, 1997; Gao et al.,2018).

In the literature, there are several definitions of knowledge management by different authors. In the study of Davenport (1998), the process of obtaining value from intangible assets is defined as knowledge management. According to Dayan and Evans (2006), knowledge management comprises a process of capturing, documenting, reusing, transferring, sharing, retrieving knowledge in an ordered and logical way to create a competitive advantage among competitors by increasing innovation. Alavi and Denford (2011) express knowledge management as a combination of socio-cultural, organizational, behavioral and technological-information-related perspectives (e.g. data mining, data acquisition). The important point is that there is no meaning of effective knowledge management without combining technological factors with social factors.

When project-based organizations are considered, at the end of the project, experts or skilled staff who accumulate valuable assets throughout the project tend not to share the knowledge with others, then organizations face a high probability of loss of valuable assets in situations like retirement, turnover. Thus, effective knowledge management procedures applied in the company might probably solve the problem mentioned above by collecting, storing and disseminating valuable assets inside the company (Haghgooie, 2012; Williams, 2008). Another advantage of knowledge management in organizations is preventing the probability of occurrence of similar problems again and again because the lessons learned from previous practices' experiences prohibit the occurrence of similar problems (Lin, 2008; Carrillo, 2004). In the study of Williams (2008), several advantages of knowledge management are mentioned as follows.

- It provides a consistent background for future projects' initial planning and risk analyses.
- It can be used for improving the project management process.
- It gives an opportunity for validation of knowledge obtained from previous projects in upcoming projects.
- It gives a chance to compare the knowledge within different projects.

- It provides an evolution of strategy and continuous improvements both in phases of the cycle and different cycles thanks to the evaluation of knowledge obtained from previous experiences.
- It allows observing the positive effect on staff's performance.

Knowledge management is divided into several sub-categories in different research. In Zaremba and Smoleński's (2000) study, phases of knowledge management are classified as “identification, acquisition, retention, maintenance, search and retrieval, distribution, selling and logistics of knowledge”. Bhatt (2001) defines the knowledge management cycle as “knowledge creation process, knowledge validation, demonstration and utilization”. Figure 2 represents Bhatt's (2001) knowledge management process activities. The author also states that these activities enable organizations or individuals to learn, reflect, unlearn and relearn. In another study, Kasvi et al. (2003) categorize the knowledge management cycle in four main parts; “creation of knowledge, administration of knowledge, dissemination of knowledge, utilization and productization of knowledge”. Tseng and Lin (2011) define it as “creating, securing, capturing, coordinating, combining, retrieving, and distributing knowledge”.

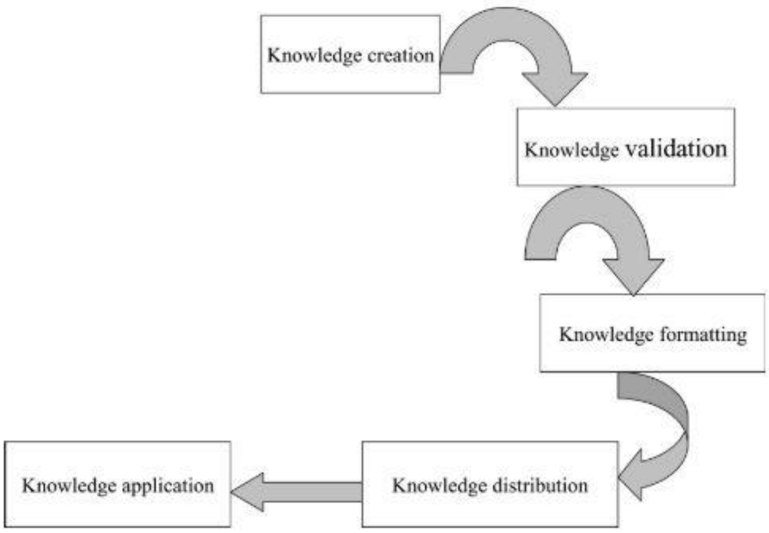


Figure 2:Knowledge Management Process Activities (Bhatt, 2001)

2.3 Knowledge Management in Construction Industry

As global competition increases, organizations become larger, companies spread out to different regions all around the world, construction industry becomes concerned about knowledge management as well (Carrillo, 2004). According to the literature review study of Yu and Yang (2018) on knowledge management in the construction industry, Figure 3 represents the change in published researches in the category of knowledge management in the construction industry between 1995 and 2015 among 217 publications. It is clearly seen that there is an exponential increasing knowledge management trend in the construction industry. However, although knowledge management is applied much more in different areas, there is still a lack of effective implementation of it in the construction industry (Robinson et al., 2004). Also, the main source of knowledge management in the construction industry are employees who have gained, learned and shared the experiences from previous projects (Ribeiro, 2009). In the following sections, firstly, the limitations and advantages of knowledge management in the construction industry are examined. Then, knowledge management applications in the construction industry are discussed.

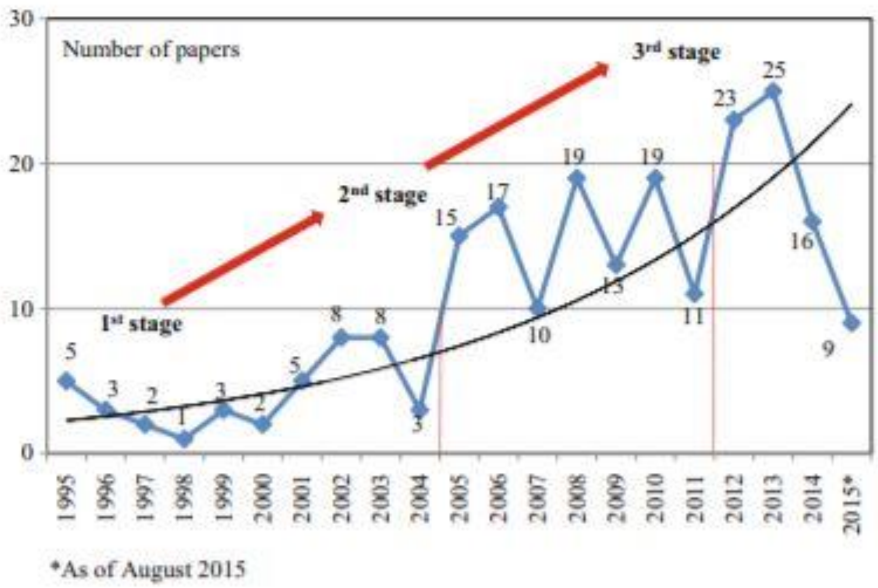


Figure 3: Number of Papers Published between 1995 and 2015 (Yu & Yang, 2018)

2.3.1 Limitations of Knowledge Management in the Construction Industry

In the construction industry, the fact that there exist different stakeholders, such as contractors, sub-contractors, suppliers, clients, consultants and other factors that mostly come from fragmentation due to the project-based nature of the construction industry, such as different project characteristics, extensive market competitors, etc. revealed the necessities, importance and challenges of knowledge management (Erkan, 2007). Other challenging characteristics are the unstable nature of the construction industry, constraints in schedule, budget and quality, being short-term and task-oriented. All these characteristics of the construction industry make knowledge management implementation hard in terms of coordinating, storing, and reusing knowledge (Tserng et al., 2009). Consequently, due to the mentioned characteristics, knowledge can get lost easily (Özorhon, 2004; Özyurt, 2018).

Although construction companies are good enough at storing knowledge, they are not good at retrieval, transfer and sharing of knowledge. Due to the aforementioned conditions, experiences that are accumulated from solutions to the problems may not transfer to the outside of the project. Thus, organizations lose the opportunity of reusing the knowledge in similar problems in different projects. As a result, the project faces massive expenditure in terms of time, cost, labor, quality and safety (Woo et al, 2004; Özyurt, 2018). When a project is completed, the project server is shut down generally. Additionally, people who are engaged in the project take the copy of explicit and tacit knowledge with them and look for another project. Both situations create a big challenge for upcoming projects in terms of saving, spreading and reusing the knowledge including contracts, documents, pictures, e-mails etc. Consequently, the information with great value might be destroyed significantly. Ly et al. (2005) also list several factors that show the necessities of knowledge management in the construction industry, as seen in Figure 4.

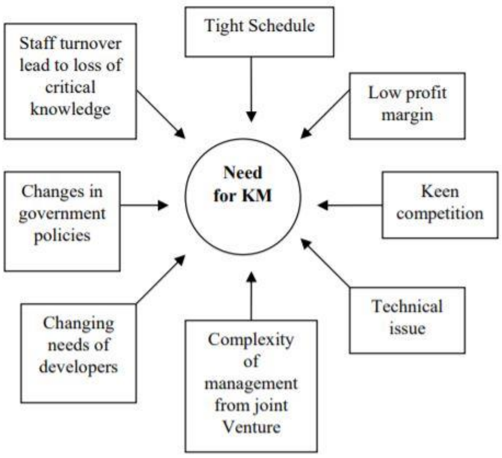


Figure 4: Factors Contributing to the Need for KM in the Construction Industry (Ly et al., 2005)

2.3.2 Advantages of Knowledge Management in the Construction Industry

Kamara et al. (1999) state several advantages in their study. The first one is that the knowledge obtained before can be utilized for the operation and maintenance stage. Secondly, it enables firms to reuse collective learning. Additionally, knowledge management in the construction industry provides development in working conditions, improvement in health and safety aspects, encouragement to further engagement to knowledge management tools and methods, better quality in end-product, conserving the environment and natural resources (Vakola & Rezgui, 2000).

In the book titled "Knowledge Management in Construction", written by Anumba et al. (2005), the benefits of knowledge management in the construction industry are defined as follows;

- Continuous improvement can be caught for future projects through the use of the lessons learned from previous projects.
- It provides effective interaction thanks to knowledge transfer between participants, departments, stages, and organizations.
- It gives great potential to prevent failure that repeats again and again.
- It provides a bridge between employees' and organizations' know-how to decrease the gap between them.
- It gives priority to responding to clients' needs.
- It encourages the reinforcement of team knowledge in organizations.
- It allows storing or retaining of tacit knowledge that provides great opportunity against loss in the condition of staff retirement, leave or die.
- It provides a more agile and adaptive environment against changing conditions.
- It decreases the uncertainties and ambiguity so the risks can be minimized concurrently.

2.4 Lessons Learned

Companies or organizations focus on seeking effective solutions to compete with their competitors in a globalized environment. With the effects of this situation, they put great efforts on continuous improvement of four key categories: lower costs, on-time delivery, improved quality, and fewer accidents (Paranagamage et al., 2012). One of the ways to deal with such a competitive environment is the effective reuse of knowledge acquired through previous experiences for future practices. In other words, LL systems are a part of knowledge management solutions for military, commercial and governmental organizations (Weber et al., 2003; Carrillo, 2005).

In the literature, there are many definitions with similar ideas about LL. Schindler and Eppler (2003) define LL as "key project experiences which have a certain general business relevance for future projects". According to Secchi (1999) (as cited in Weber et al., 2003), LL are the knowledge that comes from gained experiences. In another definition, Stewart (1997), (as cited in Weber et al., 2001), defines LL as guidelines, tips, or checklists about the successes and failures of organizations. Bickford (2000) explains LL as good practice and an innovative approach to discourage the reoccurrence of similar events. In addition to the above-mentioned explanations, Carrillo (2005) emphasizes the LL in terms of damage to the company's reputation and budget.

When LL are implemented into the organizations' culture effectively, it brings great advantage in the management of time, better profits, good relations, and connections between companies and clients for upcoming projects (Carrillo, 2004). Also, LL are used as the process or method of benefiting from previous information to make better decisions for the future. They can be implemented over operational and project-level works (Vignos, 2014). Also, lesson learning encourages better learning of executed works, and it is the key factor for better improvement (Paranagamage et al., 2012). LL are not only important for learning the failures while executing the project, but also critical for learning projects' successes. Gained experiences might be both positive like a successful mission and negative like a failure on a mission. Although failure or success seem like they only matter for the current situation, all these LL reinforce the future positive results (Weber et al., 2003).

Although there are several advantages of LL and great investments towards the LL systems, it is obvious that effectively benefitting from LL is rather limited in organizations (Orange et al., 2009). In the survey of Milton (2010) on 74 organizations, just 40% of organizations are satisfied with LL application. In another survey that was carried out with 522 participants, 62% of organizations implemented the LL system. (Williams, 2007).

Rowe and Sikes (2006) state that learning lessons should be spread over the project cycle, it should not be only at the end of the project. This is because this prevents the loss of information due to staff turnover, loss of information as time passes and so on. They also divide the LL process into five steps in terms of capturing and using:

1. Specify remarks and recommendations that could create important value for upcoming projects,
2. Document and share the findings,
3. Analyze and organize the LL to implement the results,
4. Store LL in a database,
5. Retrieve to benefit from LL for ongoing projects.

The main components of a generic LL system are presented in Figure 5.

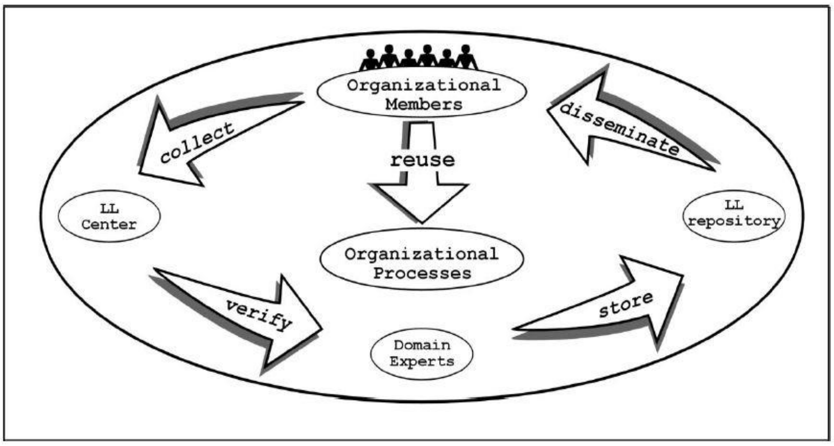


Figure 5: Generic LL Process (Weber et al., 2001)

Similar to the challenges mentioned in knowledge management, Cooper et al. (2002) explain the main challenges about the ineffective implementation of LL in the projects. The first reason is that different projects have different constraints and dynamics, so it is difficult to make similarity assessments between projects. The second reason is about unwillingness to share successes and failures throughout the project lifecycle. The last reason is related to the hardness of implementing systematic assessing and learning from staff's experiences due to the movement of staff to other organizations, the retirement of staff and so on.

Another perspective of the LL system is post-project review. Post-project review is one of the main inputs for LL. It is important in terms of disseminating the knowledge across different divisions and teams. Anbari et al. (2008) state that the database that can be obtained from post-project reviews brings crucial information about customer profiles, and it analyzes the environment that might affect the success of further projects. Also, it provides a comprehensive project plan that addresses all the project management knowledge areas. Busby (1999) mentioned about major benefits and drawbacks of post-project reviews in Table 1.

Table 1: Benefits and Drawbacks of Post Project Reviews (Busby, 1999)

Benefits	Drawbacks
• Allows employees to assemble the different experiences and draw coherent conclusions. • It allows employees to consultant others to know the outcome of their performance. • What employees learn from doing a project is disseminated to others who may have to do similar tasks in the future.	• They take time which means it incurs a cost. The beneficiaries are future projects, not the current one. • Reviews involve looking back at potentially embarrassing situations. • Employees are reluctant to engage in activities that lead to blame, criticism or recrimination. • Many people believe that you learn from your own experience and that others without that experience cannot learn from it.

2.4.1 Lessons Learned in the Construction Industry

LL systems in the construction industry are initiated with capturing, organizing, validating and storing good and bad experiences in a formal and structured way. Then, they are disseminated among different teams and parties in the project to take advantage of LL for future reuse and achieving organizational goals (Fong & Yip, 2006). Unfortunately, LL systems are not applied commonly and effectively in the construction industry. According to the survey that was conducted by Fong and Choi (2009), the most common situation faced in construction projects LL process is that the successes or failures are not being recorded or stored during the project execution time effectively. Another situation is about the unwillingness of staff to share bad experiences. This might result in missing the opportunity for future projects or lawsuits due to failures. The last finding from the survey is that captured or stored experiences are not disseminated across project participants, so they are kept in their minds. In the following sections, challenges and advantages of LL, different LL models and applications, and strategies to implement LL effectively in the construction industry will be reviewed in detail.

2.4.1.1 Challenges of Lessons Learned Practices in the Construction Industry

Carrillo et al. (2013) carried out a survey with regional and head officers who are responsible for LL practices. This study summarizes the barriers of current LL practices as follows.

- Process: Although it is known that LL practices should be applied throughout the project, most of the companies or organizations just carry out LL practices at the end of the construction project. Additionally, project reviews at the end of the projects are carried out by specific personnel i.e., the absence of different perspectives. Also, sharing LL within different projects is still another limitation in the construction industry.

- Reluctance to obtain external advice: It is realized that people do not want to learn from others' failures or share their bad practices with the project participants.
- Duplication of workload: The fact that there are no consistent formats in the LL report increases the hardness of getting similar information and result in duplication of workload.
- Lack of perceived value: There is no formal and connected way to get knowledge from previous projects. Additionally, team members are not informed, trained, or forced to perceive the importance of LL practices.
- Legal issues: LL practices are avoided due to negative consequences of failures or problems that are identified in the LL system.
- Inadequate communication: There exists a lack of communication between head office and teams that are on site. Also, the lower-level staff is not integrated into the decision-making process, so LL in the lower level is generally neglected. This causes the loss of valuable information for future reuse.
- Time constraints: Due to the tight schedule, the perception in a construction site is that the only important issue is finishing the work that staff is responsible for.
- Culture: Culture encompasses most of the practices mentioned just before. Most of the participants who attended the survey believe that there should be supportive learning culture in organizations to make the process more efficient.

In the survey study of Fong and Yip (2006), professionals indicate that there is not suitable or enough time to carry out LL practices. Also, it is mentioned that a lack of effort in transferring the LL across different projects decreases the positive impact on organizational learning. Carrillo (2004) states that the main obstacles behind LL implementation are related to a lack of senior-level support and vision. Furthermore, inadequate organizational culture for LL and unwillingness to share bad or good experiences are two main barriers for LL implementation in construction industry (Al-Ghassani, 2003).

The survey conducted by Paranagamage et al. (2012) reveals that the most common barriers to LL in the construction industry are “a lack of incentive, a lack of learning culture, a lack of outlets to share LL, a lack of technical infrastructure, obtaining senior management support, unawareness of value-added”. According to the survey, the most common obstacle is a lack of incentive followed by a lack of learning culture. In this study, other obstacles mentioned by survey participants are as follows: Time constraints due to tight project schedule for LL practice, unwillingness to share failures, the generic implementation of LL at the site.

2.4.1.2 Advantages of Lessons Learned in the Construction Industry

Similar to the advantages of knowledge management implementation, the direct and general advantages of LL in the construction industry are continuous improvement in processes and procedures and creating competitive advantage in the sector (Caldas et al., 2009). Gibson et al. (2007) mention several advantages such as the chance to develop future performance in the construction industry, solution development before problems occurrence, avoidance of adverse solutions and so on. Paranagamage et al. (2012) also mention similar advantages such as learning from previous knowledge to avoid repeating mistakes for future projects, encouraging innovation. In general view, an increase in resource efficiency, more satisfied customers, staff career improvement are obtained for companies.

In the study of Eken (2017), LL bring to organizations difficult to measure advantages. These advantages are enabling knowledge dissemination, project cost-benefit with an increase in profits, common implementation of best practices, diminish in rework, more satisfied workers, better application for future projects.

2.4.1.3 Studies and Implemented Lessons Learned Practices in the Construction Industry

LL practices consist of people, processes and tools that enable organizations to acquire, analyze, store and reuse the information or experiences that add value to organizations (Caldas et al., 2009). Paranagamage et al. (2012) define the practices for LL in the construction industry. These are post-project reviews, company intranet-extranet, face-to-face meetings with the project team, telephone conversation, brainstorming, knowledge repositories, minutes of meetings, project files, communication of practices, technical forums, skills and expertise database and video conferencing. According to the survey in the study, post-project reviews are the most common technique with 68% in the construction industry. Company intranet-extranet, face-to-face meeting with the project team, telephone conversation has the percentage of usage with 64%, 62% and 32%, respectively. Other practices are less popular (less than 32%). According to the findings in the study, face-to-face meetings with the project team and post-project appraisal are the practices that are more common and more informative compared to other techniques. Apart from the techniques mentioned above, there are other LL methods available in the construction industry such as “company Wikis, appraisals, tender approval meetings, customer satisfaction surveys, performance reviews, subcontract reviews, personal development reviews and training workshops” (Paranagamage et al., 2012).

Allen and Barnes (2004) mention that Federal Highway Administration implemented an LL program that aims to provide continuous improvement in the highway projects. In that program, upcoming projects utilize the previous highway projects’ information. East and Fu (1996) propose a new computer program, called the Lessons-Learned Generator. According to the study, frequently used comments are evaluated in terms of usefulness, generality, and content stability. Then, they are abstracted to make easily accessible by different teams and participants. In another study, Kartam and Flood (1997) propose “the Constructability Lessons Learned Database (CLLD)”. This database has the ability to automatically acquire, organize and apply crucial construction information from daily tasks. Cushman (1999) introduces the Cross-Organizational Learning Approach (COLA) that combines the set of tools and methods. The proposed model aims to increase feedback quality and organizational learning with learning-focused, value-added reviews or decisions. Fong and Yip (2006) focus investigation on the application of LL systems in the construction industry by conducting a questionnaire. Udeaja et al. (2004) focus live capture and reuse of project knowledge in construction by the CAPRICON project.

Carrillo et al. (2013) propose a project learning roadmap to improve LL practice in the construction industry. The aim behind the approach is to derive the most appropriate lessons with the most appropriate time and format. Project learning roadmap addresses three main parts: “The key elements” that are essential to bringing about change in practices, “the action” that is undertaken by leaders in a corporate manner and “an implementation guide” that aims to support the approach with checklists. Deshpande et al. (2014) aim to manage knowledge efficiently via building information models (BIM). The proposed method and framework have the ability to capture, store, classify and disseminate knowledge from BIM models for design and construction processes. Ferrada et al. (2016) introduce an LL system that focuses to overcome the limitation of LL implementations. Mobile cloud-share workspace is developed to enhance knowledge management in the construction industry. In the study of Oti et al. (2018), LL knowledge management is integrated with BIM. Combining the nonstructured query system with the BIM model provides linking LL information to the model. It enables participants to reuse LL to enhance knowledge. Eken et al. (2020) developed the web-based LL IT tool (LinCTool) that focuses LL management processes and improvement in organizational learning. This model facilitates the knowledge capturing, storing and disseminating across different projects.

2.4.1.4 Strategies to Implement Lessons Learned into the Construction Industry

In the study of Fong and Yip (2006), it is observed that professionals in construction sites do not have enough time and resources to handle LL implementations, so a dedicated person like a knowledge manager should follow the maintenance of the LL process efficiently. Moreover, professionals state that there should be an LL validation process between knowledge manager, top manager and LL committee, and validated LL should be disseminated across organizations by e-mail or written documents. Examining such advice and recommendations, Fong and Yip (2006) proposed a model that is made up of 4 steps to improve the efficiency of LL practices in construction projects. The first step is analyzing and digesting the existing widely used applications of LL practices in different areas extensively. The second step is training the whole staff from the uppermost level to the lowermost level in the project to create a culture among staff and to perceive the importance of the application of LL. Thirdly, the knowledge manager should be in an active role for the initial stages to establish the culture. The last step is that all the phases related to LL practices in the project should be monitored in detail. Figure 6 represents an overview of the LL process.

Carrillo (2004) proposes another strategy to perform successive procedures for LL practices in a convenient way.

- It should be prescribed in a consistent manner and applied to all projects, especially for complex projects that have large potential in terms of knowledge acquisition.
- It should be inspected and evaluated periodically from project initiation to completion in order to not lose the LL as time passes, key personnel move to another project or retire, pressure occurs over personnel due to resource and time constraints and so on.
- It should be spread to different teams, even supply chains so that the root cause of problems can be examined from different perspectives and ideas.

- There should be a fixed and consistent template to make the dissemination of LL across all projects easily and logically, and they should be stored electronically to make them ready to access.
- These practices might be available via intranets.

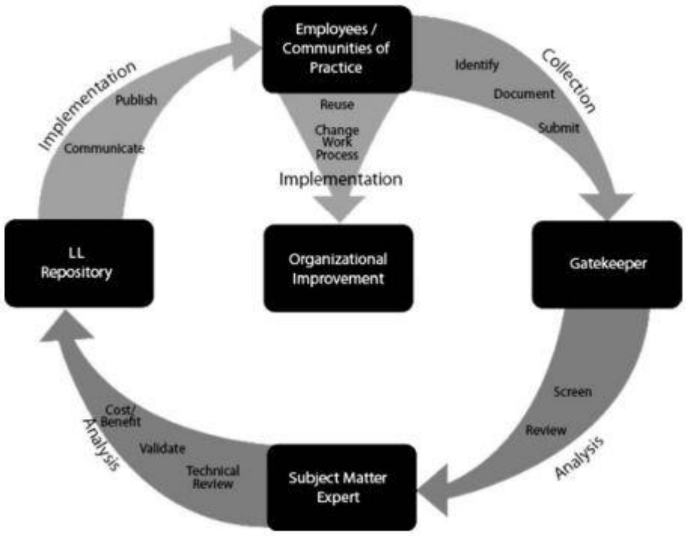


Figure 6: An Overview of the LL Process (Caldas et al., 2009)

2.5 Project Scheduling in the Construction Industry

In the "Construction Project Scheduling and Control" book (Mubarak, 2021), a schedule is defined as the determination of the "timing" and "sequence" with interrelation in overall project completion time and deals with answering what, when, by whom, where, who, why questions. It can be seen that good planning brings a high rate of return like saving time, money, effort, change order, claims and disputes. When inverse relation between time of planning and time of execution is considered, a lack of planning causes an increase in the likelihood of occurrence of such undesired situations. Furthermore, the schedule provides critical information for stakeholders.

- The contractor makes sure that the schedule meets the dates that were agreed on at tendering stage in order not to face undesired consequences like penalties.
- It gives an opportunity for planning specific or critical activities in advance.
- The schedule provides great coordination between different participants, such as different sub-contractors.
- The schedule enables the owner or contractor to monitor cash flow periodically. Also, it gives chance to prove claims due to delays.
- It improves work efficiency with effective project control.

In the literature, it is stated that 70% of construction projects face with time overrun and cost overrun. Even, 14% of the construction projects exceed the project contract sum (Willmott Dixon, 2010; Dallasega et al., 2021). So, in the construction industry, the planning process is vital to complete the project on time and within the budget. When scheduling is considered as a crucial part of the planning process, to achieve project parameters mentioned before with higher productivity, construction organizations should execute and monitor the work schedule effectively throughout the project in terms of time, cost, resources, etc. (Faghihi et al., 2015).

When the construction industry is considered as traditional and fragmented, the occurrence of several disputes among project participants, i.e., clients, contractors, sub-contractors, consultants is common due to duration allocation to the activities, relationship logic between activities, procedures to implement activities and so on. One of the main problems that are faced in construction projects is the gap between planning and actual resource and information due to uncertainties. In other words, it was seen that the variance is significant between what was planned at the planning stage and what happened or actualized at the end of the project. Workflow mostly deviates from the initial planning stage. (Ahankoob et al., 2012). As a result, ineffective management of the planning process might result in a significant amount of cost overrun and project delay (Ahankoob et al., 2012). At this point, while preparing a schedule for a project, the background and experiences of the person who prepares the schedule play an important role. In case of misunderstanding the scope of the project by the scheduler, it might result in cost and time overrun, mislead the project's goals and objectives and so on (Faghihi et al., 2015). Although there are several implemented methodologies, research and tools for general project management, there is still not an effective scheduling and proper monitoring way that meets the project-related needs. To deal with this undesired condition, the root causes of problems should be determined and identified by taking advantage of previous knowledge, LL.

In the literature, there are two main knowledge management approaches about scheduling perspective in the construction industry. The first approach is related to the development of the construction schedule. There are plenty of approaches for this type of scheduling approach. These are mostly related to optimization tools and artificial intelligence such as case-based reasoning and knowledge-based, model-based, genetic algorithm, expert systems, neural networks and so on (Faghihi et al., 2015). For case-based reasoning and knowledge-based approach, it has the ability to come up with a solution to present problems from a formerly practiced situation (Aamodt & Plaza, 1996). For genetic algorithm approach, it is a meta-heuristic optimization method that is suited for solving multi-objective problems like construction schedules (Konak et al., 2006). Expert systems are generated to solve problems like human decision-making abilities by reasoning about knowledge like the If-Then statement (Mcgartland et al., 1986). For artificial neural networks, it acts as pattern recognition like all-or-none characteristic of nervous functions (Faghihi et al., 2015). Several research papers on this type of knowledge management for scheduling are presented in Table 2.

Table 2: Several Research Papers on Construction Scheduling

Category	Study Description	Source
Case-Based Reasoning & Knowledge-Based Approaches	The research introduces a knowledge-based project network generator (GHOST) from a set of activities to generate a schedule with logical relationships.	(Navinchandra & Sriram, 1988)

Table 2: Several Research Papers on Construction Scheduling (continued)

Case-based Reasoning & Knowledge-based Approaches	The focus of the study is to identify a work breakdown structure and precedence relations by mimicking the decision process of expert staff so that it enables inexperienced schedulers to improve productivity by developing a knowledge-based prototype system for planning and scheduling.	(Benjamin et al., 1990)
	An artificial intelligence system that is integrated with Microsoft Project software, Case-based project management assistant (CaBMA), is presented. Functions are capturing cases from project plans, generating project plans from captured plans, preserving the consistency of the whole project schedule.	(Xu & Muñoz-Avila, 2004)
	The study aims to generate a single construction schedule with several alternatives-options by case-based reasoning application, also reuse of previous project experiences.	(Tauscher et al., 2007)
Model-Based	The paper presents computer-interpretable models for automatic generation of construction schedules by elaborating higher-level activities into suitable lower-level activities to link schedules of various levels of detail with five attributes; domain, constituting activities, activity sequencing, constituting objects, and resource requirements.	(Fischer & Aalami, 1996)
	Automated generation of construction planning from 3D is presented in the study according to vertical and horizontal relationships between construction components.	(de Vries & Harink, 2007)
Genetic Algorithm	It is carried out research to obtain optimal planning and scheduling for repetitive construction projects. In the study, a multi-objective optimization model for the planning and scheduling of repetitive construction projects is proposed. The aim is to obtain minimum project duration and maximum crew work continuity by generating and evaluating optimal construction plans.	(Hyari & El-Rayes, 2006)

Table 2: Several Research Papers on Construction Scheduling (continued)

	Genetic algorithm implementation (for resource optimization) to construction scheduling with/out resource constraints is presented.	(Toklu, 2002)
	The paper investigates to find out the ideal point by integrating the adaptive weight obtained from previous generations for time-cost optimization.	(Zheng et al., 2004)
	The approach is based on obtaining information from the BIM of a project to develop construction sequencing for the installation of the project elements by using the genetic algorithm concept.	(Faghihi et al., 2014)
Expert System	An explicit hierarchical rule-based framework, MASON, is described on masonry construction duration estimation.	(Hendrickson et al., 1987)
	Integration of construction scheduling with CAD drawings. The logic is extracting data from CAD drawings, activity breakdown, determination of relations between activities, generating construction scheduling, respectively.	(Wang, 2001)
Neural Networks	It is aimed to get more flexible, powerful, maintainable, and reusable software that presents construction scheduling, cost optimization, change order management by using ANN.	(Karim & Adeli, 1999)
	ANN-oriented single machine to obtain schedule with the operation, deadline types, setup time, processing time, due date time variables are presented.	(Rondon et al., 2008)
	Automatic construction scheduling activity precedence network, finish-to-start relation, is presented by using ANN.	(Golpayegani & Parvaresh, 2011)

In the second approach, research focuses on LL-knowledge management (tacit or explicit) of the scheduling perspective in the construction industry. On the other hand, there is much less research that focuses LL from the schedule level in terms of tacit and explicit knowledge management in the construction industry. In this perspective, one of the problems is that each project is considered separate or unique, and the knowledge or LL are not transferred or disseminated across different projects. To overcome this problem, Tserng and Lin (2004) developed construction activity-based knowledge management (ConABKM) system. When the activity is selected to get knowledge from previous projects, the system provides the reuse of domain knowledge and experiences of similar activities of previous projects and available activity-related knowledge of the current project automatically.

In summary, although there is various research on managing knowledge in construction projects, there are only limited studies on how LL from previous projects can be integrated into scheduling. The aim of this thesis will be to fill this research gap and develop a learning process model for construction projects in the light of expectations from practitioners, which will be depicted in the forthcoming sections.

CHAPTER 3

RESEARCH OBJECTIVES AND METHODOLOGY

3.1 Problem Definition

It is stated that 70% of construction projects face time overrun and cost overrun. Even, 14% of the construction projects exceed the project contract sum (Willmott Dixon, 2010; Dallasega et al., 2021). When the construction industry is considered as an experience-based discipline, knowledge or experience accumulated from previous projects plays a very important role in the successful performance of new works. Unfortunately, the live capture and reuse of construction project knowledge have remained a major challenge that has not been adequately addressed, and lessons learned systems are not applied commonly and effectively in the construction industry. Especially, in the planning process of construction projects, a lack of planning effort causes an increase in the likelihood of occurrence of project delay and cost overrun. When scheduling is considered as a crucial part of planning process, to achieve project parameters mentioned before with higher productivity, it is seen that construction organizations do not benefit from previous schedule information with the support of accumulated tacit and explicit knowledge-lessons learned for both activity and project level throughout the project in general.

3.2 Research Objectives

Based on the above problem definition, the objective of this thesis is to develop an activity-based lessons learned process model for scheduling for construction companies. The process model is expected to;

- Have a theoretical background that is based on literature survey findings

- Meet expectations of domain experts about the utilization of lessons learned from previous projects during scheduling.
- Be utilized in practice with a web-based application.

3.3. Research Design and Methodology:

Based on the research objectives, a research process is designed, and its steps are given in Figure 7.

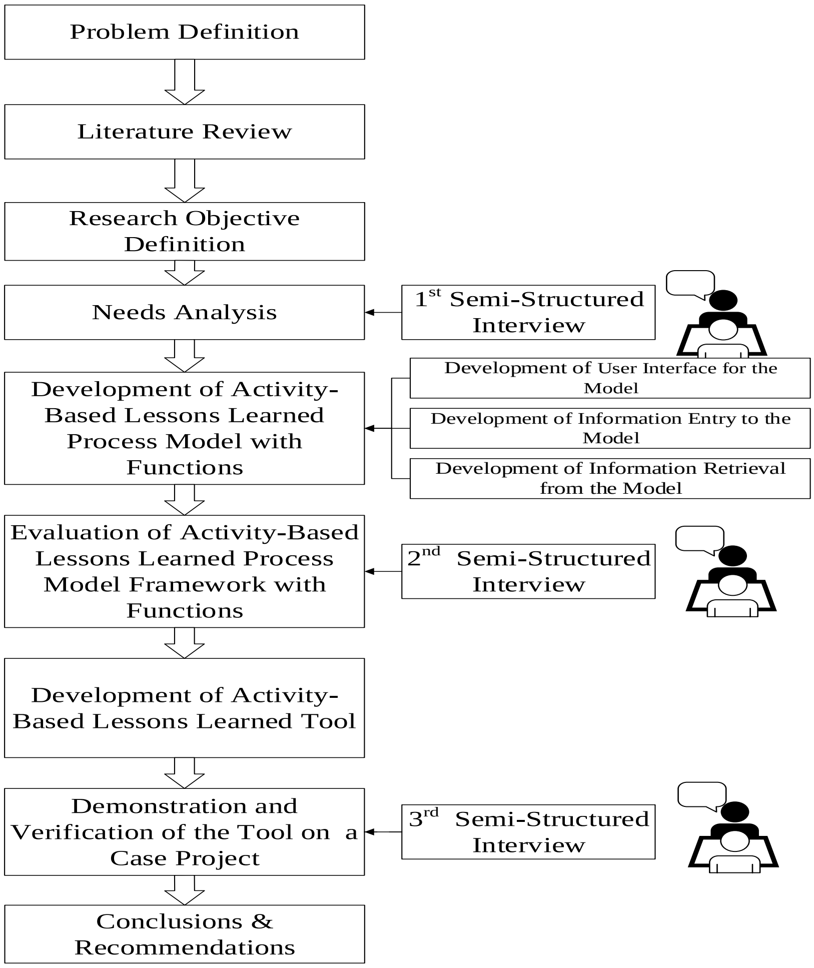


Figure 7: Steps of Research

3.3.1 Needs Analysis

After investigating the literature and determining the research objectives of the thesis study, a needs analysis has been carried out. Semi-structured interviews with domain experts are chosen as the research method. Six construction industry professionals have participated in the needs analysis study. An interview form that states problem definition, literature review findings and research objective was sent to the experts to get crucial information about the points that are important and should be improved in current practices. The interview form is provided in Appendix A. The results of the needs analysis will be given in Chapter 4.

3.3.2 Determination of the Activity-Based Lessons Learned Process Model for Scheduling Framework with Functions

While developing the ALLPMS framework, an activity-based LL taxonomy was developed with an extensive literature review and results of needs analysis. This taxonomy provides classification and categorization of activities in a structured and consistent manner to enable users to enter and retrieve project activity-based information easily. Additionally, this taxonomy enables users to classify the different projects' activity data in a structured way such as activities' names, planned dates, actual dates, activity productivity rates/unit man-hours and so on. Determined taxonomy is divided into 5 main categories with their sub-categories. With this, activity LL can be stored and retrieved easily from solutions of similar cases that can be used to create a new potential solution for the existing problem. The proposed activity-based lessons learned taxonomy is designed as both sufficiently detailed and also meeting general needs easily for construction companies, and it can be customized according to the company's specific needs for further adaptation for different companies. Then, through the literature, factors are determined that may affect the activity productivity rates/unit man-hour throughout the project lifecycle. When the activity is actualized, factors that affect activity are recorded to estimate similar activity's productivity rate/unit man-hour for future projects. When preparing a schedule for the tender stage or baseline for project execution, these activities' productivity rate/unit man-hour information with affecting factors and their impact rates and available LL related to activity in taxonomy can be used for more accurate activity duration estimation and consistent project schedules.

3.3.3 Evaluation of the Lessons Learned Model on Scheduling Framework with Functions

After the preparation of the framework that is mentioned in the previous section, the 2^{nd} semi-structured interview was conducted with four experts who have long-term experience in the construction industry to evaluate the framework from different perspectives. For the 2^{nd} semi-structured interview, a different set of people (except one expert) are preferred compared to 1^{st} semi-structured interview. In the 2^{nd} semi-structured interview, the form that includes major functions and components, and the user interface of the ALLPMS framework in detail was shared with the experts to get general opinions, recommendations & comments about the framework. After comments and recommendations on framework evaluation, the final version of the framework was developed. The interview form is provided in Appendix C.

3.3.4 Development of the Tool on Activity-Based Lessons Learned Process Model on Scheduling

Activity-based Lessons Learned Process Model on Scheduling was made up of three main components. The first component is "User Interface for Model". Within the context of this component, "Knowledge Manager", "Knowledge Facilitator" and "Knowledge User" are defined as roles for the authorization system, and the definition of the roles and distribution of the roles are explained in related chapters. The second component is "Information Entry to Model". In this component, two types of knowledge, "Activity-Related Lessons Learned Entry" and "Activity-

Related Productivity Rate (Unit Man-Hour) Information Entry", are captured and stored in the system with the aid of "Taxonomy" and "Activity Attributes". The last component is "Information Retrieval from Model". "Information Retrieval from Model" section focuses the utilization and facilitation of this knowledge for reusing purpose with the aid of "Filtering Taxonomy Development" by using "categories" in "taxonomy" to find related activities LL, "Filtering by Activity Attributes" uses "activity attributes" to narrow down the scope and "Productivity Rate/Unit Man-Hour Information Retrieval" to retrieve the similar activities with affecting factors and impact rate. Three main components will be explained in detail in the following sections.

3.3.5 Demonstration of Applicability of the Tool on a Case Project

After the tool was developed, a demonstrative case project was conducted to verify the tool's applicability in practice. "Dormitory Construction Project" was used to demonstrate the tool's functions and its effectiveness was verified by two experts from the construction management and planning division. For the 3rd semi-structured interview, a different set of people are preferred compared to 1st and 2nd semi-structured interviews. Only one expert is the same for three semi-structured interviews.

The details of various steps of research will be given in the next chapters.

CHAPTER 4

NEEDS ANALYSIS

4.1 Steps of the Needs Analysis

A needs analysis was carried out with six construction industry professionals/experts to find out the points that need further improvement in the construction industry.

The professionals/experts who participate in the needs analysis are construction experts and academicians who have direct relations with construction project management, especially in construction planning and cost control division. Before conducting needs analysis between experts from the construction industry, a form was prepared and sent to the experts via e-mail. The form constitutes 3 main parts. In Part 1, personal information about experts' backgrounds & experiences in terms of educational and professional life was obtained. In Part 2, general information about the proposed thesis study objective was introduced. In Part 3, 2 general questions were asked to the interviewees to determine both specific and general needs in the construction industry within this context. Then, face to face interview was carried out with each expert/professional via video call to make the objective and details of the needs analysis clear. The interview form is given in Appendix A. General descriptions of Part 1, Part 2 and Part 3 are as follows:

In Part 1,

- To get general information and to define profiles about experts' professional careers in the construction industry, division, positions and experience information were asked to each expert separately. According to the survey conducted by construction professionals, the information about respondents is presented in Table 3.

Table 3: Respondents Information

Respondent	Division	Position	Experience
Expert 1	Construction Project Management	Lead Planning and Cost Control Engineer	9 Years
Expert 2	Construction Project Management	Academician and Planning Expert	10 Years
Expert 3	Construction Tender Management	Lead Tendering and Proposal Engineer	7 Years
Expert 4	Construction Project Management	Senior Planning & Claims Management Engineer	13 Years
Expert 5	Construction Project Management	Senior Planning and Cost Control Engineer	18 Years
Expert 6	Construction Project Management	Lead Planning and Cost Control Engineer	9 Years

In Part 2,

- Brief information about problem statements/ observed problems in practice is defined to the interviewees in the construction industry.
- The gap in the literature about the problem definition in the construction industry is
- According to the gap in the literature, the general scope of the thesis study is proposed extensively. In this session, possible features and components that meet the requirements of the gap in the literature and the proposed scope of the thesis study are presented to give a general idea to the interviewees. Then, a possible target group that might facilitate from research objective is mentioned in the form.

In Part 3,

- In the first question, general ideas (pros, cons or neutral) about possible features & components that meet the requirements of the gap in the literature and proposed scope of thesis study were asked to the interviewees. By asking this question, it is aimed to determine points or areas that still lack perceived value, and should be emphasized & desired, improved, took attention to different perspectives to be considered in the construction practice.

- In the second question, recommendations and comments about the proposed scope of the thesis study were asked to the interviewees to determine what should be added, developed, emphasized further on the model. The idea behind this question is to avoid getting stuck to the same horizon and look at it from experts' points of view. By doing so, the needs or points that are overlooked while doing research could be brought to the light and investigated in detail.

4.2. Findings from Interviews

Responses of each interviewee regarding 1st question of Part 3 are as follows:

- Expert 1 stated that "utilization of previous project data for schedule management is very limited in the construction industry due to lack of organized and reliable data from previous projects. Because of that, duration, relationship, productivity rates and cost information of activities are mostly estimated by expert judgment. Since this information is changing according to the location of the project, experience of labor, requirements of the owner, climate conditions, etc., the accuracy of estimations of experts is very low. In the light of the above information, the establishment of such knowledge management tool will increase the accuracy of estimations, which as a result will help projects to be completed on time, on budget and with fewer disputes."
- Expert 2 stated that "the construction industry definitely needs a tool that is defined in the scope of the thesis for benchmarking purposes. Developing schedules with an assisting knowledge management tool would improve the quality of the overall planning process."
- Expert 3 stated that "the knowledge integration is a very crucial part for the successful construction operation of the companies. The Board of

management of the construction companies generally wants to apply their experience in the new projects to overcome any problem before they arise. Therefore, I can say that the idea behind the thesis is solid and the need is valid. The integration of the knowledge into the scheduling of the new projects will provide effective management and minimize the possible problems. Even highly experienced companies and managers continue to make the same or similar mistakes while facing familiar problems. However, in this industry, the professionals generally keep the information to themselves to be more valuable for the companies. They try to solve the problem without providing information to anybody, even the board of management if they somehow play a role in the creation of the problem. Therefore, obtaining information from the ones who have the knowledge is a huge work. The most challenging part of the knowledge management topic is this issue. Another con is the integration of the previous data to the scheduling of a new project. Defining the similarity is a very challenging issue. As all the writers say, each project in the construction sector is unique. The application of the previous knowledge will be suitable to a certain degree."

- Expert 4 stated that "Although the proposed model that purports to integrate lessons-learned data and scheduling program is promising, it should be clarified for practical implementation."
- Expert 5 stated that "Paying less attention on scheduling logic always ignores benefits of scheduling for project management. Scheduling should be kept alive during project execution. Keeping the system alive needs people who are trained well about scheduling technic. Trained manpower always has an important role for the establishment of new models, but the model needs some extra manpower to keep the system alive, so, it means extra cost."
- Expert 6 stated that "The model could increase the attention of the project team members to LL with their possible effects on the current schedule."

Responses of each interviewee regarding 2nd question of Part 3 are as follows:

- Expert 1 recommended that “while recording productivity rates of activities, additional information such as weather, disrupted/undisrupted period, quality requirements, etc., which affect costs and/or productivity rates of activities should be recorded. For instance, while performing one activity, the employer may change design requirements related to these activities and performance of the activity may be disrupted and productivity may be adversely affected. Such periods should be recorded, and future project estimations should disregard these periods, if necessary”.
- Expert 2 recommended that “As a scheduler, I am interested in the scheduling tool integration of the model more. I would definitely want to use a tool that helps me to decide on activity duration & cost. Previous productivity information (unit man-hour) can be more helpful for future projects activity estimations. I want to know this information if I will use data from previous projects”.
- Expert 3 recommended that “What knowledge will be obtained from the experts should be identified clearly and assured that it can be obtained. The similarity definition and degree should be examined comprehensively. If there are no similar projects, the similarity is low or a completely new kind of project, then the tool may offer some general knowledge integration. What is considered for the scheduling part, should be seen in the report clearly. If it will be possible to see the effect of previous knowledge to the original duration (schedule), it will be very useful for the user.”
- Expert 4 recommended “Firstly, the estimations upon which a project schedule is established can be identified. After that, the benefits of replacing these assumptions with solid data extracted from lessons-learned or project close-out records can be itemized. Then, the lessons-learned data which can replace the assumptions can be identified. Finally, a flow chart or a similar diagram can be presented to show the logical process of the proposed model. In this way, it can be shown that the proposed model is practical, rather than a theoretical one”.

- Expert 6 recommended that "The focus shouldn't be only the activity-specific experiences. Also, LL related to generic problems in the projects (slippages, delay in BL, etc.) should be considered while developing the model. The model should include the risk coefficient for each LL in the system. Accordingly, cumulative risk data could be calculated according to disciplines, milestones, etc."

4.3. Discussion of Findings

Common findings from needs analysis show that the construction industry still significantly needs effective implementation of knowledge management-LL tool on scheduling to increase the efficiency in terms of time, budget and quality. As a sub-part of this common finding, professionals want to capture and reuse the activity-based information to get more accurate estimations to improve the quality of the overall further projects' planning process. As seen in interviews with experts, it is obvious that all of the interviewees agree on the importance of LL model implementation that combines scheduling perspective and live capture of knowledge for future projects. Within this context, the need is mostly focused on benefits from previous productivity/unit man-hour information and tacit and explicit knowledge throughout the construction life cycle. To come up with a solution to needs, professionals emphasize their concerns and recommendations on the importance of retrieval of information effectively whenever it is desired.

According to the needs and expectations from literature review and expert opinions, the main components and focuses of the model are proposed as follows:

- Development of an LL tool that enables capturing and reusing the knowledge obtained from previous projects.
- Storing the project generic information.
- Provide company-based taxonomy that can be customized according to the company's needs to make retrieval of similar information easily.

- Capturing and storing activity-specific tacit and explicit knowledge in a structured way in the taxonomy including features of knowledge description, information of the LL facilitator and approvers, solution description, evaluation of the solution, pictures, images, video, reports.
- Capturing and storing actual (realized) activity productivity rate/unit man-hour data in a structured way in the taxonomy.
- Identifying and providing factors with impact rate that can affect the productivity rates/unit man-hour for activities throughout the project to estimate similar activity's productivity rate/unit man-hour for future projects.
- Developing the interface to retrieve activity-based tacit and explicit knowledge from developed taxonomy easily.
- Developing the interface to retrieve activity-based productivity/unit man-hour information with affecting factors to make more accurate estimations for future projects.

CHAPTER 5

DEVELOPMENT OF ACTIVITY-BASED LESSONS LEARNED PROCESS MODEL FOR SCHEDULING

The objective of the thesis is to develop an activity-based lessons learned model for scheduling (ALLPMS) in construction companies to prepare more consistent and accurate schedules and benefit from previous knowledge in creating solutions for new projects. With the integration of LL in scheduling, the model is expected to meet the requirements of schedulers from tendering stage to project closeout. The expected outputs of the model are listed as follows:

- Initially, while preparing the project schedule,
  - Previous projects' activities that are similar to current activities can be retrieved by filtering with taxonomy, activity attributes and a list of factors in terms of;
    - Activity related LL information (captured explicit-tacit knowledge for failure & success situations) and,
    - Activity-related productivity rate (unit man-hour) information. Day-by-day unit man-hour information with affecting factors and impact rate is retrieved for the desired activity to prepare more consistent and accurate duration estimations.
- By learning from experiences,
  - It aims to capture and organize both tacit and explicit LL knowledge to enhance organizational learning inside the construction company. For this aim, when activity is actualized/realized, failure & success

practices are captured and stored with activity attributes: “Activity Name”, “LL Type”, “Event Description”, “Solution Description & Recommendation”, “Create Date”, “Related Factors”, “LL Approvers”, “Extra Documents (Pictures, images, video, reports)”

To get the main outputs that are mentioned in the previous part, the proposed model consists of 3 main components. Details of components will be explained in the following sections. Briefly, 3 main components are as follows:

1. **User Interface for the Model**: Roles in the model, definition of the roles and distribution of the roles are included. Three main roles are as follows:

- Knowledge Manager
- Knowledge Facilitator
- Knowledge User

2. **Information Entry to the Model**: Main types of knowledge that should be captured and stored in the system and the reasons behind these efforts are presented. These are:
    - Activity-Related LL Information Entry: It captures the events or situations that are directly related to activity and stores them in a structured manner in the company domain.
    - Activity-Related Productivity Rate (Unit Man-Hour) Information Entry: It stores activity-related productivity rates with their affecting factors and impact rate day by day through the activities’ lifecycle.
3. **Information Retrieval from the Model**: It focuses on the utilization and facilitation of knowledge for reusing purposes.
    - Filtering by Taxonomy Development: It categorizes the construction activities and knowledge in a structured way so that ALLPMS and organizational learning are stored in a consistent manner and retrieved easily by users.
    - Filtering by Activity Attributes: Users can make a more detailed search to find relevant information with activity attributes like “activity unit”, “activity name” and “activity country”.

- Productivity Rate/Unit Man-Hour Information Retrieval: Users can retrieve the similar activities' productivity rate/unit man-hour information with affecting factors and impact rate.

5.1.Process Model

After examining the gap in the literature and conducting the need analysis with experts, activity-based lessons learned process model for scheduling was developed. As a first step, the project's schedule is created according to the project requirements. This process is carried out by the "Knowledge Manager". In Step 2, after activity information is used as input for Step 2, actual activity information, especially productivity rate/unit man-hour information is entered by the "Knowledge Facilitator", but the "Knowledge Manager" has the right to enter the captured information. For a more structured and organized process, activity information is controlled by "Taxonomy", "Factors" and "Impact Rate". In Step 3, when an event occurs about an activity, activity-related LL information is entered by "Knowledge Manager", "Knowledge Facilitator" and "Knowledge User". "Taxonomy" and "Activity Attributes" are used to make information organization in a more structured manner. In Step 4, the output of Step 3, "Proposed Lessons", is reviewed by the "Knowledge Manager" according to company needs and value of information. After being reviewed by the "Knowledge Manager", proposed lessons are modified, approved or deleted. In step 5, the output of Step 2 and Step 3 are used as input for Step 5. Obtained activity-related information can be retrieved by "Knowledge Manager", "Knowledge Facilitator" and "Knowledge User". To retrieve the information efficiently according to knowledge needs, 3 different information retrieval mechanisms are used: "Taxonomy", "Activity Attributes" and "Factors". At the end of Step 5, the process is completed. The process model is demonstrated in Figure 8. Within the scope of the model, details about the process model with assigned roles are going to be explained in detail in the following sections.

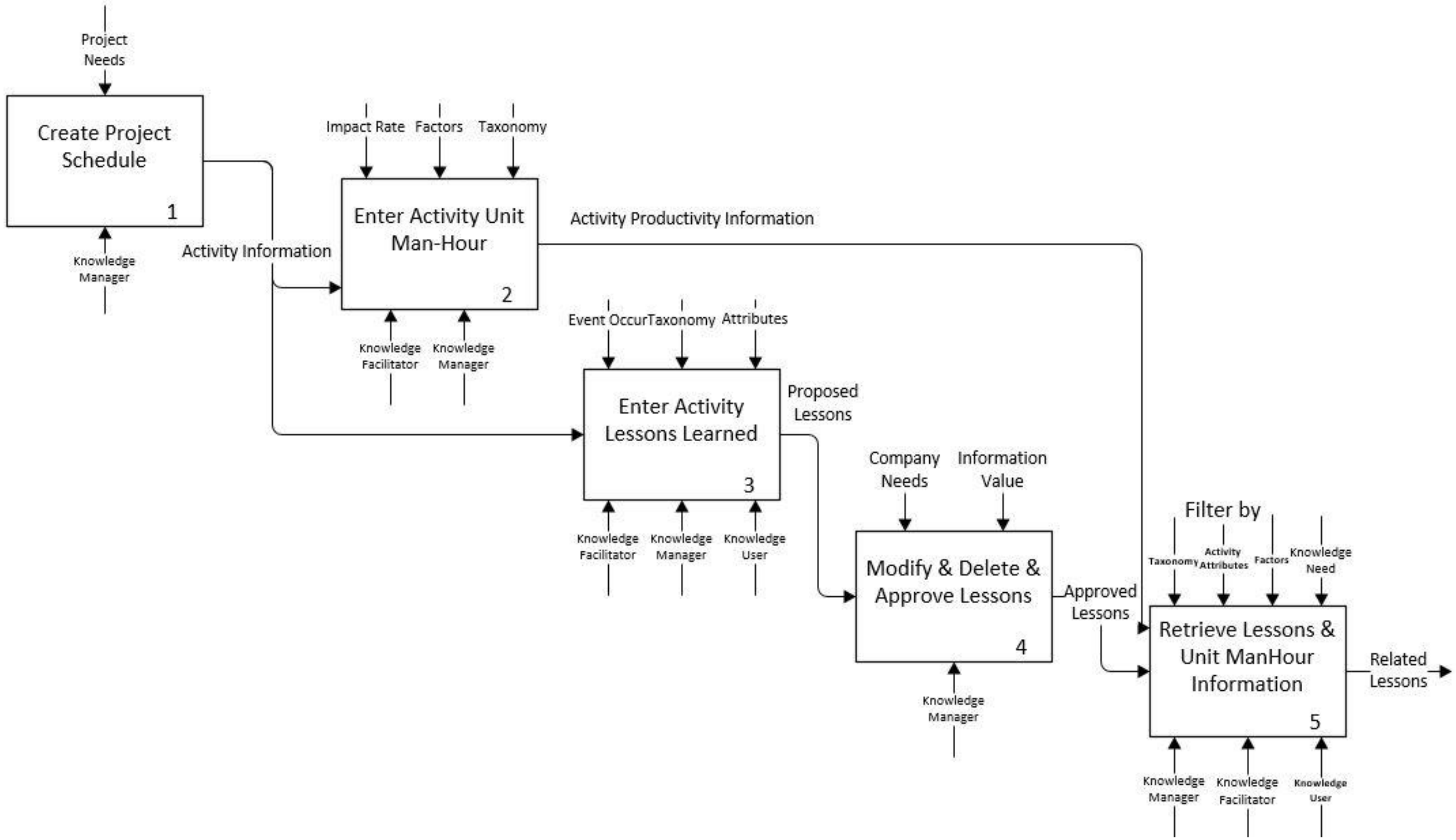


Figure 8: Process Model

Figure 9 represents the process of LL information entry-retrieval roadmap flowchart for the model. To enter the LL information into the system, first project schedule is checked whether it is available in the system or not. Then, taxonomy is checked whether it meets the project needs or not. After LL entry is completed in the system according to taxonomy and activity attributes, they are checked by the "Knowledge Manager" to ensure the quality and reliability of the information. Lastly, they are stored in the system database in a structured manner. Details are explained in chapter 5.2.2 Information Entry from Model.

For LL information retrieval, users can benefit from three main options: "Filtering by Taxonomy Development" by using "categories" in "taxonomy" to find related activities LL, "Filtering by Activity Attributes" uses activity attributes such as "activity name", "activity measurement unit", "activity country" to find related activities' LL and "Productivity Rate/Unit Man-Hour Information Retrieval" to retrieve the similar activities' productivity rate/unit man-hour information with affecting factors and impact rate. Details are explained in chapter 5.2.3 Information Retrieval from Model.

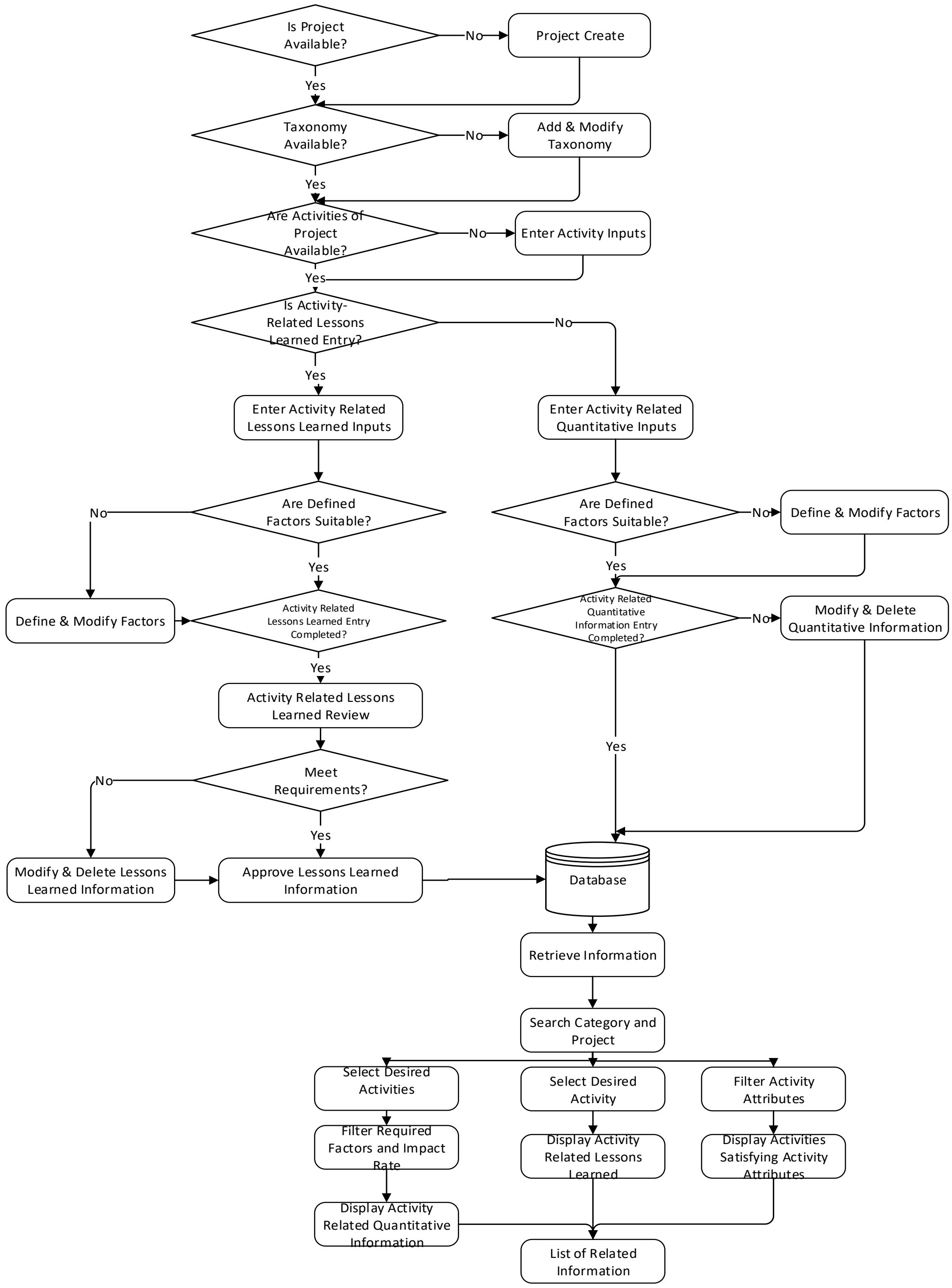


Figure 9: Information Entry-Retrieval Roadmap Flowchart for the Model

5.2.Main Components of the Model

ALLPMS is made up of three main components. The first component is "User Interface for the Model". Within the context of this component, roles in the model, definition of the roles and distribution of the roles are explained. The second component is "Information Entry to the Model". In this component, the main types of knowledge that should be captured and stored in the system and the reasons behind these efforts are presented in detail. The last component is "Information Retrieval from the Model". The "Information Retrieval from the Model" section focuses on the utilization and facilitation of knowledge for reusing purposes. Three main components are explained in detail in the following sections.

5.2.1. User Interface for the Model

To increase the efficiency of the system integrity and become more controllable between different parties, roles in the model, definition of the roles and distribution of the roles should be explained and structured properly. The proposed system is made up of different crucial parts like activity-specific information entry, editing taxonomy, deleting-modifying-approving LL information, so there is a significant need to assign roles and responsibilities or authorization levels of these roles. Within this scope, roles and their authorization levels are presented in detail. These roles are as follows:

- Knowledge Manager
- Knowledge Facilitator
- Knowledge User

Knowledge Manager: The "Knowledge Manager" is responsible for reviewing (editing/deleting/approving) LL that are entered into the system. This prevents excessive information overload (mostly useless information) and increases the system's efficiency and reliability. The "Knowledge Manager" should be highly experienced in the company because system reliability is highly dependent on the

“Knowledge Manager”. When new lessons are entered into the system by the “Knowledge User”, they are filtered and checked by the “Knowledge Manager”, then approved, deleted or modified as the last and highest authority. Also, the “Knowledge Manager” is responsible for initial project creation and transferring of activities into the system.

Knowledge Facilitator: The **“**Knowledge Facilitator” is responsible for collecting activity-related quantitative information day by day on site. Especially, activity’s “Unit Man-Hour” with “Factor List” and “Impact Rate” are recorded by the **“**Knowledge Facilitator” to get more reliable information about activities. Collected activity-related information is entered into the system by the **“**Knowledge Facilitator”. It may be personnel from the site or the Project Planning Department.

Knowledge User: The **“**Knowledge User” is a role that has the right to enter or display already entered LL information. Within the scope of the “Knowledge User” role, it only has the right to enter the new LL information, and search & display already entered the LL information. Roles and their authorization system are illustrated in Figure 10 to increase the simplicity and make the system clear.

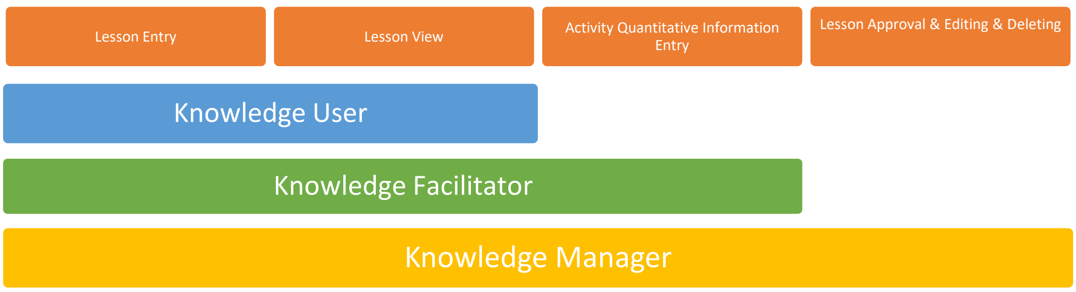


Figure 10: Roles with Authority Level

5.2.2. Information Entry to the Model

Within the scope of the “Information Entry to Model” section, the main types of knowledge that should be captured and stored in the system and the reasons behind these efforts are presented in detail. Inputs or information is comprised of two main parts. These parts are “Activity-Related Lessons Learned Entry” and “Activity-Related Productivity Rate (Unit Man-Hour) Information Entry”. “Activity-Related Lessons Learned Entry” part aims to capture and organize more qualitative (tacit and explicit) LL knowledge inside the construction company. On the other hand, the “Activity-Related Productivity Rate (Unit Man-Hour) Information Entry” part aims to utilize more quantitative information like productivity rate (unit man-hour) information.

5.2.2.1. Activity-Related Lessons Learned Information Entry

As stated in the literature review chapter, capturing, storing and transferring the explicit and especially tacit knowledge is still a significant problem in the construction industry. To deal with this problem, the information entry framework of ALLPMS is presented in detail. The idea is to capture the events or a situation that is directly related to activity and store them in a structured manner in the company domain.

Within this context, the information entry framework is comprised of 8 different activity-related event descriptions to capture the information. These are “Activity Name”, “Lessons Learned Type”, “Event Description”, “Solution Description & Recommendation”, “Create Date”, “Related Factors”, “Lessons Learned Approvers”, “Extra Documents (Pictures, images, video, reports)”. Brief information about these is summarized as follows:

> **Activity Name**: It is necessary to make a connection between the LL event and related activity. It comes automatically when the activity is selected.
>
> **Lessons Learned Type**: It is used to group LL type as “Failure” or “Success”. Labeling the activities’ Filtering in LL information as “Failure” or “Success” enables users to distinguish the knowledge easily according to users’ direction or focus.

Event Description: This part is one of the main parts of the framework because it contains detailed information about LL and provides organizations to capture and store tacit and explicit knowledge. This area is text-free, and users could enter failure or success events & practices, personal experiences, some issues that should be the focus on the following process, etc.

Solution Description & Recommendation: This part is another important part of the LL framework. This section provides critical information to deal with the situation stated in "Event Description". Possible options or recommendations are presented in this section to prevent the undesired situation in "Event Description" or possible improvements or suggestions to make the process better for upcoming similar activities or projects.

Create Date: The date that the "Knowledge Manager" approved the knowledge into the company domain.

Related Factors: The factors that affect the activity-based LL. The details are presented in Section 5.2.

Lessons Learned Approvers: The person who is assigned as authorized "Knowledge Manager" in the LL framework.

Extra Documents: The specific documents that might support LL for that activity such as pictures, images, video, reports, etc. The framework is not considered as a document control system, so it is just about specific information directly related to that activity. Uploading activity-specific documents or making a link to the main source are allowed within the body of "Extra Documents".

As stated in Section 5.2.2.1, the activity's LL event description is evaluated later (edit/delete/approve) by the "Knowledge Manager" because the quality and efficiency of the framework are highly dependent on the information that is entered into the system, so it is ensured to store LL in the same level of quality instead of the accumulation of the excessive number of LL in the system.

5.2.2.2. Activity-Related Productivity Rate (Unit Man-Hour) Information Entry

It is known that, in the construction industry, activity-related information such as activity productivity rate/unit man-hour is not usually accumulated in a structured way, so a decision-maker generally estimates the productivity rates/unit man-hour to estimate the duration of activity with the guidance of experiences from past projects subjectively for the future projects especially in tender stage. This increases the deviation from the accurate estimation of durations both at the activity level and overall project levels. Thus, capturing and storing activity-related productivity rate/unit man-hour information with the factors affecting the activity in an organized manner may be a very useful function for planners. By doing so, planners might benefit from activity-related productivity rates from previous projects for consistent planning for future projects by taking advantage of the previous similar activities with affecting factors and their impact rates through the activities lifecycle.

There are several explanations in the literature about productivity measures. Two commonly used are total factor productivity (TFP) and a partial factor productivity (PFP) (Thomas & Sudhakumar, 2015). Total factor productivity (TFP) is an economic model and measured as shown in equation (5.1);

$$TFP = \frac{Total\ Output}{Labor + \ Materials + \ Equipment + \ Energy + \ Capital} \qquad (5.1)$$

On the other hand, partial factor productivity (PFP) is s expressed as the ratio of the outputs to a single or selected set of inputs. “Labor Productivity” is one of the measures of partial factor productivity (PFP) and measured as shown in equation (5.2);

$$PFP = \frac{Output\ Quantity}{Labor\ Hours} \qquad (5.2)$$

After the literature review and experts' guidance, as a productivity measure, partial factor productivity (PFP) is preferred in all calculations while developing the process model.

5.2.2.2.1. Factors Affecting Activity Productivity Rate/Unit Man-Hour

When operating and executing a project in the construction industry, organizations or companies try to deal with different factors due to project characteristics. To improve productivity in the construction industry, influencing factors should be investigated.

In this part of the thesis study, factors that are available in the literature are determined and presented that might affect the productivity rate/unit man-hour information of activities. While doing this, construction industry project-specific and activity-specific factors are considered as focus. As a literature review, various research papers and numerous academic studies related to factors affecting activities are investigated. Reviews of several research papers are presented in Table 4.

Table 4: Literature Review on Factors Affecting Activity's Productivity Rate

Study Description	Type of Factors in Study	Source
Study on "prediction of the productivity of earthmoving equipment is critical for accurate construction planning and project control"	Machine Intensive	(Ok & Sinha, 2006)
Focuses on "estimating process of pile construction productivity and cost is intricated because of several factors"	Machine Intensive	(Zayed & Halpin, 2005)
Focuses on "assessing the effect of subjective factors on bored pile construction productivity"	Machine Intensive	(Zayed & Halpin, 2004)
Study on "statistically analyze the factors that affected pavement operation in order to verify the cause-and-effect of those factors."	Machine Intensive	(Choi & Ryu, 2015)
Aims to "develop models to estimate reasonably accurate production rates for controlling activities of highway projects"	Machine Intensive	(Woldesenbet, 2005)
Focuses on "the highway construction production rates and various measures of production rates were obtained to capture the main features of the highway construction production."	Machine Intensive	(Jiang & Wu, 2007)
Aims to "develop an estimation model for construction labor productivity that provides reliable production rates that also takes into account the influencing of the factors for concreting of the beam on project sites from different parts of Malaysia	Labour Intensive	(Muqeem et al., 2011)
Focuses on "estimation of the productivity prediction of construction projects of marble finishing works for floors"	Labour Intensive	(Al-zwainy et al., 2012)

Table 4: Literature Review on Factors Affecting Activity's Productivity Rate (continued)

Aims to "describe a statistical model developed to forecast the productivity of masonry activities"	Labour Intensive	(Sanders et al., 1993)
The main objectives of this research are: "(i) to document approaches for conducting MEP coordination using BIM, (ii) to identify metrics for measuring the productivity of MEP coordination; and (iii) to identify factors affecting MEP coordination productivity".	Labour Intensive	(Ashuri & Yarmohammadi, 2014)
This research study investigates the "impact and the influence of labor performance through the perception of electrical construction workers"	Labour Intensive	(Offiah, 2017)
Aims to "investigate the influential factors on labor productivity and developing on installing the concrete foundations of gas, steam, and combined cycle power plant construction projects in the developing country of Iran"	Labour Intensive	(Heravi & Eslamdoost, 2015)

The main reason to determine and analyze the factors is to make a quantitative judgment and comparison on productivity measurement for future projects. By doing so, captured productivity information could be utilized for different scenario analyses for upcoming projects. The list of factors proposed in this thesis research is "default factors". It means that the proposed activity-based lessons learned taxonomy is designed as both sufficiently detailed and also meeting general needs easily for construction companies, and it can be customized according to the company's specific needs for further adaptation for different companies. After reviewing the different types of factors affecting the productivity of activities, 3 main categories are determined as classification of these factors: "General Factors", "Machinery Intensive Factors" and "Labor Intensive Factors". The reason to divide these factors into 3 main categories is that most of the research in literature divides the factors that affect the activity productivity into 2 categories: "Labor-related factors" or "Machine-related factors" on activity productivity. In this thesis, as a third category, "General Factors" are added to comprise the factors that affect both "Labor-related factors" and "Machine-related factors". Additionally, this category may be considered more generic compared to the other two categories. Factors and related categories are presented in Table 5.

Table 5: Activity-Related Factors

Activity-Related Factors		
Factor Code	**Factor category**	**Source**
General		
G.1.	Weather Condition	(Ok & Sinha, 2006; Zayed & Halpin, 2005; Zayed & Halpin, 2004; Choi & Ryu, 2015; WOLDESENBET, 2005; Jiang & Wu, 2007; Al-zwainy, 2016; Sanders, Member, & Thomas, 1993; Muqeem & Idrus, 2011)
G.2.	Activity Complexity	(Choi & Ryu, 2015; WOLDESENBET, 2005; Ashuri, Yarmohammadi, & Shahandashti, 2014)
G.3.	Organizational Complexity	(Ok & Sinha, 2006; WOLDESENBET, 2005; Jiang & Wu, 2007; Ashuri, Yarmohammadi, & Shahandashti, 2014)
G.4.	Site Condition	(Ok & Sinha, 2006; Choi & Ryu, 2015; Muqeem & Idrus, 2011; Al-zwainy, 2016)
G.5.	Location of Project	(WOLDESENBET, 2005; Jiang & Wu, 2007; Muqeem & Idrus, 2011; Ashuri, Yarmohammadi, & Shahandashti, 2014)
G.6.	Planning- Schedule Concern	(Zayed & Halpin, 2005; Choi & Ryu, 2015; Ashuri, Yarmohammadi, & Shahandashti, 2014; Heravi & Eslamdoost, 2015)
G.7.	Construction Method	(Zayed & Halpin, 2005; Zayed & Halpin, 2004; Sanders, Member, & Thomas, 1993)
G.8.	Design Quality & Requirements	(Sanders, Member, & Thomas, 1993; Ashuri, Yarmohammadi, & Shahandashti, 2014;
G.9.	Site Management (Coordination & Organization & Interoperability)	(Ok & Sinha, 2006; Zayed & Halpin, 2004; Zayed & Halpin, 2004; Ashuri, Yarmohammadi, & Shahandashti, 2014; Ashley & Offiah, 201; Heravi & Eslamdoost, 2015)
G.10.	Material Availability	(Zayed & Halpin, 2004; Choi & Ryu, 2015; Muqeem & Idrus, 2011; Al-zwainy, 2016)
Machinery Intensive		
M.1.	Equipment Condition &Ability	(Ok & Sinha, 2006; Zayed & Halpin, 2005; Muqeem & Idrus, 2011; Zayed & Halpin, 2004)
M.2.	Equipment Availability	(Ok & Sinha, 2006;Choi & Ryu, 2015)
M.3.	Earth Condition	(Ok & Sinha, 2006; Zayed & Halpin, 2005; Zayed & Halpin, 2004; WOLDESENBET, 2005)
Labor Intensive		
L.1.	Labor Competence & Experience	(Ashuri, Yarmohammadi, & Shahandashti, 2014; Ashley & Offiah, 2017; Heravi & Eslamdoost, 2015)
L.2.	Safety & Security Condition	(Al-zwainy, 2016; Ashley & Offiah, 2017)
L.3.	Labor Motivation	(Al-zwainy, 2016; Heravi & Eslamdoost, 2015)
L.4.	Labor Availability	(Zayed & Halpin, 2004; Muqeem & Idrus, 2011;

The system works as follows:

- Productivity Rate/Unit Man-Hour information with affecting factors (mentioned in Table 5) are recorded on-site day by day and checked by the "Knowledge Facilitator". This procedure aims to make information flow more reliable and consistent. The impact of these factors is also recorded according to the real site conditions.
- When each activity is proceeded or actualized, actual productivity rate/unit man-hour information of activity and factors are collected and recorded into the system by the "Knowledge Facilitator".
- While assigning affected factors to daily activity, impact rate (1-5 scale) is also assigned to the activity concurrently by the "Knowledge Facilitator". Impact rate is determined according to productivity loss compared to optimal working conditions and assumptions. Each change from 1 to 5 scale represents from minor to severe impact on productivity rate.
- Considering the factors with impact rates, for the tender stage and schedule preparation of future projects, the decision-maker can assign the more accurate duration of activities by looking at similar activities in the past projects.
- Also, factors with impact rates provide decision-makers scenario planning for potential conditions that are foreseen for the determination of activity duration in the tender stage or initial stages for projects.
- In the model, "Activity Data ID", "Activity Name", "Creation Date", "Quantity", "Man Count", "Worked Hours", "Spent Man-Hour", "Productivity", "Unit", "Related Factors" and "Impact Rate" information is stored as a default information structure.
- Details of productivity rate/unit man-hour information retrieval are explained in Chapter 5.2.3.3.

5.2.3. Information Retrieval from the Model

The "Information Entry to Model" section explains which and what type of information is captured and stored in the model. On the other hand, the "Information Retrieval from Model" section focuses on the utilization and facilitation of the knowledge for reusing purposes. The main objective of this section is to create a model that facilitates the reuse of captured information that meets users' desires or problems. To deal with the problem of accessing the required similar information efficiently, an information retrieval mechanism is developed with three different options: "Filtering Taxonomy Development" by using "categories" in "taxonomy" to find related activities LL, "Filtering by Activity Attributes" uses "activity attributes" to find related activities LL and "Productivity Rate/Unit Man-Hour Information Retrieval" option to specify or narrow down the activity's "Actual Unit Man-Hour" according to the factors and impact rates that affect the activity. Details of each different option for information retrieval mechanism are explained with their development processes in the following sections.

5.2.3.1. Filtering by Taxonomy

The idea behind the development of taxonomy is categorizing the construction activities' quantitative and qualitative information and knowledge in a structured way so that activity-related LL knowledge is stored in a consistent manner and retrieved easily by users. The taxonomy proposed in this thesis research is "default taxonomy". It means that the taxonomy is designed as both sufficiently detailed and also meeting general needs easily for construction companies, but the proposed taxonomy would be editable in the tool to meet company-specific needs. After conducting an extensive literature review, hierarchical taxonomy is developed. Initially, the taxonomy is divided into 5 main top categories as "General", "Structure", "Services", "Equipment & Furnishing& Fittings", "Site & Urban & Open Spaces". Top categories are selected considering generality and vitality in the construction industry. Also, the taxonomy is detailed up to a reasonable and comprehensive level so that the default taxonomy structure can fit and comprise most of the construction companies' requirements.

To develop a taxonomy structure, the literature is reviewed first. In the literature, several activity-based classification tables are available. Although there are plenty of classification systems, frameworks that are readily available in the literature, within this thesis context, CI/SfB Construction indexing manual, Uniclass, OmniClass (CSI), MasterFormat (CSI), Natspec (Australian) and NMR have been used for developing top and lower-level categories. As a supplementary source, ISO 12006-2:2015 Building construction — Organization of the information about construction works — Part 2: Framework for classification is examined to get the idea behind such classification frameworks mentioned just before. Thesis sources are mostly commercial and institutional classification-taxonomy tables that are widely used in different regions in the world for the construction industry. As brief information, CI/SfB Construction indexing manual is Swedish Committee for Building Investigation based on the BS1192-5:1998 British Standard for Construction Drawing Practice and constitutes 5 Tables: Table 0: Built Environment, Table 1: Elements, Table 2-3: Construction Forms/Materials and Table 5: Activities and Requirements. Uniclass is another classification system developed under the sponsorship of the CPIC and NBS, UK. It provides a consistent classification structure for all disciplines in the construction industry. In the latest version of Uniclass, called Uniclass 2015, 11 tables are available inside. Especially, the Elements/Functions table provides detailed information guidance about activity classification. In OmniClass (CSI), 15 tables are designed & created inside that are based on ISO 12006-2 (Organization of Information about building Works – Framework for Classification) in the North American architectural, engineering and construction (AEC) industry. Within the context of Table 21: Elements (includes Designed Elements), it assists about processes or activities' classification. Apart from OmniClass, MasterFormat is another construction specification for construction contract documents with 50 divisions in Construction Specifications Institute (CSI). Nat spec (Australian) is the National Master Specification used for all types and sizes of projects. Lastly, NMR (The New Rules of Measurement) is created by the RICS as a classification system, especially focusing on measuring units.

After extensive review and examination of mentioned literature resources, the taxonomy is developed that would be both sufficiently detailed and also meet general needs easily for construction companies. A complete list of upper & lower-level categories inside the taxonomy is presented in Appendix B. Due to the detailedness of taxonomy, activity taxonomy is presented up to 2 Levels in Figure 11. To become more familiar with the taxonomy, brief information will be given about to top categories.

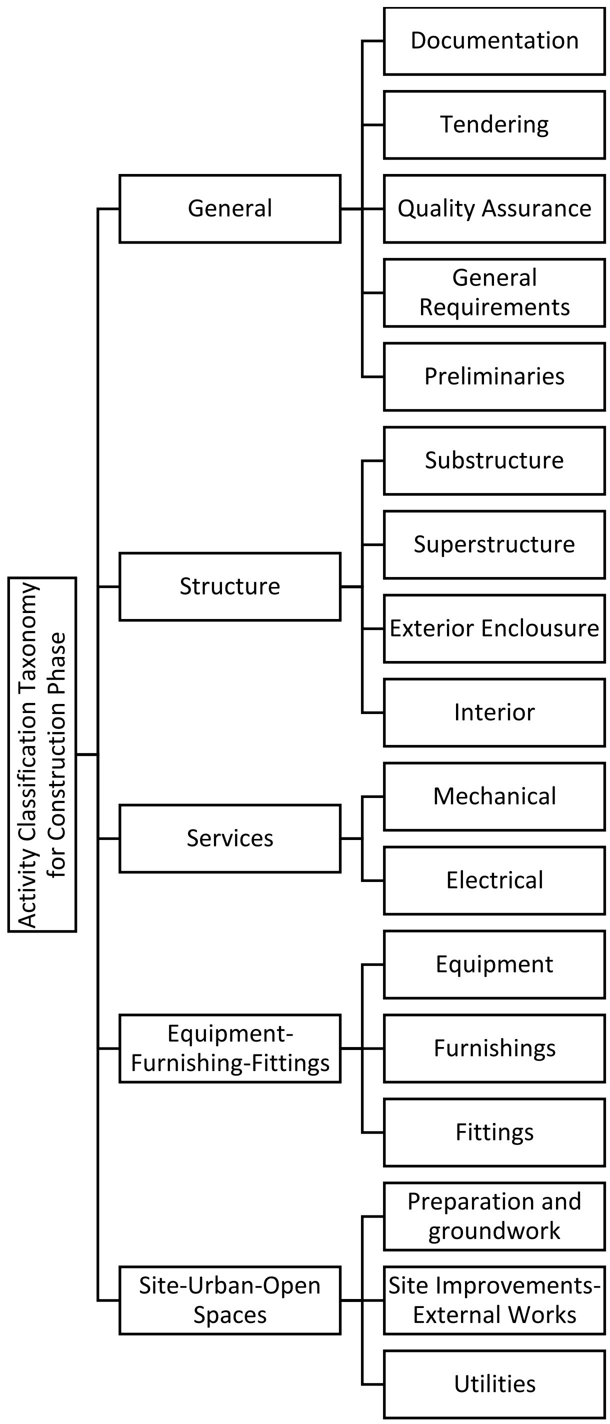


Figure 11: Company-Oriented Activity Classification Taxonomy for Construction Phase

General:

In the category of "General", the main objective is to store and organize project general activities' information and general information about the project such as checklists, requirements, etc. in a structured manner. This category contains 5 main sub-categories: "Documentation", "Tendering", "Quality Assurance", "General Requirements", "Preliminaries".

Structure:

The category of "Structure" is divided into 4 main sub-categories: "Substructure", "Superstructure", "Exterior Enclosure", "Interior". In total, "47" items are located in the "Structure" category with up to 5 Levels of detailedness. It is aimed to organize and classify activities that are mostly related to structural civil works in the construction site.

Services:

In the category of "Services", there are 2 main sub-categories: "Mechanical" and "Electrical". In total, "15" items are located in the "Service" category with up to 4 Levels of detailedness. As understood from the category names, the "Service" category is focused on mostly mechanical and electrical issues on construction sites.

Equipment-Furnishing-Fittings:

The category of "Equipment-Furnishing-Fittings" is divided into 3 main sub-categories: "Equipment", "Furnishing" and "Fittings". In these sub-categories, a total of "14" items are located in the "Equipment-Furnishing-Fittings" category with up to 4 Levels of detailedness.

Site-Urban-Open Spaces:

In the category of "Site-Urban-Open Spaces", there are 3 main sub-categories: "Preparation and Groundwork", "Site Improvements-External Works" and "Utilities". In total, "19" items are located in the "Site-Urban-Open Spaces" category with up to 4 Levels of detailedness.

When the project schedule is prepared, all activities with related information & attributes are transferred from the scheduling tool to taxonomy's related categories & sub-categories by the "Knowledge Manager". As activities are actualized, activity-related qualitative (LL) and quantitative (such as productivity rates, activity dates, etc.) information are recorded and stored in these categories. The significant advantage of taxonomy is retrieving activity-related information easily.

5.2.3.2. Filtering by Activity Attributes

"Filtering by Activity Attributes" is carried out by activity-related attributes that are entered when planned activity's information is transferred into the model. These are "activity name", "activity unit" and "activity country" that are directly related to the activities. In this perspective, the user can make a more detailed search to find relevant information. For example, after narrowing down the activities by using the "filtering by taxonomy" option, users can filter "activity name" to take the search one step further. Also, users would filter the activity-related lessons according to the "activity unit and country" option. This option enables users to focus and identify activity units and, also country easily to narrow down the scope. These options bring significant advantage to the decision-makers to make more accurate estimations for future projects' activities duration by considering possible factors that may affect the activity.

5.2.3.3. Productivity Rate/Unit Man-Hour Information Retrieval

After the entry of activity related to "Executed Quantity" and "Actual Man-Hour" information to get "Actual Unit Man-Hour" day by day with its factors affecting the activity and impact rate, the system provides users "Productivity Rate/Unit Man-Hour Information Retrieval" option to specify or narrow down the activity's "Actual Unit Man-Hour" according to the factors affecting the activity and impact rate. The main focus is retrieving "Actual Man-Hour" information from previous projects' activities to get benefit from them for future projects activity duration estimation. In this perspective, for example, the user can select "Factor 1" from the drop-down menu to filter the activity's "Unit Man-Hour" information with its "Impact Rate" value that includes "Factor 1". In this option, the system provides not only filter just "Factor 1" but also filter other factors that occur with "Factor 1" concurrently with their "Impact Rate" information. Another option in this section is excluding activity-related information that is not taken into consideration for future projects' activities. For example, exclude option for "Factor 3" means that the user can exclude the activity information including "Factor 2". With the filter option of including and excluding factors, the process model also retrieves the assigned "Impact Rate" of filtered activities. As explained in the "Activity-Related Productivity Rate (Unit Man-Hour) Information Entry" section, the "Impact Rate" shows the effect of the assigned factor on the productivity rate for that activity. A hypothetical example is illustrated to get the idea behind the philosophy in Table 6 and Table 7.

Table 6: An Example Demonstration without Filtering Search

Date	Activity	Executed Quantity	Unit	Actual Man Hour	Unit Man-Hour (Output/Total Man-Hour)	Factor 1		Factor 2		Factor 3	
						Occurrence	Impact	Occurrence	Impact	Occurrence	Impact
2/1/2021	Excavation	10	m3	30	0.33	0	0	0	0	0	0
3/1/2021	Excavation	20	m3	55	0.36	1	3	0	0	0	0
4/1/2021	Excavation	15	m3	60	0.25	1	2	0	0	1	3
5/1/2021	Excavation	18	m3	72	0.25	1	4	1	1	0	0
6/1/2021	Excavation	22	m3	88	0.25	0	0	1	4	0	0
7/1/2021	Excavation	28	m3	140	0.2	0	0	0	0	1	5
8/1/2021	Excavation	18	m3	90	0.2	0	0	1	4	1	3
9/1/2021	Excavation	15	m3	75	0.2	1	3	1	1	1	2

Table 7: An Example Demonstration with Filtering Search-Include Factor 1 & Exclude Factor 3

Date	Activity	Executed Quantity	Unit	Actual Man Hour	Unit Man-hour (Output/Total Man-hour)	Factor 1		Factor 2		Factor 3	
						Occurrence	Impact	Occurrence	Impact	Occurrence	Impact
3/1/2021	**Excavation**	**20**	**m3**	**55**	**0.36**	**1**	**3**	**0**	**0**	**0**	**0**
5/1/2021	**Excavation**	**18**	**m3**	**72**	**0.25**	**1**	**4**	**1**	**1**	**0**	**0**

5.3. Evaluation of the Lessons Learned Process Model

LL process model is verified by conducting interviews with four experts. All of the experts are working in the private sector in the construction industry as a manager in the “Planning & Construction Management Department” in reputable international companies. One of them is also working as a part-time academician in the construction engineering and management division in reputable universities. The information about experts is presented in Table 8. The form presenting the proposed model is sent to experts by e-mail. It includes major components (inputs & outputs) of the model. Then, their responses are collected via both e-mail and face-to-face communication to make clear some points. The form is provided in Appendix C.

Table 8: Experts Information

Respondent	Position	Experience
Expert 1	Lead Project Planner	9 Years
Expert 2	Projects Control Director	19 Years
Expert 3	Projects Monitoring and Control Specialist	9 Years
Expert 4	Technical Office Manager	21 Years

Expert 1 is currently working in the Turkish branch of an international construction company as a Lead Project Planner that is listed in the ENR 250 list. He has also significant experience in the Planning, Budget and Cost Control division of large-scale industrial projects. Also, he has Project Management Professional (PMP)® and Scheduling Professional Certificates that are the world's leading project management certification system.

Expert 2 is a Director with a Ph.D. degree. He has 19 years of experience with expertness in delay analysis, dispute resolution, program management, scheduling, bid preparation in reputable Turkish and foreign construction companies listed ENR top 250.

Expert 3 and Expert 4 work in the same construction company with different roles. Expert 3 is currently working as a Projects Monitoring and Control Specialist. He participated in both industrial and commercial projects in reputable companies as a Planning Engineer. Expert 4 has also significant experience in reputable construction companies. She is currently working as Technical Office Manager. Before this position, she worked as Projects Monitoring and Control Coordinator (PMO), Deputy Project Manager, Deputy Contracts Manager in reputable construction companies that are listed ENR top 250.

The interview consists of three main sections. The first section was designed to get personal information about experts' backgrounds & experiences in terms of education and professional. In the second part, general information like problem statement, the gap in the literature and objective about the proposed thesis study was introduced. The first two parts are similar to 1st Interview Format as supposed in Appendix A. As a last step of the interview, the main components with their details were presented to experts. Then, it was requested to review each section of the "Activity-based lessons learned process model for scheduling" as well as its functions (input & outputs) that are provided beyond each section. In detail, the proposed process model was shared with experts, e.g., "User Interface for Model", "Information Entry to Model" and "Information Retrieval from Model" were presented with their significant functions. Then, general ideas and suggestions for possible improvements were asked to experts about the main components with their functions of the model. Furthermore, they were requested to review to what extent the proposed model can be efficient and useful in the construction industry. All suggestions were taken into consideration and the main components with their functions of the model have been revised accordingly. Then, the proposed activity-based lessons learned process model in Section 5 was developed with respect to suggested revisions.

Expert 1

Expert 1 stated that the "Activity-Related Lessons Learned Information Entry" part of research with "taxonomy" development is a good idea to receive information from every project with the same structure, and mentioned that activity related LL information entry with taxonomy is sufficient enough. In that way, comparison and future use of the information will be possible. On the other hand, companies may need to break down the proposed taxonomy into measurable levels. Details or sub-categories should meet and match the company's needs for further utilization of information, but it is not required to be very detailed as a default taxonomy. Determined levels can be the default and each project may add more measurable activities under them. After that, information can be summarized by default level or can be analyzed by detailed level. Expert 1 also extended his suggestions & comments with an example, "for example, proposed taxonomy shows that Piping is in the lowest level of classification, but Piping activity contains Pipe Prefabrication, Pipe Installation, Valve Installation, etc. However, with the modifications in default taxonomy, taxonomy could be improved to meet the company's and project's needs easily. For the "Activity-Related Productivity Rate (Unit Man-Hour) Information Entry and Retrieval" part, Expert 1 stated that the availability of productivity rate information from past projects is very beneficial for a Contractor in order to create realistic project schedules and budgets. Productivity rates may change according to many conditions/factors, but these factors are rarely recorded in practice, if at all. Due to that, the incorporation of such factors into the model will result in more accurate productivity rate information. Expert 1 also suggested recording activity related productivity rate as a single measure with affecting factors and impact rates throughout the activity occurrence is more subjective and qualitative, so productivity rate as a single measure with affecting factors and impact rates should be recorded daily since factors affecting each activity may change during the course of the project. Expert 1 also extended his suggestions & comments with an example, "for instance; Excavation activity may be impacted by rainy weather condition at the first day of the activity, weather condition can be good at the second day, and it may be rainy again at the third day of the activity, so it is better to change occurrence and impact rate with more quantitative method". The main emphasis of Expert 1 is that recording productivity rates in accordance with changing factors day by day enables users to analyze previous productivity rates in a more quantitative manner and utilize them efficiently for future projects.

Expert 2

According to Expert 2, for the "Activity-Related Lessons Learned Information Entry" part of the thesis research, the main concern is whether the proposed model is implemented into the construction site successfully or not, especially for capturing failure information because employees or users intend to keep failures or unfavorable information in their minds. Indeed, in general, employees try to solve the problem inside the team without notifying upper-level authorities. Also, Expert 2 mentioned that there is a layer of "Data confirmation" before the data is stored in a DB, this role is crucial as it is at the heart of all quantification processes. It might affect the effectiveness of all processes. From the "Taxonomy" perspective, it should be comprehensive enough to comprise different construction areas such as energy, infrastructure, transportation, etc. The proposed taxonomy should be extended as required as possible to include mentioned areas. Indeed, it should be noted that the structure inside the taxonomy would vary greatly according to needs and dynamics. For the "Activity-Related Productivity Rate (Unit Man-Hour) Information Entry and Retrieval" part, Expert 2 emphasized the importance of determining the factors that affect the activity productivity and the impact rates for these factors because factors and impacts information should be reliable enough to get consistent result for further interpretation. Therefore, the person who assigns the factors and impacts should dominate the control over the activity process because information requires a high level or commitment to accurately record progress during the project and authority level of that person should be specified clearly. Also, the factor list should not be so detailed and complex. It should be simple enough to increase the efficiency for utilization on site. Additionally, a factor list is used as a general purpose for different projects and activities, so the list should be comprehensive as well as simple for use.

Expert 3 and 4

Expert 3 and Expert 4 stated that both "Activity-Related Lessons Learned Information Entry" and "Activity-Related Productivity Rate (Unit Man-Hour) Information Entry and Retrieval" are quite important for organizational learning for construction companies. In general, the research objective with functions & features in the proposed model were considered beneficial in terms of real-life applicability at the construction site by Expert 3 and Expert 4.

Both Experts initially focused on the "Activity-Related Productivity Rate (Unit Man-hour) Information Entry and Retrieval" part of the research. The initial point that Experts emphasized was that "the scope of 'Activity-Related Factors' that are stated in the thesis should be stated clearly. In other words, there should be a kind of manual that states the content of each factor. For example, within the context of Factor G.4.Site Condition, staff should know which conditions could be considered as Factor of G.4. Site Condition. In addition to explanation, there should be examples that illustrate the usage area of that factor. This helps to distinguish the factors between each other explicitly. The same condition should also be applicable for 'Impact Rates'. As stated in the thesis, Impact Rate is calculated according to a "1-5" scale. User or staff should be aware of the difference between scales for Impact Rate. For example, it should be clear that in which case the user sign Impact Rate as '5' or '1'. The idea behind this separation is to prevent unnecessary usage of factors and impact rates on activities. As a result, system integrity becomes more consistent". Another point was that "company culture or organization should be embedded with the system. Executed or actual quantity with spent man-hour on-site should reflect the real site information and also should be parallel with construction schedule or construction method so that proposed model would be effective and applicable for future projects. If employees or managers are not willing to apply the system effectively and transparently, implementation of the system in a company will become less effective and useful." Furthermore, Expert 3 suggested adding country information for information retrieval. He pointed out that "while retrieving the similar activities from the previous project, it would be beneficial for users to get information about the country of desired activity”.

Activity-related LL information and user interface for the proposed model are sufficient enough for applicability. The only point that should be emphasized is that the staff who record the executed quantity and spent man-hour information should be authorized and integrated with site activities efficiently.

5.4. The Output of the Interview Results and Recommendations

In general, the proposed model is tested and evaluated in terms of reliability, efficiency and applicability in the construction industry. It can be confirmed that the proposed activity-based lessons learned process model with functions & features is suitable for thesis research objective, problem statement, and useful & beneficial in terms of real-life applicability at the construction site. However, some improvements may be necessary to increase the functionality of the tool. Some features that are criticized by Experts are summarized and presented as follows;

- Capturing lessons and knowledge at the activity level is found very useful by all of the participants. It is thought that this brings great advantages to companies for both tender stages and further projects. In a broad view, it encourages the development of organizational learning inside the company. However, the fact that there is a great bias against such an application most probably decreases the potential of the proposed model.
- Data entry and retrieval according to taxonomy has great potential to facilitate activity-related lessons and productivity information retrieval. However, according to all participants, there is a doubt about the efficiency of retrieving the desired knowledge from the model, but being editable of taxonomy according to companies’ needs increases flexibility and efficiency of the tool.

- The factors that are used both LL entry and unit man-hour entry are sufficient enough for applicability in the proposed model. All experts stated that defined factors are neither less nor more. Also, being editable of factors provides flexibility to companies. Expert 2, Expert 3 and Expert 4 also added that the boundary or scope of the factors and impact rates should be clearly defined and illustrated in research to get consistent results for further interpretation.
- All Experts agreed that unit man-hour information is important for companies for further projects, so information retrieval from unit man-hour is very useful. The concern for all the Experts is about the quality of retrieved information. It is vitally important to record the information that reflects almost real site conditions, so company culture and emphasis on the applicability of the proposed model comes into prominence. If it is applied effectively and strictly, the model creates great potential for companies.
- All Experts agreed that the proposed user interface model for lessons entry and retrieval is useful and sufficient enough for further usage.

CHAPTER 6

ConSALL: APPLICATION ON A CASE PROJECT

In this chapter, details of the web application of the “activity-based lessons learned process model for scheduling” are provided. The Tool is named ConSALL which comes from Construction Industry Scheduling with Activity-Based Lessons Learned. The ConSALL is developed according to the LL management model proposed in Chapter 5. In the following subsections, a framework will be provided broadly on a case project.

6.1 General Information about the Tool

The ConSALL is applied to the web-based environment that could be used in different web browsers on both personal computers and mobile environments. The user interface is designed as default. In case of any need of modification, the interface and its details could be editable easily according to companies’ needs. The link that users can access to the web application of the tool is http://thesis.eba-atqcmezm.us-west-2.elasticbeanstalk.com/. Software components are programmed with Python3 (v3.6.15) programing language. To store and retrieve the required information, SQLite (v3.36.0) is used. As a web framework design, Django Web Framework (v2.1.5) is preferred because of its user-friendly interface. For website Front-End, Bootstrap Front-End Toolkit (v5.0.2) and jQuery (v3.2.1) library are preferred with the help of Javascript programing language. Also, to publish the website to the global Amazon Web Service Elastic Beanstalk is used with Amazon S3 (Simple Storage Service) database. Details of how users could enter the information into the model, retrieve the stored information from the model and configuration between the data entry and retrieval by user interface are provided on Roadmap Flowchart for Tool that is shown in Figure 9. Then, the main components and their details of the Tool to follow that flowchart are provided in the following subparts; “User Interface of the Tool”, “Information Entry to Tool” and “Information Retrieval from Tool”. The general layout of the ConSALL is represented in Figure 12. In the following subchapters, the main features of the ConSALL are demonstrated in a case project.

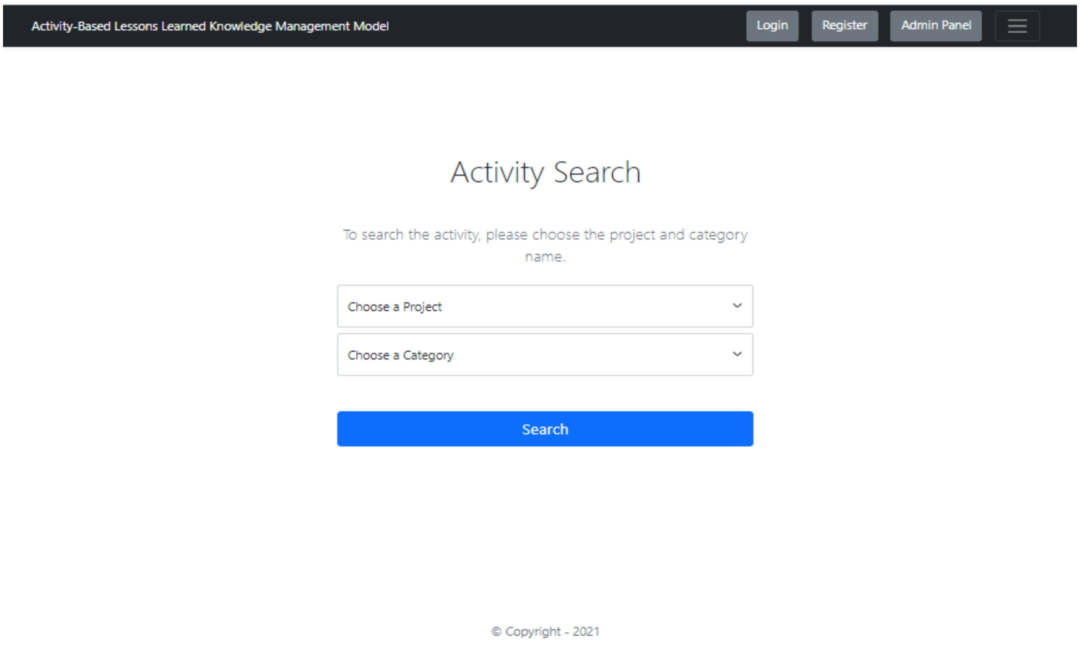


Figure 12: General Layout of the ConSALL

6.1.1 User Interface for the Tool

As stated in Chapter 5.2.1, different roles are assigned to the model to increase the efficiency of the system integrity and become more controllable between different parties. In this chapter, the definition, distribution and authorization of the roles in the model will be introduced in detail via tool representations. Through the Admin Panel, roles and three authorization levels can be defined easily. In the proposed model, users’ roles are as follows;

- Knowledge Manager
- Knowledge Facilitator
- Knowledge User

Knowledge User: The **"**Knowledge User" has the lowest authority level in the model. The permission level corresponding to the "Knowledge User" is named as "Active" in the ConSALL that is shown in Figure 13. Within the scope of Knowledge User Role, it only has the right to enter the new LL information, and search & display already entered LL information. When users enter the new LL information, they are either released & published after approvement by the "Knowledge Manager", or they are deleted or modified by the "Knowledge Manager" due to not satisfying the required information quality for the system. Any registration in the Tool is assigned as the "Knowledge User" in the system. Then, the authorization level can be changed just by the admin.

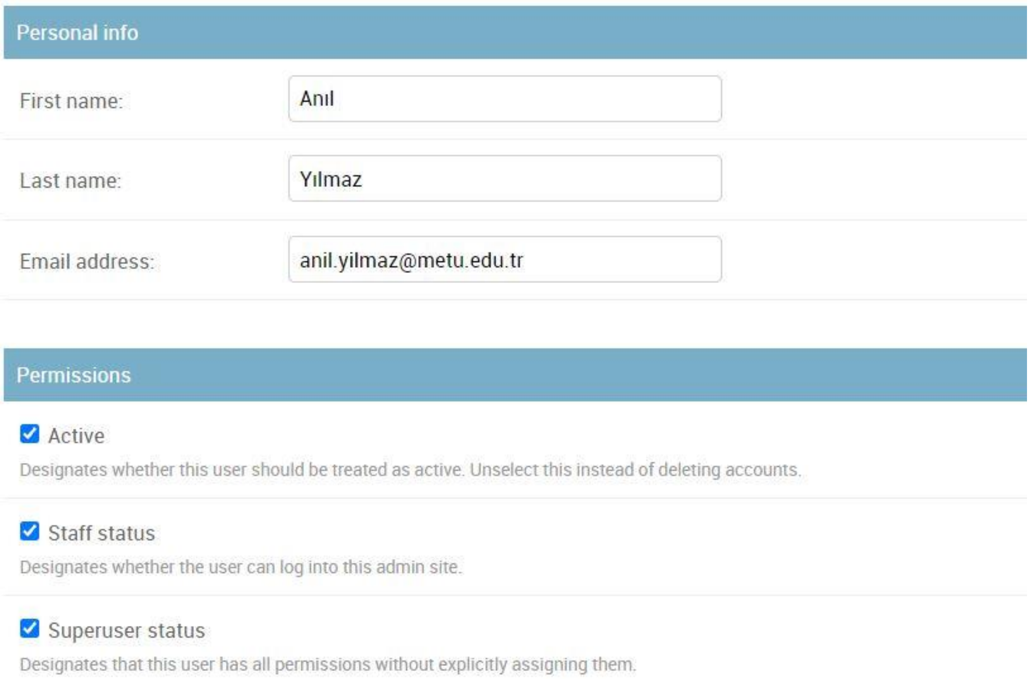


Figure 13: Authorization of Users' Roles

Knowledge Facilitator: The **"**Knowledge Facilitator" is responsible for collecting activity-related quantitative information day by day on site. It has all the rights which the "Knowledge User" has. In addition to that, it can enter the daily quantitative information about activities into the tool. Especially, activity's information such as "Quantity per Day", "Man Count", "Worked Hours", "Productivity (Unit Man-Hour)", "Factor List" and "Impact Ratio" is recorded by **"**Knowledge Facilitator" to get more reliable information about activities. The permission level corresponding to the "Knowledge Facilitator" is named as "Staff Status" in the Tool that is shown in Figure 15. The "Knowledge Facilitator" may be a staff from the site or Project Planning Department.

Knowledge Manager: The "Knowledge Manager" has the highest authority level in the system, and it is responsible for reviewing (editing/deleting/approving) LL entered into the system. When new lessons are entered into the system by the "Knowledge User", they are filtered and checked by the "Knowledge Manager", then they can be approved, deleted or modified. Also, the "Knowledge Manager" is responsible for initial project creation and transferring of activities. The permission level corresponding to "Knowledge manager" is named as "Superuser Status" in the ConSALL as shown in Figure 14.

According to the roles and their authorization levels, as stated above, the use case diagram of the ConSALL is provided in Figure 14.

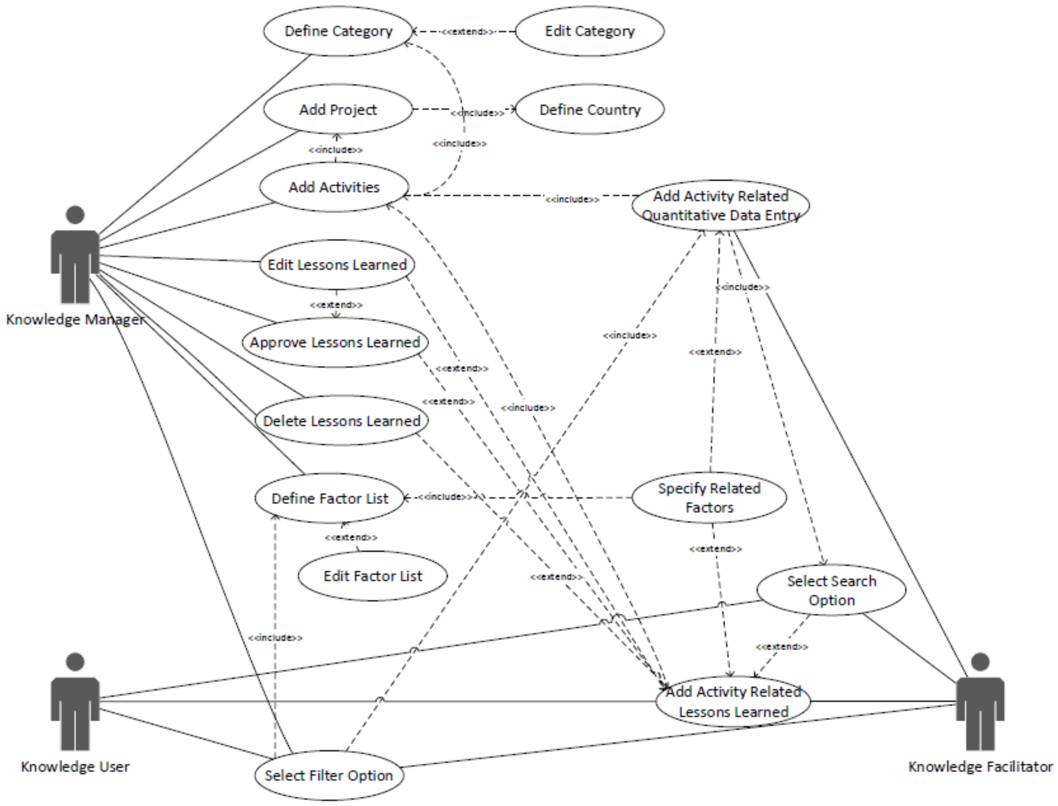


Figure 14: The Use Case Diagram of ConSALL

6.1.2 Information Entry to the Model

Within the scope of this section, inputs or information are divided into three main parts. The first part is “Project Creation in the Tool”. The second part is “Activity-Related Lessons Learned Entry” and the third part is “Activity-Related Productivity Rate (Unit Man-Hour) Information Entry”. For “Project Creation in the ConSALL”, planned schedule information of the project is inserted into the Tool. The “Activity-Related Lessons Learned Entry” part focuses on capturing and organizing more qualitative (tacit and explicit) LL information inside the construction company. However, the “Activity-Related Productivity Rate (Unit Man-Hour) Information

Entry" part focuses on the benefits from more quantitative information like productivity rate (unit man-hour).

6.1.2.1 Project Creation in the ConSALL

When a new project and its activities are desired to be entered into the system, a new project is created in the "Projects" category with "Project Country" information in Admin Panel. New project and its activities' information can be created just by "Knowledge Manager". Then, activities information is inserted into the "Activities" category in Admin Panel. While recording information of activities, the system asks to fill the "Activity Name", "Connected Category", "Connected Project", "Original Duration", "Planned Start Date" and "Planned Finish Date". "Connected Category" is defined according to the default taxonomy mentioned in Chapter 5.2.3. These activities' information can be obtained from construction project scheduling tools easily.

6.1.2.2 Activity-Related Lessons Learned Information Entry

In the "Activity-Related Lessons Learned Entry" part of the ConSALL, activity-related LL are captured and stored while the activity is in progress or finished. First, activity-related LL type (i.e. failure or success) is selected, then, according to the LL and LL type, the event and its solution description & recommendation are described briefly and comprehensibly. Afterward, factors from the factor list are selected to tag the LL example. By doing so, LL can be retrieved easily. If necessary, links or documents would be attached as an attachment for entered LL. After completing the activity-related LL, LL will be published and become visible for lower authority level users if the LL is approved by the "Knowledge Manager". An example from the case project is demonstrated in Figure 15.

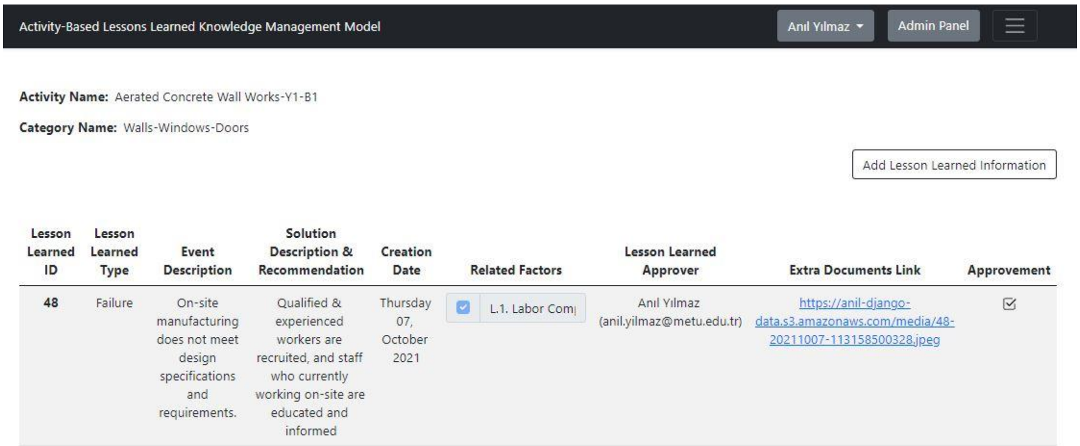


Figure 15: Activity-Related LL Information Entry

6.1.2.3 Activity-Related Productivity Rate (Unit Man-Hour) Information Entry

After the creation of project and project-related planned activities information into the system by the "Knowledge Manager", activity-related actual quantitative information is entered via "Data Entry Page" by the "Knowledge Facilitator" when activity is started, in progress or finished day by day. To enter activity-related information entry, the "Add Activity Data" button is used as seen in Figure 16.

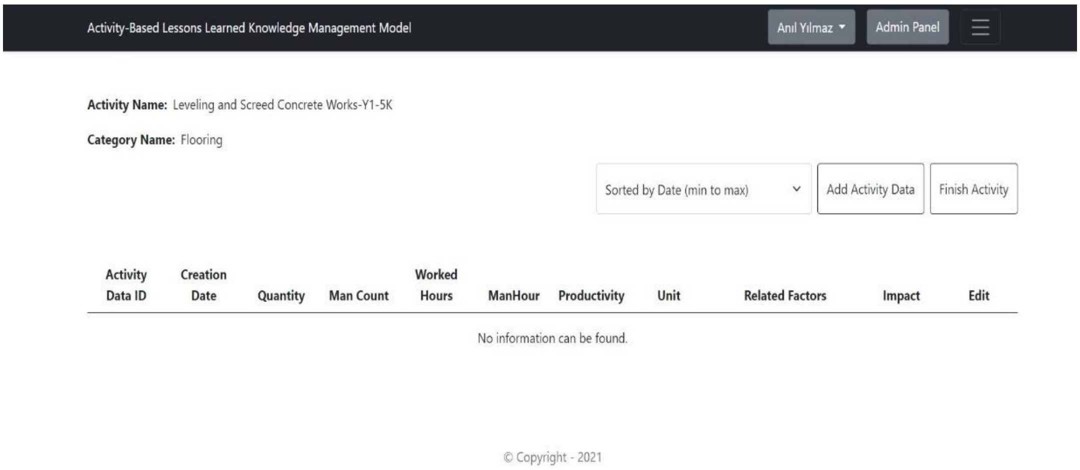


Figure 16: Activity Related Quantitative Information Entry.

When “Add Activity Data” is clicked, the system asks the user to fill several necessary information related to the selected activity. Compulsory ones are “Creation Date”, “Executed Quantity”, “Man Count”, “Worked Hours”, “Unit”. Then, the system calculates productivity as stated in the previous chapter. If there exists any factor that affects the productivity, the user should select the “Related Factors” from the 17 main factors and “Impacts” of these factors as seen in Figure 17 (non-compulsory). The “Knowledge Facilitator” enters all necessary information day by day until the activity is completed. In Figure 18, as an example, ROOF-Slab-Formwork-Y1-(A BLOCK 1-9) activity is illustrated from the case project. When the activity is completed, the “Knowledge Facilitator” should finish the activity and enter the “At Complete Duration” by clicking the “Finish Activity” button. After finishing the activity, activity’s “Actual Start”, “Actual Finish”, “At Complete Duration” and “Unit” information will appear on the home “Activity Search” page. As an “Actual Start”, the system takes the initial creation date that the user entered. As an “Actual Finish”, the system takes the last creation date that the user entered. As an “At Complete Duration”, the system asks the user to enter the duration of the activity according to the calendar of that activity. Additionally, when the first data is entered into the system, the system asks the unit of measure for the selected activity. For the second data entry, the system does not ask the unit information again and takes the unit of measure information of the first entered data.

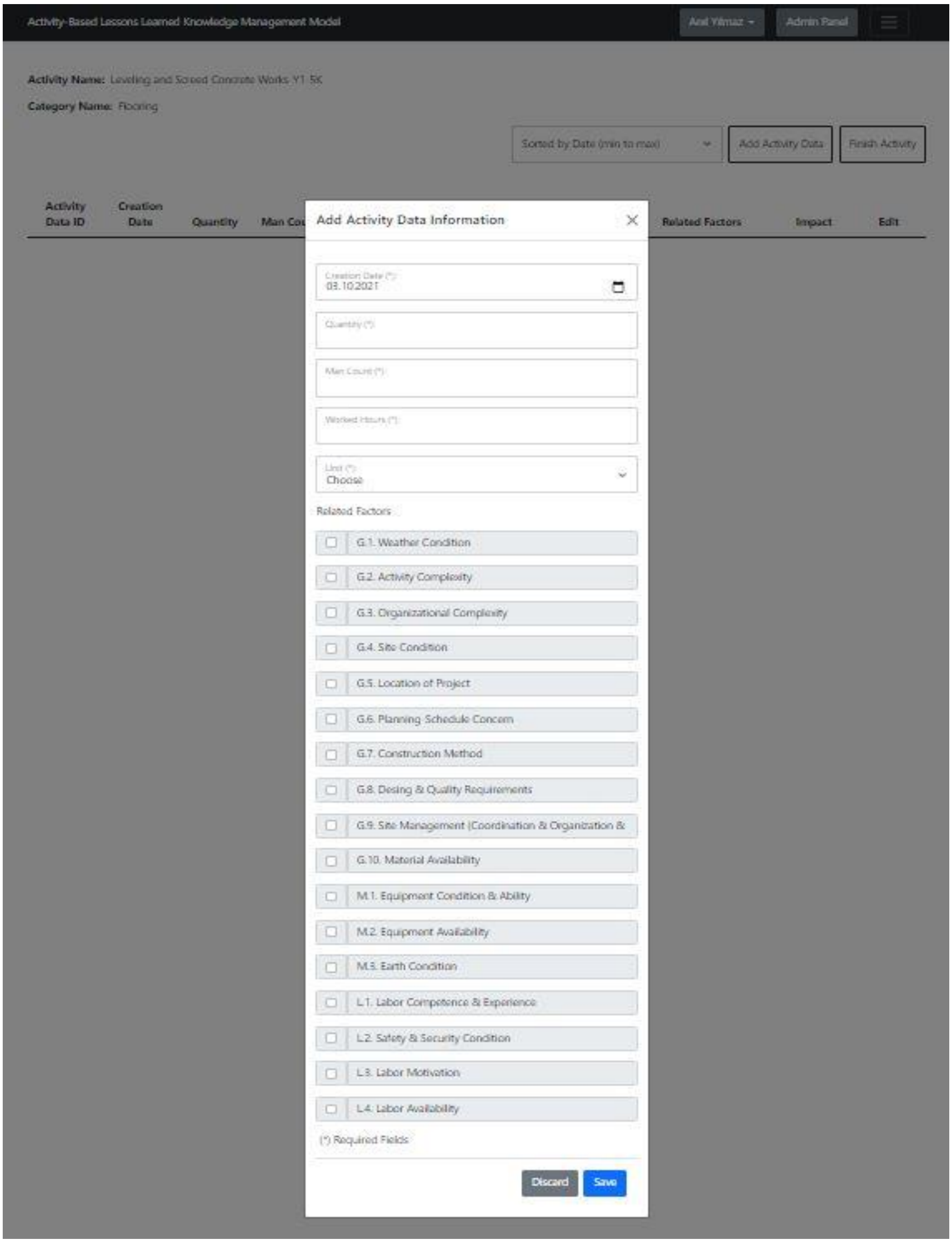


Figure 17:Add Activity Data Information Page.

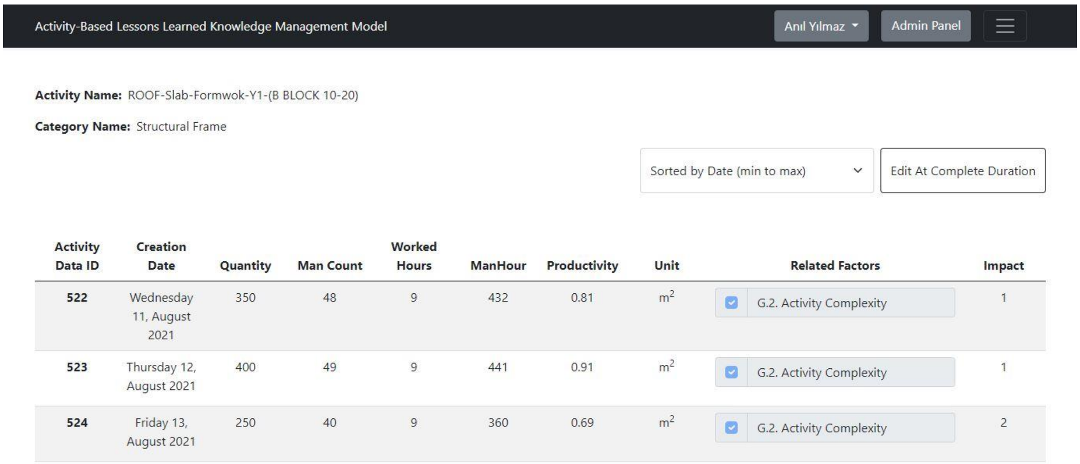


Figure 18:An Example Activity for Data Entry Page.

6.1.3 Information Retrieval from the Model

To benefit from previous project information, as stated in Chapter 5, the proposed tool provides three main information retrieval mechanisms. These are “Filtering by Taxonomy Development”, “Productivity Rate/Unit Man-Hour Information Retrieval” and “Filtering by Activity Attributes”, respectively.

6.1.3.1 Filtering by Taxonomy Development

According to the default taxonomy development stated in Chapter 5.2.3.1, activities are inserted into the ConSALL database with planned activity information. After selecting the project and desired category from the home page, users can search for the information easily. Search results show “Activity Name”, “Project Name”, “Country”, “Category Name”, “Planned Start”, “Planned Finish”, “Original Duration”, “Actual Start”, “Actual Finish ”, “At Complete Duration”, “Unit”, “Lesson Learned Information Entry Page”, “Data Entry Page”, respectively. However, “Actual Start”, “Actual Finish”, “At Complete Duration” information just appears when the activity is finished by “Knowledge Facilitator”. Additionally, when an upper-level category is selected, information from the sub-categories of the selected category also appears automatically. Figure 19 illustrates “Filtering by Taxonomy Development Example from Case Project”. According to the activity search, users can reach the “Lessons Learned Information Page” and “Data Entry Page” easily and effectively. Through the “Lessons Learned Information Page”, users can benefit from previous projects similar activities’ LL Information effectively.

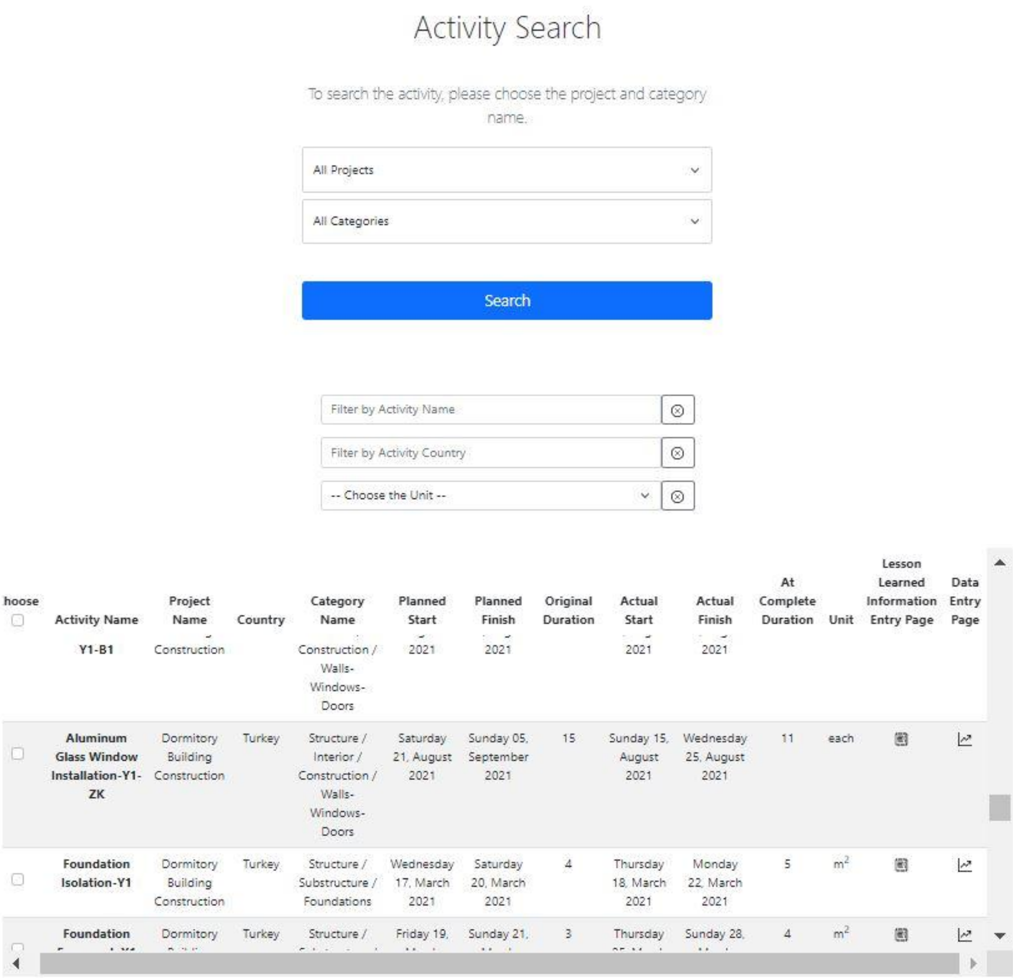


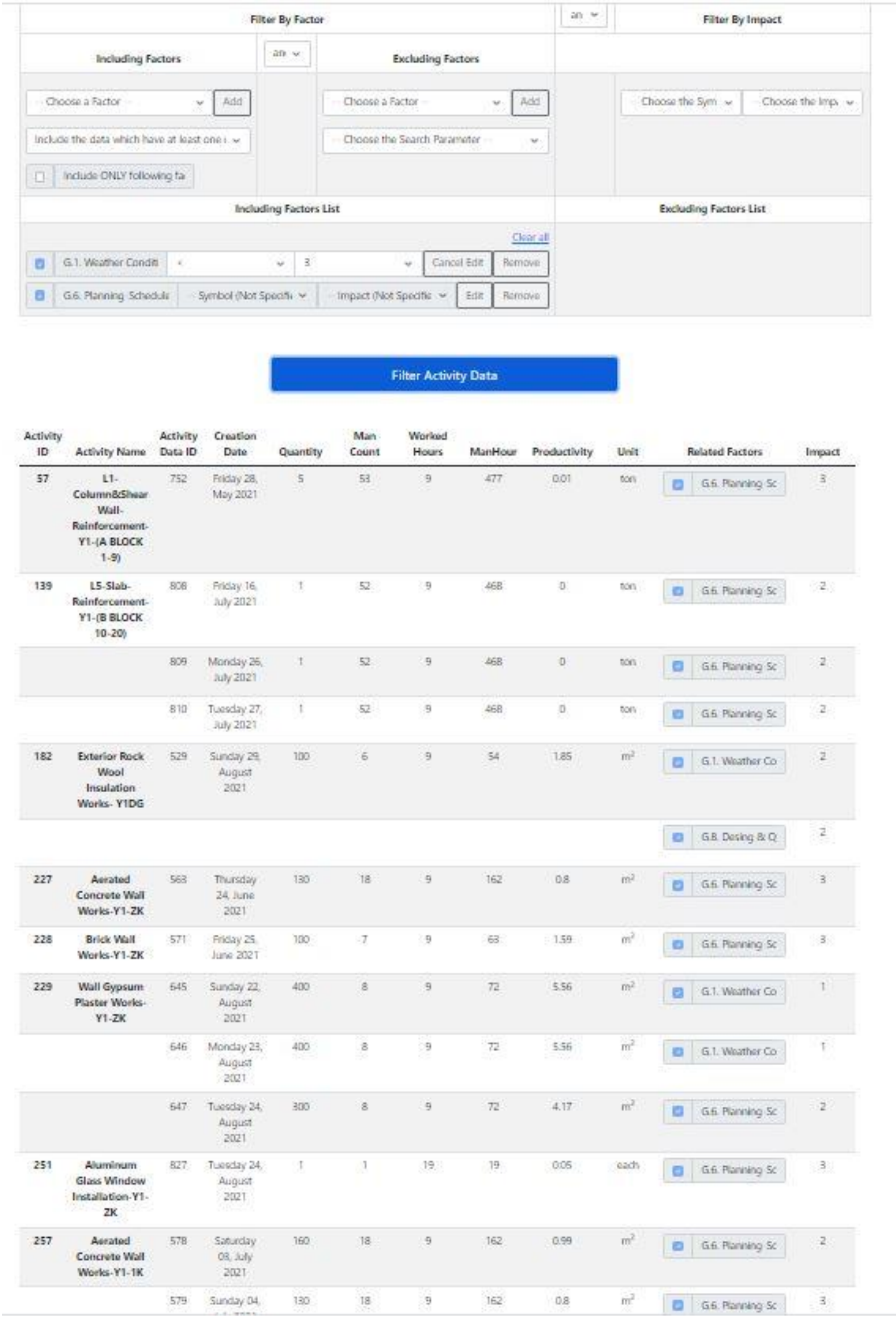
Figure 19: Filtering by Taxonomy Development Example from Case Project

6.1.3.2 Productivity Rate/Unit Man-Hour Information Retrieval

Within the scope of "Productivity Rate/Unit Man-Hour Information Retrieval", users could retrieve Productivity Rate/Unit Man-Hour Information by selecting "Factors" and "Impacts". ConSALL provides broad filter options to the users to retrieve information effectively. The main features are that users could filter the factors that exist or exclude the factors that do not exist in recorded activity-related information. While doing this, ConSALL also enables users to narrow down activities data information by filtering impact rate. Figure 21 illustrates the filtering option results of the case project. As seen in Figure 20, G.1. Weather Condition with Impact Rate less than 3 and G.6. Planning and Schedule Concern without impact rate are selected as including factors and impact rate.

6.1.3.3 Filtering by Activity Attributes

Within the scope of "Filtering by Activity Attributes", activity-related information could be retrieved according to "Activity Name", "Project Country" and "Activity Unit" as seen in Figure 19. These features increase the efficiency of activity-related data retrieval with the other options that are stated in previous parts.



Activity ID	Activity Name	Activity Data ID	Creation Date	Quantity	Man Count	Worked Hours	ManHour	Productivity	Unit	Related Factors	Impact
57	L1-Column&Shear Wall-Reinforcement-Y1-(A BLOCK 1-9)	752	Friday 28, May 2021	5	53	9	477	0.01	ton	G.6. Planning Sc	3
139	L5-Slab-Reinforcement-Y1-(B BLOCK 10-20)	808	Friday 16, July 2021	1	52	9	468	0	ton	G.6. Planning Sc	2
		809	Monday 26, July 2021	1	52	9	468	0	ton	G.6. Planning Sc	2
		810	Tuesday 27, July 2021	1	52	9	468	0	ton	G.6. Planning Sc	2
182	Exterior Rock Wool Insulation Works- Y1DG	529	Sunday 29, August 2021	100	6	9	54	1.85	m^2	G.1. Weather Co	2
										G.8. Desing & Q	2
227	Aerated Concrete Wall Works-Y1-ZK	563	Thursday 24, June 2021	130	18	9	162	0.8	m^2	G.6. Planning Sc	3
228	Brick Wall Works-Y1-ZK	571	Friday 25, June 2021	100	7	9	63	1.59	m^2	G.6. Planning Sc	3
229	Wall Gypsum Plaster Works-Y1-ZK	645	Sunday 22, August 2021	400	8	9	72	5.56	m^2	G.1. Weather Co	1
		646	Monday 23, August 2021	400	8	9	72	5.56	m^2	G.1. Weather Co	1
		647	Tuesday 24, August 2021	300	8	9	72	4.17	m^2	G.6. Planning Sc	2
251	Aluminum Glass Window Installation-Y1-ZK	827	Tuesday 24, August 2021	1	1	19	19	0.05	each	G.6. Planning Sc	3
257	Aerated Concrete Wall Works-Y1-1K	578	Saturday 03, July 2021	160	18	9	162	0.99	m^2	G.6. Planning Sc	2
		579	Sunday 04,	130	18	9	162	0.8	m^2	G.6. Planning Sc	3

Figure 20: Illustration of Productivity Rate/Unit Man-Hour Information Retrieval of Case Project.

6.2 Demonstration and Verification of ConSALL on a Case Project

6.2.1 The Case Project

As a case project, a superstructure project, a dormitory building construction, was selected and demonstrated on the ConSALL. Dormitory building construction is a reinforced concrete structure that consists of a basement floor+ 6 floors+ roof floor. The case project lasts 11 months from signing of the contract to provisional acceptance. While preparing the schedule baseline, the Critical Path Method (CPM) is utilized and, the calendar of the construction activities was planned as 7 days working per week with 9 hours working per day. The religious and national holidays are excepted from the calendar. Different disciplines (e.g. civil, mechanical and electrical) are involved in the construction of the dormitory building. According to the architectural design, at the basement floor and roof floor, mostly mechanical equipment regarding HVAC, Fire Protection, Plumbing Systems are located. The rest of the area for the basement floor was planned as shelter, storage or wet area. For the remaining 6 floors, each floor has the same architectural design and qualification. If one of the 6 floors is set as an example, the floor consists of student rooms, study rooms and mutual wet areas. The defined areas are separated from each other by masonry brickworks. For the sake of simplicity, general works for interior and exterior are introduced as follows: When masonry brickworks are over, electrical cabling is applied, then, finishing works are applied over bricks. For the ceiling, after mechanical and electrical works are finished, finishing works are applied. For the floor coating, firstly screed, then, granite or tile coating is applied over the floor. For the façade, siding is preferred for exterior closure. The project creation & demonstration, activities and their category assignment on a few project data are demonstrated on case project in Figure 21, Figure 22 and Figure 23, respectively.

Figure 21: Dormitory Building Construction Project in Projects Division

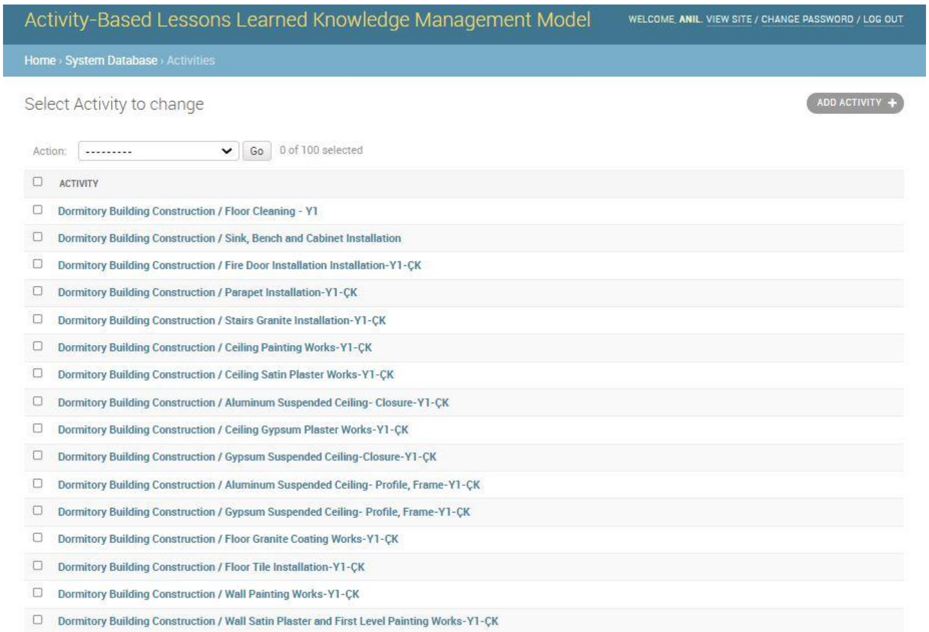


Figure 22: Dormitory Building Construction Project Activity Information Entry in Activities Division

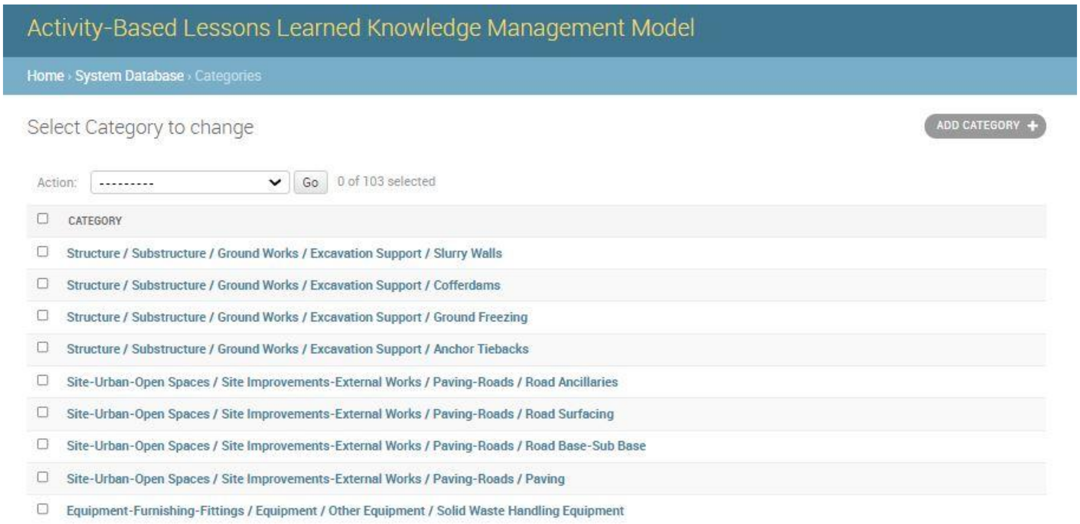


Figure 23: Dormitory Building Construction Project Category Assignment in Categories Division

6.2.2 Testing with Experts

ConSALL is tested and verified by conducting interviews with two experts. A web-based application with a case project was shared with two experts and experts were asked to evaluate the ConSALL in terms of the pros and cons of the tool and recommendations about the tool. Both experts are working in the private sector in the construction industry as a manager in the "Planning & Construction Management Department" in reputable international companies.

Expert 1 is currently working in the Turkish branch of an international construction company as a Lead Project Planner that is listed in the ENR 250 list. He has also 9 years of experience in the Planning, Budget and Cost Control division of large-scale industrial projects. Also, he has Project Management Professional (PMP)® and Scheduling Professional Certificates that are the world's leading project management certification system. Expert 2 has been working for an international Turkish company for more than 8 years as a Lead Project Planning Engineer. He has significant experience in large-scale superstructure projects in different countries.

Expert 1 stated that the tool satisfies the objectives of the thesis research according to the problem statement. Users could reach similar activities with both qualitative and quantitative information easily thanks to the user-friendly environment of the ConSALL. While doing this, categories, activity attributes and filtering options provide users to reach desired information more efficiently. On the other hand, the schedule-related retrieved information is made up of mostly quantifiable activities. There is still a need to get information about the activities that are harder to quantify from the previous projects' activities. Additionally, the ConSALL should be configurated with a construction project scheduling tool to decrease the operation time in the ConSALL. As an advantage, if activity-related information is entered into the system according to the rules and regulations mentioned in the process model, the filtering option provides users to broaden the search and make results closer to what users' are looking for. Moreover, deleting the miswritten information is complicated in the data entry page because it can be only carried out in the admin panel. Also, after clicking the finish the activity button, correcting the mistake is rather hard because the admin should correct the mistake in both activity data entries and activities category in the system database in the admin panel. If necessary improvements are carried out in related pages without visiting admin panels, system efficiency increases significantly. All in all, when ConSALL drawbacks are eliminated according to the recommendation and suggestions, the tool will become more promising and in great demand in terms of knowledge management perspective for scheduling in the construction industry.

Expert 2 initially stated that the tool meets almost all requirements and features that are stated in the process model. It is easy to retrieve previous activities with the help of developed default taxonomy. Although an enormous amount of activity information from the previous projects decreases the model efficiency, with the help of activity attributes search and category selection, listed activities from search results will become closer to desired objectives. Additionally, different filter options to retrieve the activity's daily quantitative information from previous activities are beneficial and good enough in terms of satisfying expectations. However, there is still a lack of efficiency while creating or transferring the activities' planned information into the ConSALL. If there exists an efficient synchronization between the ConSALL and construction scheduling software, it would be easy to operate the information between each other. This prevents the possibility of a loss of information or misleading information. Another disadvantage is related to the export option. Users could transfer the filtered or desired information from the tool to another platform like Excel. By doing so, retrieved information could be utilized on different platforms. In addition, a login entry should be added to the homepage to reach activity and project information. This creates obstacles and challenges to protect the information and system integrity against any bad attempts to the system. Furthermore, editing the miswritten information in the activity data entry page is easy enough, but deleting the miswritten information is rather complicated because it can only be carried out in the admin panel. Another drawback is related to the web browser. If the user wants to return to the previous page, the designed website directs the user to the first search page. This causes extra efforts to reach the desired search due to web browsers. All in all, all features that are mentioned before highly depend on company culture and staff initiative, thus it is vitally important to train staff who will enter the necessary information into the ConSALL to keep the performance of the model stable. As a result, with improvements that are suggested by experts, the proposed model may become more promising in terms of knowledge management for scheduling in the construction industry.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

As globalization increases, a huge amount of information is spread and transferred all around the world between different disciplines, geographic areas, companies and so on. It is widely discussed in the literature that storing valuable knowledge in a structured way within companies, especially in the construction industry, and utilizing this knowledge in forthcoming projects is vital for success. On the other hand, project-based organizations especially construction companies suffer from the lack of capture and reuse of valuable knowledge throughout the project cycle due to staff turnovers, cultural bottlenecks tendency of not sharing their knowledge with each other. Planning is a process that can be enhanced with LL from previous projects. When scheduling is considered as one of the most important phases of project management, construction organizations should execute and monitor the work schedule effectively throughout the project because capturing and storing schedule-related tacit knowledge and explicit knowledge may bring great advantages of using LL in future projects. Literature review shows that there are different kinds of research on improving scheduling practices with effective knowledge management and automation and LL applications in construction projects. Nevertheless, there is still a lack of an efficient process model and a tool that can be used to improve scheduling practices in construction companies by integrating LL.

For this purpose, this thesis aims to integrate scheduling and LL applications for construction companies. Propose activity-based lessons learned process model (ALLPMS) for construction companies is a generic model that was developed by referring to literature and interviewing with domain experts. First, a needs analysis was conducted with six experts to determine the points that need further improvements in the sector. A process model was developed and the user interface, information entry to the model and information retrieval functions of the model were determined according to findings of needs analysis. The activity-based lessons learned process model for scheduling (ALLPMS) was evaluated with four experts from the construction management and planning domain to evaluate the model. Lastly, a web-based tool was developed, and a case project was conducted to demonstrate how the web-based tool can be used in practice. Benefits and potential improvements of the tool as mentioned by 2 experts will be discussed in the next section.

7.1 Benefits of the Process Model and the Tool

Benefits of research outputs, particularly the process model and the tool can be summarized as follows;

For Process model:

- It provides organizations to capture, store, reuse the project-related activities' lessons learned for scheduling to utilize them for further projects. Especially, data entry and retrieval according to process model features has great potential to facilitate activity-related lessons and productivity information retrieval.
- It decreases the chance of making similar mistakes in future projects and enhances organizational learning inside the companies.
- It gives an opportunity to capture lessons learned instantly while executing the project.
- The customizability of the features enables organizations to adjust the model according to their needs easily.
- Benefiting from previous projects' activity-related lessons learned information provides more accurate duration estimation and more realistic schedules in future projects.

For ConSALL:

- Developed taxonomy provides users to categorize the activities according to the divisions. After selecting the desired category, the user could retrieve activities that belong to the selected category from all projects or a specific project. This brings great flexibility to the users to easily retrieve any activity-related LL information and activity schedule information from any project that satisfies category match.
- According to the site labor productivity changes, factors from the proposed factor list with impact rate are assigned to the activities day by day with other quantitative information. After selecting the desired category, users could select desired factors and impact rate from the previous projects' activities to get productivity information. For future projects, according to the foreseen factors and impacts, more accurate activity duration estimation could be carried out.
- Activity attributes search helps users to narrow down the scope. This increases the efficiency of the model and enables users to find more appropriate and similar activities and their schedule-related information with their LL.

7.2 Limitations and Recommendations for Future Studies

As mentioned in the literature review and expert reviews, the LL knowledge management model has several crucial tangible and intangible benefits. On the other hand, still there are existing limitations to the implementation of the model into the construction industry. One of the limitations of the model is that the efficiency of the model is highly dependent on company culture and personal behavior. Users should be fully embedded into the system and integrate the construction site with the model in order to reflect almost the reality. Another limitation is related to default taxonomy, factor list and impact rate. For the proposed model, it is assumed that users that will enter the information are qualified enough about content and features of taxonomy, factors and impact rates because, for further use, model performance is highly dependent on previously captured and stored information. Before utilization, companies should inform or educate the staff who will enter the information to keep system quality at a high level. For this purpose, companies may publish manuals or frequently asked question part that describes or explains these features with examples or illustrations. Yet another limitation is about system capabilities. Exporting to or importing from other platforms is rather limited in the proposed tool, so improving such features may increase the efficiency of the tool and make the system more user-friendly. Also, ALLPMS and ConsALL were evaluated and verified by interviews with a limited number of experts. Additionally, it is supposed that similar research results will be obtained if a different set of people are selected for evaluation and verification processes thanks to an extensive literature review. However, the high number of experts with real case implementations might provide different perspectives and improve the efficiency of the process model and ConsALL. Lastly, thesis research is mostly based on research papers in the literature and experts' guidance because it is assumed that the literature review and experts' guidance cover the general applications in the industry, so investigation of similar industry applications might provide a valuable contribution to the process model and tool development.

For future works, the proposed model can be supported with multi-criteria decision-making methods, case-based reasoning or machine learning algorithms to estimate activity productivity rate/unit man-hour information with desired factors to get activity duration estimation. With selected previous similar activity and desired factors, an algorithm could estimate possible activity duration for future projects. Also, for ongoing activities, the algorithm may calculate the possible finish duration of the activity with the help of quantitative information entered until the desired date.

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APPENDICES

A. Needs Analysis- Semi-Structured Interview Form

This semi-structured interview has been prepared for needs analysis about the activity-based lesson learned process model. Information gathered from this semi-structured interview will be used in a thesis study entitled "Needs Analyses within the context of thesis scope in the construction industry" at Middle East Technical University (METU) Department of Civil Engineering in supervisory of Prof. Dr. İrem Dikmen Toker.

The semi-structured interview form is composed of three parts. In Part 1, personal information about experts' backgrounds & experiences in terms of educational and professional life was obtained. In Part 2, general information about the proposed thesis study objective is introduced. In Part 3, 2 main questions are asked to the interviewees to determine the needs in the construction industry within the thesis scope context.

Responses to the interview will be strictly confidential and used only for academic purposes. If you have any questions and suggestions, you can contact me through the following e-mail address; anil.yilmaz@metu.edu.tr

Thank you for your cooperation.

Prepared by

Anıl Yılmaz

Master of Science Student

METU-Civil Engineering Department

Part 1: It is kindly requested to fill personal information form about background & experiences in terms of educational and professional life.

1-	Education: PhD ( ) MSc ( ) BSc ( ) Others ( ) ________________
2-	How many years of experience do you have?
	____
3-	What is your area of expertise in the construction industry?
	____
4-	What is your job title in the company you are working or worked?
	____
5-	What is the size of the company that you are still working or worked?
	____

Part 2: General information about the proposed thesis study objective is introduced.

Problem Statement/ Observed Problem in Practice: When the construction industry is considered as an experience-based discipline, knowledge or experience accumulated from previous projects plays a very important role in the successful performance of new works. Unfortunately, the live capture and reuse of construction project knowledge have remained a major challenge that has not been adequately addressed, and LL systems are not applied commonly and effectively in the construction industry. Especially, in the planning process of construction projects, lack of planning effort causes an increase in the likelihood of occurrence of project delay and cost overrun. When scheduling is considered as a crucial part of the planning process, to achieve project parameters mentioned before with higher productivity, it is seen that construction organizations do not benefit from previous schedule information with the support of accumulated tacit and explicit knowledge-LL for both activity and project level throughout the project in general.

The Gap in the Literature: In the literature, there are a lot of LL knowledge management methodology- systems- tools in practice, but there is no research about the integration of scheduling features in the knowledge management system.

The objective of the Thesis Study: Developing an effective activity-based lesson learned process management model that enables integration of scheduling programs. This integration helps to combine crucial features of scheduling and LL knowledge management system in the construction industry. In this study, the activity-based process model is proposed.

Firstly, the proposed tool aims to solve the problems that occur in construction based on lessons learned from previous projects. The cases that are similar to the new problems are selected from the previous cases of different projects. If similar cases are found, the solutions can be used to create a new potential solution for the existing problem in the following reuse phase.

Secondly, this system helps schedulers to generate schedules to increase the productivity of inexperienced schedulers and the consistency of the entire project schedule by looking at previous projects data (simple storing of cost or time characteristic values in a database). Also, the integration of schedule features with a knowledge management system enables stakeholders to manage dispute resolution and claim management effectively.

Target Group:

- People who are located from the lowest level to the upper level can take advantage of similar data of previous projects by searching, filtering options when faced with a problem at the site.
- Schedulers who want to generate a consistent schedule for the whole project in terms of duration and cost.
- Companies or contractors that want to accumulate project-specific information, know-how, etc. for future projects, claim management, dispute resolution.

The major components of the model;

Activity Case-Based Knowledge Lesson;

- Problem description — describing the problem or innovation encountered in the construction process;
- Information of the LLF writer and approvers — providing contacting information for further consultation;
- Retrieve the information- getting cases with high similarities from previous projects by searching, filtering and tagging options.
- Solution description — describing the technical and procedural details of problem and innovation resolution;
- Evaluation of the solution — assessment of the effectiveness and benefits resulting from the lesson learned.
- Pictures, images, video, reports…

Schedule Based Information;

- Retrieve the information – Get cost, duration, resources information of similar cases from previous projects to analyze case dynamics to generate a consistent schedule for future projects.
- Lesson learned entry from "Planned-Actual differences (Earned Value Analyses)", "Milestone Achievement" etc.
- Keep the history of project knowledge with the integration of schedule to deal with claims and dispute resolution.
- Early warning signs for the upcoming cases that have high similarity with previous cases and significant impact on project duration, cost, etc.
- Report option for different conditions.

Part 2: Two general questions are asked to the interviewees to determine the needs in the construction industry within the thesis scope context.

Q2- What are your general ideas (pros, cons or neutral) about possible features & components that meet the requirements of the gap in the literature and proposed scope of thesis study?

Q3- What is your recommendations and comments (what should be added, developed, emphasized further on the model) about the proposed scope of the thesis study?

B. Company-Oriented Activity Classification Taxonomy

Table B.1: Company-Oriented Activity Classification Taxonomy for Construction Phase.

Level Code	Level 1	Level 2	Level 3	Level 4	Level 5
GNR_10	General				
GNR_10_10		Documentation			
GNR_10_20		Tendering			
GNR_10_30		Quality Assurance			
GNR_10_40		General Requirements			
GNR_10_50		Preliminaries			
STR_10	Structure				
STR_10_10		Substructure			
STR_10_10_10			Foundations		
STR_10_10_10_10				Wall Foundations	
STR_10_10_10_20				Column Foundations	
STR_10_10_10_30				Driven Piles	
STR_10_10_10_40				Bored Piles	
STR_10_10_10_50				Raft Foundations	
STR_10_10_10_60				Foundation Anchors	
STR_10_10_10_70				Caissons	
STR_10_10_20			Slab-On-Grade		
STR_10_10_30			Ground Works		
STR_10_10_30_10				Excavation-Backfilling-Compaction	
STR_10_10_30_20				Dewatering	
STR_10_10_30_30				Soil Treatment	
STR_10_10_30_40				Excavation Support	

Table B.1: Company-Oriented Activity Classification Taxonomy for Construction Phase (continued).

STR_10_10_30_40_10					Anchor Tiebacks
STR_10_10_30_40_20					Ground Freezing
STR_10_10_30_40_30					Cofferdams
STR_10_10_30_40_40					Slurry Walls
STR_10_20		Superstructure			
STR_10_20_10			Structural Frame		
STR_10_20_10_10				Concrete	
STR_10_20_10_20				Steel	
STR_10_20_10_30				Timber	
STR_10_20_10_40				Stone	
STR_10_20_20			Retaining Wall		
STR_10_20_30			Roof Construction		
STR_10_20_40			Floor		
STR_10_20_50			Stairs		
STR_10_20_60			Tunnel		
STR_10_30		Exterior Enclousure			
STR_10_30_10			Cladding		
STR_10_30_20			Walls-Doors-Windows		
STR_10_30_30			Painting		
STR_10_30_40			Insulation-Waterproofing		
STR_10_40		Interior			
STR_10_40_10			Construction		
STR_10_40_10_10				Partition	
STR_10_40_10_20				Walls-Windows-Doors	
STR_10_40_10_30				Stairs	
STR_10_40_20			Finishes		
STR_10_40_20_10				Wall Finishes	
STR_10_40_20_20				Flooring	

Table B.1: Company-Oriented Activity Classification Taxonomy for Construction Phase (continued).

STR_10_40_20_30				Ceiling Finishes	
STR_10_40_20_40				Stair Finishes	
STR_10_40_20_50				Painting	
SER_10	Services				
SER_10_10		Mechanical			
SER_10_10_10			Plumbing		
SER_10_10_20			Heating-Cooling, Ventilation, Air Conditioning(HVAC)		
SER_10_10_30			Fire Protection-Detection		
SER_10_10_40			Piping		
SER_10_10_50			Transport Functions		
SER_10_10_50_10				Conveyors	
SER_10_10_50_20				Lifts	
SER_10_10_50_30				Rail Tracks	
SER_10_20		Electrical			
SER_10_20_10			Communications		
SER_10_20_20			Electric Safety and Security		
SER_10_20_30			Integrated Automation		
SER_10_20_40			Electrical Distribution and Lightening Function		
SER_10_20_50			Electrical Power Generation and Transmission		
EFF_10	Equipment-Furnishing-Fittings				
EFF_10_10		Equipment			

Table B.1: Company-Oriented Activity Classification Taxonomy for Construction Phase (continued).

EFF_10_10_10			Commercial		
EFF_10_10_20			Intuitional		
EFF_10_10_30			Residential		
EFF_10_10_40			Vehicle and Pedestrian		
EFF_10_10_50			Other Equipment		
EFF_10_10_50_10				Process Heating, Cooling and Drying Equipment	
EFF_10_10_50_20				Water-Wastewater Equipment	
EFF_10_10_50_30				Solid Waste Handling Equipment	
EFF_10_20		Furnishings			
EFF_10_20_10			Movable Furnishing		
EFF_10_20_20			Fixed Furnishing		
EFF_10_30		Fittings			
SUO_10	Site-Urban-Open Spaces				
SUO_10_10		Preparation and groundwork			
SUO_10_10_10			Earthwork		
SUO_10_10_20			Site Clearing		
SUO_10_10_30			Site Demolition-Relocation		
SUO_10_20		Site Improvements-External Works			
SUO_10_20_10			Paving-Roads		
SUO_10_20_10_10				Paving	

Table B.1: Company-Oriented Activity Classification Taxonomy for Construction Phase (continued).

SUO_10_20_10_20				Road base-Sub-Base	
SUO_10_20_10_30				Road Surfacing	
SUO_10_20_10_40				Road Ancillaries	
SUO_10_20_20			Landscaping		
SUO_10_30		Utilities			
SUO_10_30_10			Stormwater Inst.		
SUO_10_30_20			Wastewater Inst.		
SUO_10_30_30			Freshwater Inst.		
SUO_10_30_40			Gas Inst.		
SUO_10_30_50			Fire Inst.		
SUO_10_30_60			Site Communication Inst.		
SUO_10_30_70			Site Electric Dist. Inst.-Lighting		

C. Evaluation of Lessons Learned Process Model on Scheduling Framework with Functions- Semi-Structured Interview Form

This semi-structured interview has been prepared for evaluation of lessons learned knowledge management model on scheduling framework with functions. Information gathered from this semi-structured interview will be used in the subsection of the thesis study entitled "Evaluation of Lessons Learned Knowledge Management Model on Scheduling Framework with Functions" at Middle East Technical University (METU) Department of Civil Engineering in supervisory of Prof. Dr. İrem Dikmen Toker.

The semi-structured interview form is composed of three parts. The first part was designed to get personal information about experts' backgrounds & experiences in terms of education and professional. In the second part, general information like problem statement, the gap in the literature and objective about the proposed thesis study was introduced. In the last part of the interview, the main components of the model with their details were presented to experts. Then, it was requested to review each section of "Activity-based lessons learned process model for scheduling" as well as its functions (input & outputs) that are provided beyond each section.

Responses to the interview will be strictly confidential and used only for academic purposes. If you have any questions and suggestions, you can contact me through the following e-mail address; anil.yilmaz@metu.edu.tr

Thank you for your cooperation.

Prepared by

Anıl Yılmaz

Master of Science Student

METU-Civil Engineering Department

Part 1: It is kindly requested to fill personal information form about background & experiences in terms of educational and professional life.

1-	Education: PhD ( ) MSc ( ) BSc ( ) Others ( ) ________________
2-	How many years of experience do you have?
	____
3-	What is your area of expertise in the construction industry?
	____
4-	What is your job title in the company you are working or worked?
	____
5-	What is the size of the company that you are still working or worked?
	____

Part 2: General information about the proposed thesis study objective is introduced.

Problem Statement/ Observed Problem in Practice: When the construction industry is considered as an experience-based discipline, knowledge or experience accumulated from previous projects plays a very important role in the successful performance of new works. Unfortunately, the live capture and reuse of construction project knowledge have remained a major challenge that has not been adequately addressed, and LL systems are not applied commonly and effectively in the construction industry. Especially, in the planning process of construction projects, a lack of planning effort causes an increase in the likelihood of occurrence of project delay and cost overrun. When scheduling is considered as a crucial part of the planning process, to achieve project parameters mentioned before with higher productivity, it is seen that construction organizations do not benefit from previous schedule information with the support of accumulated tacit and explicit knowledge-LL for both activity and project level throughout the project in general.

The Gap in the Literature: In the literature, there are a lot of lessons learned knowledge management methodology, systems or tools in practice, but there is no research about integration of scheduling features in lessons learned knowledge management systems.

The objective of the Thesis Study: Developing an effective activity-based lesson learned process model that integrates with scheduling. This integration helps to combine crucial features of scheduling and LL knowledge management in the construction industry. In this research, activity-based lessons learned model for scheduling is proposed.

This system helps to generate more consistent and accurate schedules thanks to benefiting from previous projects activities' quantitative information like productivity rate/ unit man-hour information. Also, the activities that are similar to the current activities are searched and filtered from the previous projects. If similar activities are found, the lessons learned from these activities might be used to create a better estimation for the schedule in future projects.

Part 3: Main components of the model are presented below. It is kindly requested to review and answer the questions just below each section of the"activity-based lessons learned process model for scheduling" as well as its input & outputs. Then,

1st component: "User Interface for Model". Within the context of this component, "Knowledge Manager", "Knowledge Facilitator" and "Knowledge User" are assigned for different authorization levels of roles.

> **Knowledge Manager**: is responsible for reviewing (editing/deleting/approving) LL that are entered into the system. "Knowledge Manager" should be highly experienced in the company because system reliability is highly dependent on "Knowledge Manager". Also, the "Knowledge Manager" is responsible for initial project creation and transferring of activities into the system.

Knowledge Facilitator: is responsible for collecting and entering activity-related quantitative information, especially activity's "Unit Man-Hour" with "Factor List" and "Impact Rate", day by day on site. "Knowledge Facilitator" might be personnel from the site or the Project Planning Department.

Knowledge User: is a role that has the right to enter or display already entered the LL information.

Q1- What is your general ideas (pros, cons or neutral) about the context of 1st component?
Q2- What are your recommendations and comments (what should be added, developed, emphasized further on the model) about 1st component of the thesis process model?

2nd component: "Information Entry to Model". In this component, two types of knowledge, "Activity-Related Lessons Learned Entry" and "Activity-Related Productivity Rate (Unit Man-Hour) Information Entry", are captured and stored in the system with the aid of "Taxonomy" and "Activity Attributes".

Within this context of "Activity-Related Lessons Learned Entry", the information entry framework is comprised of 8 different activity-related event descriptions to capture the information. These are "Activity Name", "Lessons Learned Type", "Event Description", "Solution Description & Recommendation", "Create Date", "Related Factors", "Lessons Learned Approvers", "Extra Documents (Pictures, images, video, reports)".

Within this context of Activity-Related Productivity Rate (Unit Man-Hour) Information Entry", it is aimed to capture and store activity-related productivity rate/unit man-hour information with the “Factors Affecting the Activity” and “Impact Rate”, between 1-5 (1 is least impacted, 5 is most impacted) in an organized manner. (Factor list that is presented in Table 5 was shared with experts.)

Q1- What is your general ideas (pros, cons or neutral) about the context of 2nd component?
Q2- What are your recommendations and comments (what should be added, developed, emphasized further on the model) about 2nd component of the thesis process model?

3rd component: “Information Retrieval from Model”. “Information Retrieval from Model” section focuses the utilization and facilitation of this knowledge for reusing purpose with the aid of “Filtering Taxonomy Development” by using “categories” in “taxonomy” to find related activities LL, “Filtering by Activity Attributes” uses “activity attributes” to find related activities LL and “Filtering Productivity Rate/Unit Man-Hour Information” by selecting “Factors” and “Impact Rate”,

Within the context of “Filtering Taxonomy Development”, activity-related lessons learned knowledge is stored in a consistent manner and retrieved easily with the taxonomy. (Default taxonomy that is presented in Appendix 2 was shared with experts.)

Within the context of “Filtering by Activity Attributes”, activity-related attributes such as activity unit, keyword search, activity region, etc. are assigned to the activities to narrow down the search in the database.

Within the context of “Filtering Productivity Rate/Unit Man-Hour Information”, Filter by “Factors” and “Impact Rate” option to specify or narrow down the activity’s “Actual Unit Man-Hour” according to the factors that affect the activity and impact rate.

Q1- What is your general ideas (pros, cons or neutral) about the context of 3^{rd} component?
Q2- What are your recommendations and comments (what should be added, developed, emphasized further on the model) about 3^{rd} component of the thesis process model?