A PILOT STUDY OF WEB-BASED INFORMATION BOTTLENECK IDENTIFICATION IN AEC PROJECTS

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Construction Management – Master of Science

2022

ABSTRACT

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The success of the Architecture, Engineering, and Construction (AEC) project relies heavily on the effective communication and information exchange between project team members. A prominent reason for delays and progress shortcomings in AEC project teams is information bottlenecks, defined as missing project information bits which can be due to large influx of information or inadvertent withholding of information at a particular time. Information and communication exchange patterns between project team members shed a light on the possible occurrence of information bottlenecks.

Therefore, the research question this research aims to answer is "Can the usability and adaptability of information bottleneck prediction in AEC projects be improved through a web-based tool?" The web-based platform is designed to cater the specific information exchange trends in a typical project. Providing visual representations, and explanations further ease the understanding of the root issue. Finally, through two expert interviews, the web tool is revised, and final tool is presented, and future directions of work are discussed.

ACKNOWLEDGEMENTS

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

Process improvement, waste and rework reduction, efficiency improvement form the core values of the lean philosophy (Abdelhamid 2007). Large scale construction projects rely heavily on information exchange throughout their delivery. Information exchange can be in form of emails, through meetings, information exchanged via project documentation data (Sacks 2007). Given the amount of information that is shared between team members there remains a chance of possible wastage, and rework. This may lead to the occurrence of possible information bottlenecks. Lean Construction Organization defines bottlenecks in manufacturing as follows: "A bottleneck (or constraint) in a supply chain means the resource that requires the longest time in operations of the supply chain for certain demand." Sacks (2010) explains information bottlenecks in construction as the withholding of project related information by team members which might result in delays in potential delays in cost and schedule.

The success of Architecture, Engineering, and Construction (AEC) projects relies heavily on the effective communication, and information exchange between project team members. Turbulent information exchange can be due to a variety of personal or organizational issues. The concept of Bottlenecks in AEC teams was first introduced using the Fluid Mechanics concepts by the works of Fyall (2002). Over successive years, research has focused on using the fluid mechanics elements to define the occurrence of information or project bottlenecks in project teams. Information Bottlenecks is defined as One such issue is information bottleneck, defined as withholding or missing bits of project information. Bottlenecks both in planning and execution phases of the project have the tendency to cause schedule delays and cost overruns.

Information and communication exchange patterns between project team members sheds a light on the possible occurrence of bottlenecks. This thesis aims to contribute to the existing body of knowledge by studying if the existing prediction technique of information bottlenecks can be improved by integrating lean principles and implementing them through a web-based tool. Recent literature surrounding bottlenecks involved prediction through identification of key information and performance indicators by studying the information flow between teams. This thesis uses similar approach by identifying key performance indicators (KPIs) using archival data of two large scale expansion projects. The model was implemented using a web-based platform using python coding. After development, expert interviews were conducted to get the feedback on the usability and adaptability of the tool in actual AEC projects. Feedbacks received during these interviews were incorporated in the model, and the modified model will be presented for the readers.

1.2 PROBLEM STATEMENT

Bottlenecks in information flow is important to track progress in AEC projects. Despite a number of prior research efforts on this important topic in the literature adapting quantitative, qualitative, and mixed methods, there still is a gap in identification techniques which can readily applied to most construction projects. The issue of implementation can be explained by the complexity of some of the equations used. The inputs for the equations which are used for quantifying information metrics are rather complex and require rigorous calculations. The problem related to the usability therefore needs to be addressed for prediction of bottlenecks in AEC projects.

1.3 RESEARCH GOAL AND OBJECTIVES

The research goal is to develop a web-based platform tool and test its usability and adaptability to predict information bottlenecks in AEC Projects. The research objectives are to:

1. Determine and adjust key performance indicators and efficiency metrics to quantify information exchange trends between team members during project delivery: Difficulty in calculation of existing metrics in literature was addressed by making suitable modifications in these metrics. The modified metrics were then used to quantify metrics based on the available documentation data. These metrics include information development velocity (DV), productivity, average days to resolve project issues, work in progress (WIP) (Sacks 2011).

2. Adopt activity types (i.e., Pooled, Sequential, Reciprocal, and Intensive) based on their collaboration requirements (Bell and Kozlowski 2019) and explore their impacts on bottlenecks to further improve bottleneck predictions during project delivery.

3. Using data from two existing case study projects, test the metrics developed in Objectives 1 and 2 above. This step was completed by the research team, funded by NSF CMMI # 1825678 and IIS# 1928278, that the author of this thesis was a part of. The research team developed a predictive model for information bottlenecks based on information publication data to: (a) predict information bottleneck using information publication data that are practically feasible to estimate and (b) study the effect of activities with different interdependencies on the predictive model performance. at study

4. Applying the model and results developed in Step 3 above, design a web-based tool to test the usability and adaptability of bottleneck prediction. The web-based tool will help for easier execution of large-scale project data, capturing important project related information. Email

exchange data, meeting issues, project documentation data will be imported to the web-based tool, and it can also be used to generate graphical reports of information trends and monthly KPIs. The web-tool developed was iteratively improved using the following steps:

- The tool was presented to and allowed to be navigated by two industry specialists. Their feedback and comments were recorded by the researcher. Furthermore, the feedback were studied to understand if the tool can be used in AEC teams, who should use the tool, what improvements should be made in the tool to make it better.

- The feedback received was implemented in the tool and the final tool is presented in this thesis.

1.4 RESEARCH DESIGN

Adoption of bottleneck metrics from the literature, automation challenges, development of a web-based interface using data from two case studies, and expert interviews for verification and further development are the four main areas of the study. Quantitative and qualitative methods to address these scopes were adopted in the study design. The research is divided into four separate sections with different deliverables by the researcher.

- **Section 1:** Developing quantification metrics and modifying information metrics formulas to quantify team performance and project performance.

- **Section 2:** Automating the metrics and using the project documentation raw data to report on possible information bottlenecks.

- **Section 3**: Developing a web-based used using python coding and reporting on bottlenecks.

- **Section 4:** Interviewing industry experts to get their feedback on the adaptability and usability of the tool.

Figure 1.4 explains the automation part and conversion of meeting minutes data, documentation data to identify bottlenecks, and is divided into
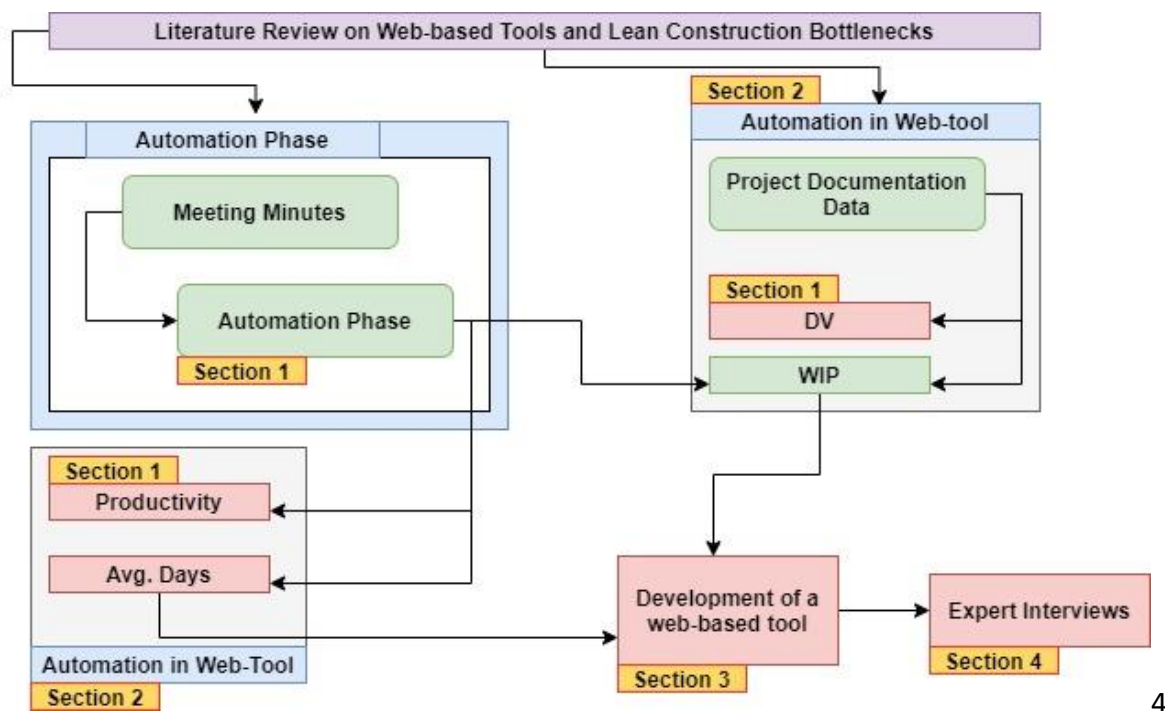
sections as mentioned above

FIGURE 1.4: RESEARCH DESIGN FOR IDENTIFICATION OF BOTTLENECKS

1.5 SCOPE AND LIMITATIONS

The scope of the research focuses on information exchange between AEC project team members. Complex AEC projects require collaboration between a number of teams including owner, designer, contractors, and sub-contractors. Such a level of collaboration involves extensive information and communication exchange. Therefore, the means through which most communication and information exchange between teams takes place are shortlisted and analyzed. These means include email communication, web-based documentation, and face to face resolution through bi-weekly meetings.

To aid with the applicability, a web-based tool that utilizes improved methods based on the literature and ML is designed to track, identify information sharing patterns between AEC project team members, and detect bottlenecks in reliable and practical manners. The web-based tool will be trained to accept information data and use performance metrics and information trends to predict possible occurrence of bottlenecks. The prediction accuracy will be further tested using a case study data from a third project. This research effort thus aims to answer the research question, "Can the adaptability and accuracy of information bottleneck prediction in AEC projects be improved through a web-based tool?" Therefore, this thesis aims at providing more reliable, applicable, and easier identifiable techniques of finding bottlenecks by using the following methodologies:

- Reviewing and modifying metrics defined in literature;

- Using dash framework to identify and report on existing information bottlenecks;

- Designing a web-based platform to implement the model; and

- Verifying and further improving the web-based interface through expert interviews.

1.6 DELIVERABLES

The key deliverables targeted through this effort include development of improved performance
indication metrics to measure efficiency of information usage, design of a web-based platform to
help with easier implementation of these metrics in complex projects and to test the accuracy of
the prediction using a case study dataset. The key deliverables are discussed in the points below
and the figure highlights key input and output for this study.

i.   Key performance indicators and efficiency metrics to quantify information trends
     between project teams. Discussions on which metrics require rigorous calculations based
     on literature and modifications made to equations.

ii. Project issues characterization into pooled, sequential, reciprocal, and intensive.

iii. Web-based platform to predict bottleneck using the lessons learned from analysis that is
     ready for beta version.

CHAPTER 2 LITERATURE REVIEW

Through this section the researcher discusses the advancements in research in the field of

project bottlenecks over the years. The section is divided into 4 major sections discussing what

bottlenecks in AEC projects, information exchange platforms used by teams which are useful in

identifying some of these issues, some of the web-based tool already available to help in

identification, and a summary section.

2.1 INFORMATION EXCHANGE IN AEC PROJECT TEAMS

AEC teams rely on coordination, communication, and participation between team members of

diversified backgrounds for the success of the project. AEC teams maybe chose to transfer

information and project related data to their project teams and other partners participating in

the projects, such technologies can be termed as Information Exchange (Baldwin et. al 1999).

Information can be characterized in several different types based on their usage. From purchase

orders, request for information (RFI), bill clarifications to minor clarifications or corrections in the

drawing sets (Journal of Institution of Civil Engineers). Substantial savings in cost can be achieved

if information management for a project is well defined. The following figure discusses the types

of data exchange between project team members.
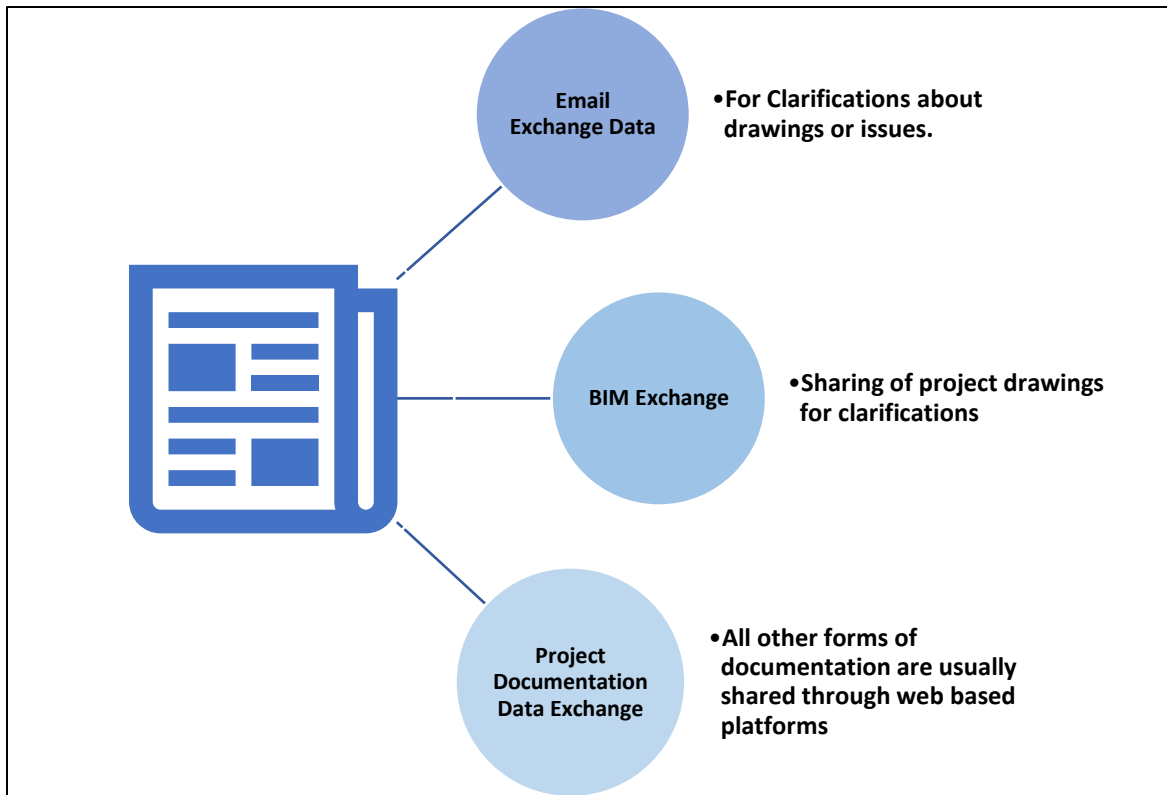
FIGURE 2.2: FORMS OF INFORMATION EXCHANGE IN PROJECT TEAMS

Trends of information exchange can be used to predict how distributed or smooth knowledge transfer is in AEC Project Teams. Such trends also have possible implications on bottlenecks. The information and knowledge which is marked by peaks and valleys meaning when information is exchanged in bulks at one point of time can have impacts on the productivity and efficiency of teams. Such turbulent information exchange can lead to the occurrence of project bottlenecks. Information provided at the right time and consistently through communication or information exchange platforms leads to a more coherent knowledge transfer.

Sacks (2007, 2009, 2010a, 2010b, 2011) highlights how team members interact when it comes to sharing project related information. Sacks (2007) explained that information exchange between team members occurs in three major forms: Through project documentation websites, emails, and face to face interactions in meetings. There are several perks attached to each type of

information exchange they are discussed in Table 2.1.2 as adapted from Foley and Macmillan (2005).

TABLE2.1.2: INFORMATION EXCHANGE AND THEIR ADVANTAGES AND DISADVANTAGES

Type of Information Exchange	Advantages	Disadvantages
Email Exchange	• Easier to use • Specific recipients can be set • Takes minimal time	• Record might not be maintained • Makes it harder for PM to track progress • May result in loss of data • Not ideal for RFIs, Change orders
Project Documentation	• Data can be archived and saved for future references • Provides insights and reduces conflicts • Suitable for large or bulk files	• Might not be adoptable equally by all team members • Takes more time than emails • Not suitable for minor clarifications
Meetings	• More feasible for on spot clarifications • Suitable for on minor clarifications • Preferred for hard documents	• Requires in-person presence

Sacks (2010a) highlighted how certain trends in formation exchange is capable of indicating the type of information exchange patterns between members. A turbulent information exchange marked by peaks and valleys reflects that information is shared in bulks, the chances of occurrence of bottlenecks in such cases is higher (Ashwini et. al. 2012).

2.2 LEAN THEORY AND BOTTLENECKS

Over the years, several efforts have been made to understand and predict bottlenecks in AEC industry. The rather innovative findings of Fyall (2002) opened an uncharted territory in the field

of project bottleneck identification. Over the years several qualitative and quantitative approaches have been pursued by researchers to come up with optimum prediction techniques. Contributions of Tribelsky and Sacks (2007, 2010, 2011) have been note-worthy . The learnings and prediction tools discussed through the works of Sacks prompted to the question whether these methodologies can be realistically applied in an AEC project. The direction chosen to answer this question revolved around adaptability of the produced methods. The easier and more user friendly the implementation, the easier it is to adapt. This prompted to the research question "Can the adaptability and accuracy of bottleneck prediction in AEC projects be improved by the use of machine learning concepts through a web-based platform?".

Quantification metrics and KPIs used to quantify information exchange have been the main area of research when it comes to prediction of bottlenecks. Staron and Meding (2011), developed a unique software platform using lean principles by conducting a case study at a software development unit and successfully identified one bottleneck in the design phase. Although this approach pioneered the use of software technology in identifying project bottlenecks, it has not been used by construction firms due to the lack of application software and its limited sample of implementation. Inspired by the metrics developed by Tribelsky and Sacks (2010a), Hattab and Hamzeh (2018) developed a mathematical model to calculate DV and WIP but did not use it for bottleneck resolution.

The literature illustrates the emphasis on development of KPIs and quantification metrics to understand how information is shared between project teams. Staron and Meding (2011), however, is striking in the sense it incorporates identification through software development. This kind of approach can be used as a benchmark for this work as it aims to contribute by using

machine learning tools for bottleneck prediction. Table 2.1.3 below highlights major developments and efforts in identifying construction bottlenecks over the years.

TABLE 2.1.3: TRACK OF RESEARCH ON BOTTLENECKS

Area of Research in Bottlenecks	2000-2005	2005-2010	2010-2015	2015-2020
Analogy drawn between fluid mechanics concepts of bottleneck flow and information bottlenecks.	Fyall (2002)			
Use of fluid mechanics equations to explain the bottleneck phenomenon	Fyall (2002), Chang and Ibbs(1999)			
Understanding how information flow effects bottleneck occurrence	Tribelsky and Sacks (2007)	Sacks et. al (2010), Tribelsky and Sacks (2010a)		
Development of quantification metrics to predict bottlenecks		Tribelsky and Sacks (2010b)		
Use of qualitative approach and waste phenomenon to understand wastage of information	Sacks et. al (2010)	Abdelhamid et.al (2009)	Tribelsky and Sacks (2011)	
Proposal of integrative approach		Dainty et.al(2011)		
Development of software to understand occurrence of bottlenecks	Stewart and Mohamed (2004)		Staron and Meding (2011)	
Enhancing already defined quantification terms to ease the calculation steps of metrics			Al Hattab and Hamzeh (2015)	
Use of tracking tool to understand if reduction in wastage can improve bottleneck calculation		Huang et. al (2009)	Wolniak (2013)	Wolniak at. Al (2018)
Comparison of results obtained through qualitative analysis with quantitative analysis		Emmitt and Gorse (2006)		Zivaljevic (2015)

2.3 BOTTLENECKS IN AEC PROJECTS

A detailed review of the available literature for identification and prediction of bottlenecks highlights that the focus has been upon quantification and formulation of information trends patterns. With the works of Sacks and Tribelsky (2007, 2009, 2010a, 2010b, 2011), Whitford and Chang (1998, 2016) a great understanding has been developed on how exactly fluid mechanics concepts can be used as a reference to formulate equations. Some of the key metrics identified through their works are DV, WIP, Action Rate, Rework, Bottleneck. Although the inputs for these equations are complex and require complex data sets from different phases of the projects. These inputs are sometimes difficult to capture with the project documentation data available as information regarding exact workflow, time stamp of work, unused documents is very difficult for a large scale project. Therefore, this research aims to contribute to the existing lean literature by providing modifications on already identified metrics and increasing its usability by designing a web-based model. The use of reporting model for identifying the instance where the probability of bottleneck occurrence might also provide insights on a more accurate and reliable prediction. Bottlenecks in AEC projects could have possible implications on project cost and schedule. Therefore, it is important to understand and mitigate the reasons which might lead to the occurrence of such bottlenecks (Dainty et. al 2009). Through the following sub-section, the researcher discusses the prior literature efforts in this area.

2.3.1 BACKGROUND OF PROJECT BOTTLENECKS

According to a global construction survey by KPMG in 2019, over 80% of all construction finish over time. This delay in construction projects can be attributed to a lot of factors including

ineffective communication, rework, poor planning, lack of coordination, and wastage. To address

these issues, over the last decades, construction firms have increasingly shown proclivity towards

adaptation of more sustainable forms of construction. Lean Construction is one such approach.

Defined by Lean Construction institute as "Lean Construction extends from the objectives of a

Lean production system—maximize value and minimize waste—to specific techniques and

applies them in a new project delivery process" (IPD and Lean Construction, 2014)

Effective communication and coherent project information exchange between multi-disciplinary

project team members serve as the benchmark for the successful and timely completion of a

construction project (Sacks et. al. 2010a). To achieve this, it is important to identify obstacles

which adversely affect the success of a construction project. Withheld information by team

members, termed as 'bottleneck' in lean literature, is one of the factors. Effective communication

and coherent project information exchange between multi-disciplinary project team members

serve as the benchmark for the successful and timely completion of a construction project (Sacks

et. al. 2010b). To achieve this, it is important to identify obstacles which adversely affect the

success of a construction project. Withheld information by team members, termed as

'bottleneck' in lean literature, is one of the factors which often results in unprecedented project

outcomes including cost overruns and schedule delays (Tribelsky and Sacks 2011). The need to

develop an ideal technique for precise bottleneck prediction to ensure smooth information

transfer between teams and optimum productivity of team members were primary influences

that drove this research.

There are two different types of bottlenecks in AEC projects which can be explained through the

literature. Information bottlenecks draws similarity from deep learning algorithms and whereas

Project bottlenecks uses fluid mechanics concepts to understand the potential issues in AEC teams. This research using the deep learning definitions of Information bottlenecks redefines information bottlenecks for AEC teams (Newvan et. al 2016).

This section highlights why a more comprehensive and reliable approach is required. Based on the current research trends on quantifying information bottlenecks, there is a lack of a more adaptable techniques for bottleneck identification. Through the following sections, the researcher will discuss information exchange in project teams, lean theory and bottlenecks, metrics for identifying bottlenecks, issue types based on literature, and role of automation in construction industry.

2.3.2 BOTTLENECK METRICS

In this section the researcher will focus on the different metrics defined for the quantification of information exchange. The section discusses the already developed metrics from prior literature efforts. Due to limitation and difficulty in extracting the exact information bits, some of these metrics have been redefined in chapter 3 of this thesis. The researcher also discusses the potential limitations of exactly implementing the metrics in the following section.

- Development Velocity (DV)- Development velocity can be defined as the development of information as represented by the accumulation of details. It is calculated between two time intervals, and the first time interval is when project information is made available to project teams from the web-tool. The DV is defined by the following equation (Tribelsky and Sacks 2010a):

$$DV_t = (PS_t - PS_{t1}) / (T_t - Tt_1)$$

DV_t – DV at time T

PS – Package size at time t and t1

T – Time interval at t and t1

Potential Limitation: In the research discussed above, the changes in the drawings is marked automatically. This makes tracking comments, and changes easier and hence calculation of package size is easier. The calculation of Package size used a software called Autovue which tracks changes and updates in the new drawing sets uploaded in the project documentation website. Since, the project involved in this research did not have an automated feature which tracks and counts number of changes made in each update, it is difficult to manually track these changes over the course of the project.

- Package Size (PS) - Quantifies the level of detail of information package. The equation used for PS in literature is explained below (Tribelsky and Sacks 2010a):

$$PS_t = \sum nIA^v_i$$

PS – Package size at time t

nIA^v_i – number of attributes of an information package

Potential Limitation: Package size calculation requires extensive marking and counting of each update or comment made in with each drawing update in the project. It can be done with certain software like Autovue automatically. However, since Autovue was not used for the projects used for this research, manual counting of each change requires extensive calculations.

- Work in Progress (WIP) – The number of available but unused information packages. The equation used is discussed below (Tribelsky and Sacks 2010a):

$$WIP = \sum nIPj \, j = 1 \, (t - Tupj) \, PSjUj$$

WIP – Work in Progress

$PSjUj - Uj = 1$ if package j has been viewed or downloaded by a team member

$Tupj$ – The day at which the package was uploaded.

Potential Limitation: Package size calculation requires extensive marking and counting of each update or comment made in with each drawing update in the project. It can be done with certain software like Autovue automatically. However, since Autovue was not used for the projects used for this research, manual counting of each change requires extensive calculations.

- Bottleneck Indicator (BN) – Bottleneck indicator is matrix developed by the works of Tribelsky and Sacks (2010a), where values of DV and WIP reflect on potential bottlenecks in a particular range. Bottleneck indicator reports 1 when WIP is ranged between 0.25-0.5, 0.5-0.75, 0.75-1 and DV is ranged between 0.75-1. Whenever the value of Bottleneck indicator is 1, chances of occurrence of Bottleneck is high (Tribelsky and Sacks 2010a).

2.4 INFORMATION EXCHANGE PLATFORMS

Even after significant improvements in the design of project documentation software, research highlights that many construction firms still rely on emails to share valuable project related information. This can be trimmed down to the ease in usage of emails over project documentation websites. While hardware access of the team members may also contribute to usage of email for information shared.

Capilla et. al. (2012), designed a web-based tool to record and manage architectural design decisions. The decision network developed support system illustrated how key decisions made during the design processes can serve as an inventory for understanding and implementing

future similar decisions. By developing a data storage drive and web-based environment facilitates the sharing and reuse processes of architectural knowledge in distributed groups. The key takeaway from the web-based tool as how it identified dependencies and constraints while making a decision. This allocation of dependencies can be used in our study to characterize tasks. Over the years, several approaches have been made to design and improve the project documentation handling. Key software used to address the documentation needs are now cloud based including Procore, Unifier, PlanGrid, JIRA, and several others. Although they incorporate all the administrative needs of a typical construction project, from a research perspective the study of collaboration patterns, and information usage remains in question. The number of advantages of using a cloud based documentation system are countless. There are however some disadvantages mainly concerning the wastage and rework needs of the information. Given the ever expanding and ever improving nature of the industry, the next milestone could be to understand how the information uploaded in the webpages are utilized by the team members. Use of ML and AI concepts can also help in understanding if conclusions can be drawn to improve trends of information sharing.

Nitithamyong (2004) studied the most used project documentation data and highlighted ways and directions of improvement. Dave and Koskela (2009) developed a knowledge base platform where all information regarding a construction project was uploaded. Based on the time and project requirements information can be drawn from this knowledge base and used by the teams. However, no explanation was made on how rework and wastage of documents can be made from this approach.

Sacks (2014) identified the key factors which contribute to the success of a web-based platform, these included 'adaptability by the teams, use of advanced technologies on site, contract agreement language between teams, time-constraint of the projects.' Deviations from these factors could result in a lot of wastage, rework, and may increase information sharing time by involvement of emails and other ways for communication. Table 2.5 highlights what different software used in the industry have in common and also reiterates the need of a new tool for bottleneck identification.

TABLE 2.5: REVIEW OF CONSTRUCTION MANAGEMENT WEB-BASED TOOLS CURRENTLY IN USE

Software	Expertise Area	Common Features							
		Document Management	Workflow metrics	Project Directory	Email Contact	KPIs	Comments or threaded discussion	Meeting minutes Gantt charts	Bottleneck identification
In Eight	Project Management	✓	✓	✓					
Service Titan	Lean KPIs		✓	✓		✓			
RedTeam	Construction Management	✓		✓	✓		✓		
FonnConstruction	Document Management	✓		✓			✓		
PlanGrid	Project Management	✓	✓	✓			✓		
BIM360	Project Management	✓	✓	✓			✓		
SAM	Issue Management		✓		✓	✓			
ProDBX	RFI Management	✓	✓	✓			✓		
Aidi	Change Management	✓	✓	✓	✓	✓	✓		
ISETIA	Progress Management	✓	✓	✓					
KAHUA	Efficiency Metrics		✓	✓		✓	✓		
Job Progress	Lean KPIs		✓	✓		✓		✓	
Unifier	Project Management	✓	✓	✓		✓	✓		

Through this section the researcher highlighted the key research areas in bottleneck identification through a comprehensive review of literature. This section helps in understanding the specific needs of the web-based tool, improvements which can be to the existing tools to get a more usable and adaptable technique for identifying information bottlenecks. The study aims to incorporate valuable findings of prior literature works and develop new metrics, integrate key qualitative factors with the quantitative ones and produce an ideal model for bottleneck prediction.

2.5 ISSUE TYPES TO INFORM BOTTLENECK CALCULATIONS

Construction issues discussed in project team meetings differ in their complexities. Project teams tend to collaborate and work depending on the complexity of the issue in hand (Michelle et. al. 2019). Bell and Kozlowski (2019) highlighted issues during the length of the project can be characterized under Pooled, Sequential, Reciprocal, and Intensive based on the collaboration patterns of the teams. The issues discussed in meeting minutes were changed into different types based on collaboration requirements as described by Bell and Kozlowski (2019). This was done to understand if different types of issues have any impact on bottlenecks. An issue which requires collaboration and engagements from team members from various disciplines could possibly have an impact on occurrence of bottlenecks. This section thus defines the different interdependencies based on Bell and Kozlowski (2019).

i. Pooled: Pooled issues are least interdependent where work and activities is distributed separately by members of the team. This type of interdependency is common for low complexity tasks and require minimal collaborations.

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ii.   Sequential: In sequential issues work and tasks flow unidirectionally between team members based on their expertise. Usually, collaboration is not required as information follows its defined path based on the functionality of the team members. Sequential type issues are also common for low complexity tasks.

iii.   Reciprocal: Reciprocal issues are those which involves back and forth of information between team members till the issue is resolved. Usually, team members of two different expertise coordinate closely to resolve such issues and thus it involves large amount of information and communication. Such issues are common for high complexity tasks which requires rechecks, and reworks.

iv.   Intensive: Intensive issues are usually of highest complexity. Due to their complexity, there is often no regular pattern which is followed by team members. Such issues are goal oriented, and the project teams of various expertise collaborate for their resolution. Intensive issues are usually high complexity tasks.

This section defines four different types of issues. Issues are characterized into their respective type by the researcher based on the protocol after the Gantt chart of issue resolution is developed by using meeting minutes. The issue types are also useful in bottlenecks and the details of that will be addressed in the methodology section of the thesis. The next section highlights the artificial intelligence and its use in bottleneck detection.

2.6 MACHINE LEARNING AND AUTOMATION IN BOTTLENECK DETECTION

Through this section the researcher discusses the details of the prior literature works which links machine learning concepts with bottleneck detections and automation in AEC projects. Over the

years, many literature efforts have focused on incorporating machine learning into tackling some major issues in the AEC industry.

Ahmed et. al. (2016) developed a machine learning model to study develop machine learning models in order to facilitate accurate project delay risk analysis and prediction using objective data sources. Relevant delay risk sources and factors were identified, and a multivariate data set of previous projects' time performance and delay-inducing risk sources was compiled. Subsequently, the complexity and interdependence of the system was uncovered through an exploratory data analysis. Accordingly, two suitable machine learning models, utilizing decision tree and naïve Bayesian classification algorithms, were identified, and trained using the data set for predicting project delay extents. Although this approach was one of first of its kind to study how machine learning could be used to study delays in projects, the specific constraints, properties of the unique dataset make it difficult for its practical implementation.

Vijaya et. al (2010), used a methodology to apply decision tree to analyze the construction labor productivity. The methodology addressed three areas in decision tree construction process. These included selecting more influential attributes, combining multiple attributes, and defining the threshold to ignore irrelevant attributes. This was a great approach to identify key areas where ML algorithms can be implemented in the studies of project documentation and archival data providing more realistic usage. The exact area of implementation however, through this methodology remained unanswered. Capilla et. al. (2012) designed a web-based tool to record and manage architectural design decisions. The decision network developed support system illustrated how key decisions made during the design processes can serve as an inventory for understanding and implementing future similar decisions. By developing a data storage drive and

web-based environment facilitates the sharing and reuse processes of architectural knowledge in distributed groups. The key takeaway from the web-based tool as how it identified dependencies and constraints while making a decision. This allocation of dependencies can be used in our study to characterize tasks.

2.7 USABILITY INSPECTION OF WEB-TOOLS

Nielsen (1994) highlights a technique called 'Usability Inspection' which can be used to understand the usability problems in user interfaces. Nielsen (1994) describes four basic ways to evaluate user interfaces: automatically, empirically, formally, and informally. For this study, empirical evaluation of user-interfaces will be adopted. The web-based model will be tested for its usability and adaptability on two construction industry experts, to determine how the model can provide a more applicable methodology to identify information bottlenecks.

Empirical evaluation for user interfaces can be defined as testing the usability of interfaces on real users. Since this project focuses on identifying project bottlenecks on construction projects the empirical testing will be used with construction professionals. Research has highlighted some of basic problems and issues which the developer tends to miss can possibly with identified using the empirical method. On the other hand, using a combination of more than one method of evaluation can often yield best results (Desurvire 1994) (Desurvire et. al. 1992) (Fagan 1986).

The detailed components of the breakdown of the inspection methods are discussed below:

1. *Heuristic Evaluation:* most informal method which involves usability judges to analyze the interface based on standard usability principles (Neilsen 1994).

2. *Cognitive Walkthroughs:* uses a detailed procedure to simulate the user's problem-

   solving techniques identifying if the user's primary goal can lead to the next corrective

   action in the code (Mack et. al 1994).

3. *Formal Usability Inspections* uses strictly defined six step rule to use combine heuristic

   and simplified testing (Kahn and Prail 1994).

4. *Pluralistic Walkthroughs:* Combines back and forth between users, coders, and human

   factors in form of meetings (Bias 1994).

5. *Feature Inspection:* sequence of features used to accomplish typical tasks, checks for

   long sequences, cumbersome steps, steps that would not be natural for users to try, and

   steps that require extensive knowledge/ experience in order to assess a proposed

   feature set (Bell 1992).

6. *Consistency Inspection:* takes inputs from other designers on how to improve the

   interface (Wixon et. al. 1994).

7. *Standards Inspection* has an expert on interface inspection for compliance (Wixon et. al.

   1994).

For this project, the researcher has adopted formal usability inspection technique and heuristic

evaluation to understand the adaptability of the application in construction teams.

The standard questionnaire developed for the survey to understand the usability from a

construction professional is discussed in the following section: (Mcglin et. al. 2017, Parsazadeh

et. al. 2018, Bowman et. al. 2002, Conte et. al. 2009).

TABLE 2.7. 1: LITERATURE REVIEW ON USABILITY SURVEY

Reference	Use in Literature	Derivation from Literature	Survey Question Framed
Mcglin et al. 2017	The Buildvis tool will be tested on the student teams and their feedback on the formatting will be used to improve the user interface.	Formatting of the software/tool is important based on the literature, so the question focuses on taking feedback on the formatting.	Did you feel the content used in the web-based tool is arranged in the right format?
Bowman et al. 2002	Discusses distinctive characteristics of Virtual environment and transitional interfaces. Also, highlights most issues found by the users were related to the clarity of the Virtual Environment.	Arranging the content in appropriate order is focused on Bowman et al. (2002), the question framed hence takes feedback on clarity of the content.	On a scale of 1-10 how do you rate the clarity of the content? Do you think this information is accurate /representative of your experience with the project?
Conte et al. 2009	Suggests an important part of the usability for a new identification technique is expertise's input on adaptation. Under structural part of the web-applications, discussions on background information required are shared with the industry specialists.	Key part on adaptation is how feasible it is to use the information used. This question discusses whether the data used in readily available in different AEC projects.	Do you think this information is accurate /representative of your experience with the project?
Conte et al. 2009	Discusses 10 set rule for adoption of new platform. Two of which are: "Flexibility and efficiency of use in your project", " Matching between System and Real-world implementation?"	Since all projects are different in scope, this question highlights whether the technique used is generalizable and applicable in AEC projects.	In the projects you have worked on so far, is this technique of identification of information bottlenecks looks applicable? If so, who do you think is suitable to use this identification technique?
Parsazadeh et al. 2018	While introducing new software or applications about a specified topic always useful to ask for pre, and post presentation survey.	This question aims to take feedback on whether the information provided has improved the user's understanding of the topic.	• On a scale of 1-10 what is your understanding of information exchange trends in project teams after the presentation? • On a scale of 1-10, how do you rate the overall experience? • If you had this tool, do you think this would've been useful in identifying the information bottlenecks?

2.8 SUMMARY

Through this section the researcher discussed the prior literature efforts in the field of bottlenecks in AEC projects. Recent research has focused on defining new metrics inspired from the deep learning concepts ion software development to understand the occurrence of bottleneck. Although, there has been a great development in the field of bottleneck identification in AEC projects over the last two decades, there remains a lack of recent literature in this area. With the advancements in the field of Lean Construction and machine learning, new techniques can be developed to identify and modify the current methodologies of bottleneck identification. In the following section, the main methodologies for achieving the goals of the research are discussed.

CHAPTER 3 METRICS REVISITED

With section 2.1.3 the researcher presented the key metrics that were reviewed through literature and also discussed the potential pros and cons of each of them. Through this chapter the researcher discusses the two new metrics which were developed through this research, Productivity and Average Resolution Speed. The researcher then discusses the modifications made to the existing metrics of Development Velocity (DV), Work in Progress (WIP) and defines discusses their potential in the web-based tool.

3.1 MODIFIED BOTTLENECK METRICS

DV and WIP metrics were modified because the information package definition requires complex calculations and estimating the package size of the information uploaded or shared. Sacks and Tribelsky (2010) discussed the information attributes of each type of item used during an AEC project. These attributes are then counted individually for the whole project and that comprises an information package. Since this calculation is difficult to achieve, DV and WIP definitions were modified as discussed below. Frequency of information publication and all project issues discussed during bi-weekly project meetings were used to calculate DV and WIP respectively.

WIP for modified from a team effort, through the works of IOPT4 research team (iopt4.msu.edu). WIP modifications is discussed in greater detail through a team research paper which is currently under review. DV was modified by the researcher and the modified metrics were presented to the group for review and feedback. The modified definitions are discussed

below, and Table 6 highlights the major differences between the metrics used in the literature and the modified version.

• Development Velocity (Modified): Development velocity is calculated as the development in available information for team members between two-time intervals. IP represents information package which is the total information published at a particular date.

$$DV_{a\text{-}b} = (IP_b - IP_a)/(D_{b\text{-}a})$$

$DV_{a\text{-}b}$ – Development of information between a and b

IP_a – Total information bits available at time a

IP_b - Total information bits available at time b

$D_{a\text{-}b}$ – difference of days between time a and time b.

• Modified equation of WIP for the research: WIP is defined as the resolution rate of the issues using project documentation data. (Adapted from the works of IOPT4 team - https://iopt4.msu.edu)

$$WIP = (IS_a - IS_b) \times (IP_{ab})$$

IS_a – Issues resolved using project data at time a

IS_b – Issues resolved using project data at time b

IP_{ab} – Total information bits between time a and b

TABLE 3.1: KEY DIFFERENCES BETWEEN ORIGINAL AND MODIFIED METRICS

	Metrics Used in Literature	Modified Metrics
Development Velocity (DV)	**Definition from Literature:** Development velocity (DV) can be defined as the development of information as represented by the accumulation of details (Tribelsky and Sacks 2010)	**Modified Definition:** Development velocity (DV) is calculated as the development in available information for team members between two-time intervals. The first time interval is when project information is made available to project teams from the web-tool (Garcia et. al. 2020)
	Uses package size which is calculated by accumulating all information attributes.	Uses cumulative information bits. Adds all bits of information published at a particular date to replace package size.
	Uses a software called Autovue to track and calculate Package size.	Manually imports uploads from project documentation websites to calculate information bits and filters emails with attachments and overall size more than 75KB were filtered to track information shared via email (Mulugeta 2010).
	Formula used: $DV_t = (PS_t - PS_{t1}) / (T_t - T_{t1})$ DV_t – DV at time T PS – Package size at time t and t1 T – Time interval at t and t1	**Modified Formula :** $DV_{a-b} = (IP_b - IP_a) / (D_{b-a})$ DV_{a-b} – Development of information between a and b IP_a– Total information bits available at time a IP_b- Total information bits available at time b D_{a-b} – difference of days between time a and time b.

TABLE 3.1 (cont'd)

Work in Progress (WIP)	Definition from Literature:	Modified Definition:
	The number of available but unused information packages.	WIP is defined as the resolution rate of the issues using project documentation data.
	Uses package size which is calculated by accumulating all information attributes.	Uses number of unresolved issues and cumulative information bits between two dates
	Uses a software called Autovue to track and calculate Package size.	Meeting minutes issues are tracked manually through excel document and by preparing a Gantt chart schedule, project documentation data is imported, and emails are filtered.
	Formula used: $WIP = \sum_{j=1}^{nIPj} (t - Tup_j) PS_jU_j$ WIP – Work in Progress PS_jU_j- U_j=1 if package j has been viewed or downloaded by a team member Tup_j – The day at which the package was uploaded.	Modified used: $WIP = (IS_a - IS_b) \times (IP_{ab})$ IS_a – Issues resolved using project data at time a IS_b – Issues resolved using project data at time b IP_{ab} – Total information bits between time a and b

3.2 PRODUCTIVITY AND ISSUE RESOLUTION SPEED

Two new project performance metrics were adopted by the researcher to understand and study the team performance and give insights into studying the bottlenecks during project delivery. Construction Productivity is defined in terms of input and output of volume of work performed against the fixed goal. On similar grounds, Productivity in this context is defined as the efficiency of project teams in resolving issues in hand. Whereas average days to resolve is

the average resolution speed in days of the teams in resolving these issues. The calculation

formula for both these metrics is discussed below.

- Productivity – Productivity is defined as the percentage efficiency of project team

members in resolving ongoing issues discussed in project meetings. The productivity definition is

adapted from Staron and Medding (2011) and is discussed below:

$$Productivity = (nRIS_b - nRIS_a)/ (IS_{a-b}) *100$$

nRIS $_a$ – Number of resolved issues by time a

nRIS $_b$ – Number of resolved issues by time b

IS $_{a-b}$ – total number of issues to be resolved between time a and b.

- Average Days to Resolve Issues (AR) – AR is the average days project team members take

to resolve an issue measured between a time interval.

$$AR = \sum{}^a_b (dIS) / IS$$

dIS – Total number of days required to resolve n Issues between a and b.

IS – total issues between a and b.

3.3 BOTTLENECK METRICS AND ACTIVITY TYPES

This section discusses the four different issue types Pooled, Sequential, Reciprocal, and

Intensive and their implications on bottlenecks prediction. Through section 2.5, the researcher

introduced the definitions of the four issue types, this section studies their implication on

bottleneck identification. The results of the issue types are also verified from a parallel research effort by IOPT4 team (iopt4.msu.edu) and the research paper produced from the team effort is currently under review.

3.4 SUMMARY

Through this section, the researcher addresses the section 1 of the research goal: Developing quantification metrics and modifying information metrics formulas to quantify team performance and project performance. Two new team performance metrics were developed using lean construction definitions and introduced in section 3.2. Through literature review of the metrics as previously discussed in section 2.1.3, DV and WIP metrics were modified by changing the definition of package size. The researcher also presented the differences between the new and modified metrics through table 6. The next section discusses in detail the section 2, section 3, and section 4 of the research.

CHAPTER 4 METHODOLOGY

4.1 INTRODUCTION

The previous chapter establishes the research gaps and need of a new study in identification of

bottlenecks. To answer to the research question, a new web-based tool was developed by

developing new metrics (Productivity, Average Resolution Speed), and metrics developed by

(Tribelsky and Sacks 2010a) were modified to identify project bottlenecks. The web-tool was

then presented to industry experts via an interview and their feedbacks were used to improve

the tool. The final improved tool is presented for the readers.

Through this chapter the researcher discusses the research approach taken to achieve the

objectives of the research. A summary of research objectives is presented, followed by detailed

breakdown of the steps. The research approach includes a combination of background

calculations, development of quantification metrics, coding to develop the web-based tool, and

expert interviews.

4.2 RESEARCH GOALS AND OBJECTIVES

Research Objectives and the methods followed to achieve those objectives are summarized

through the table 4.2:

TABLE 4.2: RESEARCH OBJECTIVES AND METHODS

Research Objectives	Methods
1. Develop new metrics and modify existing KPIs. Productivity, Average Resolution Speed have been developed through this research,	Review of Literature and Lean Construction concepts to develop team performance metrics termed as Productivity, and Average Resolution Speed. Quantifications provided by Tribelsky and Sacks (2007) for DV, and

TABLE 4.2 (CONT'D)

while the definitions of DV and WIP modified from the literature.	WIP modified based on the dataset available and to improve usability.
2. Adopt activity types based on the literature (Bell and Kozlowski 2019) (i.e., Pooled, Sequential, Reciprocal, and Intensive) based on their collaboration requirements, explore their impacts on bottlenecks to further improve bottleneck predictions during project delivery.	Tasks discussed during bi-weekly project meetings for the two-projects studied for this thesis were segregated based on their start date, end date, and parties involved. These activities were then separated into one of the four types Pooled, Sequential, Reciprocal, or Intensive based on the collaboration requirement and complexity of the tasks.
3. Develop a web-based tool to import project documentation data and report on bottlenecks.	A web-based tool is developed using Python coding by creating a dashboard which inputs Microsoft excel sheet with project documentation data such as Information on Meetings, Information Exchange between project teams to identify and report on bottlenecks during the length of the project.
4. Modify the web-based tool based on expert feedback and provide future recommendations.	Expert interviews were organized, and the feedback received was implemented in the python code. The results are discussed and future direction of work to improve the web-based tool even further are discussed.

The section 4.3 introduces the research approach followed to achieve the research goal.

4.3 RESEARCH APPROACH AND SCOPE

This research is focuses on development of a bottleneck reporting tool and tests the adaptability and usability of the tool in AEC teams. The bottleneck calculation is performed between intervals. Intervals are decided based on the progress loops of the project (Garcia et. al. 2020). The data points of the project were analyzed and broken down into monthly time intervals for each of the following phases Schematic Design (SD), Design Development (DD),

Construction Document (CD), and Construction for both projects. The bottlenecks during these datasets are then reported using the web-based tool.

Usability interviews is conducted by the researcher and based on the feedbacks received by the expert interviews, the researcher discusses the possible future implications of the tool and whether this tool can be successfully implemented and used during AEC projects of different scopes. Therefore, the research follows a combination of mixed methods. Literature review was used to identify the key questions which are to be asked during the expert interviews. The data collection for the study was collected by the research team over a period of 2 years and included archival data from two high visibility projects in mid-west USA. Finally, quantitative analysis was used to develop metrics and process the collected data.

4.4 RESEARCH METHODOLOGY

To address the need in the literature, the goal of this research is to study the adaptability and feasibility of the bottleneck reporting tool in AEC Projects. The study was also divided into four sections each of which use different methods.

- **Section 1:** Developing quantification metrics and modifying information metrics formulas to quantify team performance and project performance.

- **Section 2:** Automating the metrics and using the project documentation raw data. Additionally, automating the different types of issues discussed between project teams.

- **Section 3**: Developing a web-based used using python coding and reporting on bottlenecks.

- **Section 4**: Interviewing industry experts to get their feedback on the adaptability and usability of the tool.

Figure 4.4 presents the flow-chart which presents the methodology used by the researcher.
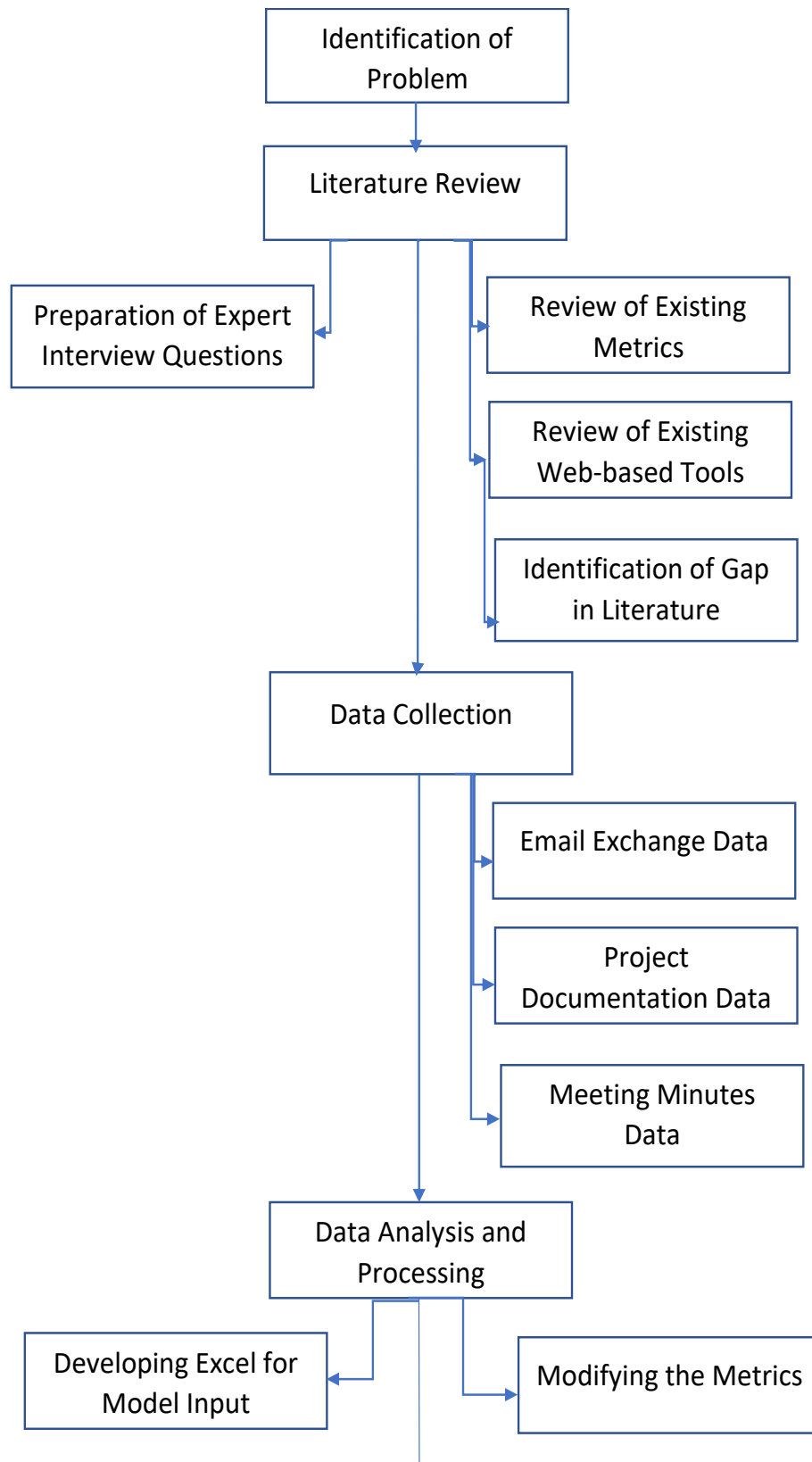
FIGURE 4.4: RESEARCH METHODOLOGY

FIGURE 4.4 (cont'd)

```
                                    ┌──────────────────┐
                                    │ Development of the│
                                    │  web-based tool   │
                                    └──────────────────┘

              ┌──────────────────┐
              │ Expert Interviews │
              └──────────────────┘

  ┌──────────────────┐              ┌──────────────────┐
  │ Modified Web-based│              │  Conclusion, and  │
  │       Tool        │              │ Recommendations   │
  └──────────────────┘              └──────────────────┘
```
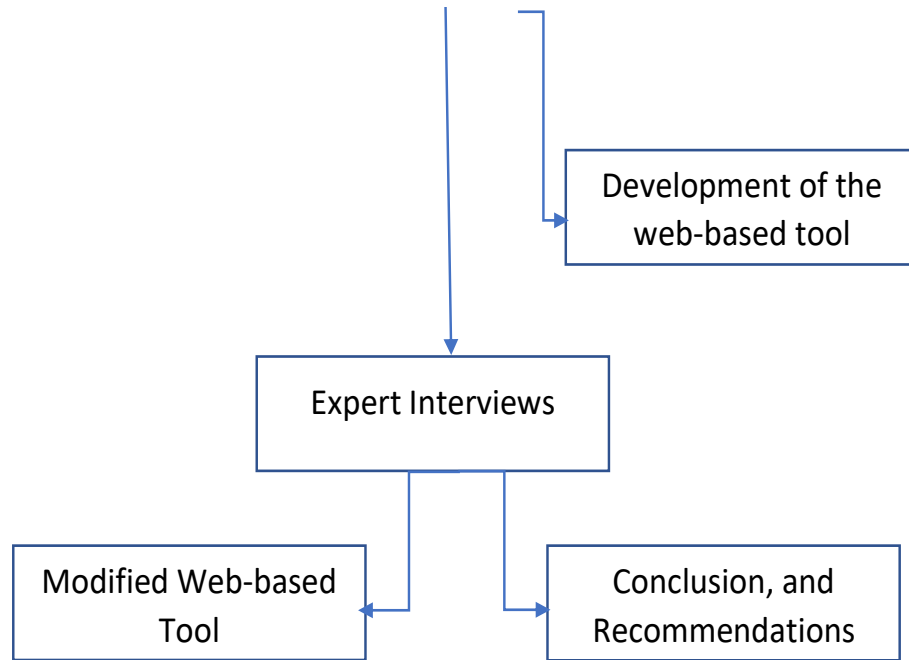
There has been limited research on development of a web-based tool to identify and report on

bottlenecks for AEC Projects. This research draws inspiration from prior research work in

identification of bottlenecks in AEC teams and uses Automation in Python to semi-automate

the raw project documentation data to report on suspected bottlenecks. The validity, usability,

and adaptability of this tool is discussed via expert interviews and their feedback is presented in

the results section, along with possible directions to make this tool even more feasible.

The literature review for the study can be divided into three main sections for different

portions of this study:

1 Identification of metrics and methodologies used by prior researchers to identify

bottlenecks in AEC projects.

2 Identification of the existing web-based platforms and study their advantages and

disadvantages.

3   Literature review to help frame the type of questions to be asked to industry

specialists in the expert interviews.

The data collection was performed by the research team over a period of two years as we

collected the archival data of the two high visibility projects. The type of data used for this

study include email exchange data from email interactions between project teams, project

documentation data which was made available to us through online web-based platforms the

two projects used, bi-weekly project meeting data provided to us in form of PDFs by the project

managers of the two projects.

These data sets were processed and converted into usable formats which are then used for

analysis and coding. The researcher then developed a Python code in Visual Studio which

extracted raw data directly from the MS Excel sheets and created a dashboard to display and

report on the bottlenecks, the tool also provides recommendations on how to avoid these

bottlenecks while detailing the various Project Performance and Team Performance metrics.

Finally, to test the usability of the tool, expert interviews were conducted. The recorded

feedback received through these interviews were used to improve the model and provide

future recommendations for the study.

4.5 DATA COLLECTION AND PROCESSING

The data for this research were collected from two mid-size projects located in Midwest, USA.

One of the projects is an Expansion project while the other is a major renovation project. The

data were largely archival in nature comprising of email exchange, meeting minutes,

ethnographic and project documentation data.

Since this thesis is a part of a larger effort by the I-OPT4 Research Team (https://iopt4.msu.edu/), protocols were developed for extracting and processing each set of raw data. Email data was extracted through a macro which was used in the project managers system. The research team was provided access as guests to the documentation platform of Unifier and PlanGrid. From that relevant data was extracted and formatted in Microsoft excel. Meeting minutes were provided to us after every weekly project meeting by the project managers of the respective projects. The following figure highlights the different sets of raw data and their formatted output. Each of the sections 4.5.1, 4.5.2, and 4.5.3 are divided into two subsections which discusses the data collection and analysis part and web tool python code in detail.

Table 4.5 highlights how each data type is used and processed for the study.

TABLE 4.5: ARCHIVAL DATA TYPE, AND DATA PROCESSING

Archival Data Type	Data Processing	Use in the Tool
Email Exchange Data	Emails cleaned and emails with attachments are cleaned.	Tool filters and graphically represent how many emails each project party (Owner, Designer, or GC) receives.
Project Documentation Data	**PlanGrid**: PlanGrid is online project data management website. Both the projects used PlanGrid and updated it regularly. Each dataset updated on PlanGrid was imported on excel sheets which highlighted the timestamps, the type of data updated, and the responsible party for resolution.	Project Documentation data imported through PlanGrid was cumulated along with Unifier and how much information each team has to process was calculated using the tool. This information is then used to calculate the quantification metrics including DV, WIP.
	Unifier: Unifier is similar to PlanGrid and was used during the course of the project. The researcher followed similar approach for Unifier and Imported project documentation data in Excel sheet.	
Meeting Minutes	Meeting minute PDFs were converted to MS Excel format so that the tool can use the issues	Issues discussed in meeting minutes are very crucial to determining the bottleneck

TABLE 4.5 (cont'd)

discussed in the minutes. The meeting minutes were formatted based on the name of issue, start date, resolution date, and responsible parties.	and for calculation of project performance and team performance metrics.

Section 4.5.1 Discusses each type of archival data in detail.

4.5.1 EMAIL EXCHANGE DATA

4.5.1.1 DATA COLLECTION AND ANALYSIS

The email exchange data was available in three different formats based on the sources.

Designer, Owner, and GC's email exchange information was available in different formats. A

Visual Basic for Applications (VBA) code (Appendix E) was developed to extract the email

information from Microsoft Outlook for the GC emails. The other two types of emails were

shared by the project personnel with the researcher. The raw email data was used to extract

emails with attachments. Email exchange remains a popular form of information exchange

between project teams (Sacks and Tribelsky 2007, Mulugeta 2010).

The email exchange data was cleaned to represent Timestamps of email exchange, receiver

information, sender information, number of attachments. This information was used as an

input for the web-based tool. Figure 5 represents the raw email data before cleaning. Figure 6

represents cleaned email data which is imported by the web-based tool.

	A	B	C	D	E	F	G
1	origin_timestamp	sender_address	recipient_status	message_subject	total_bytes	message_id	Attachments
2	Time 1	ABC1	Reciever 1	Subject 1	Size in Bytes 1	ID 1	Yes
3	Time 2	ABC2	Reciever 2	Subject 2	Size in Bytes 2	ID 2	No
4	Time 3	ABC3	Reciever 3	Subject 3	Size in Bytes 3	ID 3	Yes
5	Time 4	ABC4	Reciever 4	Subject 4	Size in Bytes 4	ID 4	No
6	Time 5	ABC5	Reciever 5	Subject 5	Size in Bytes 5	ID 5	Yes
7	Time 6	ABC6	Reciever 6	Subject 6	Size in Bytes 6	ID 6	No
8	Time 7	ABC7	Reciever 7	Subject 7	Size in Bytes 7	ID 7	Yes
9	Time 8	ABC8	Reciever 8	Subject 8	Size in Bytes 8	ID 8	No
10	Time 9	ABC9	Reciever 9	Subject 9	Size in Bytes 9	ID 9	Yes
11	Time 10	ABC10	Reciever 10	Subject 10	Size in Bytes 10	ID 10	No
12	Time 11	ABC11	Reciever 11	Subject 11	Size in Bytes 11	ID 11	Yes
13	Time 12	ABC12	Reciever 12	Subject 12	Size in Bytes 12	ID 12	No
14	Time 13	ABC13	Reciever 13	Subject 13	Size in Bytes 13	ID 13	Yes
15	Time 14	ABC14	Reciever 14	Subject 14	Size in Bytes 14	ID 14	No
16	Time 15	ABC15	Reciever 15	Subject 15	Size in Bytes 15	ID 15	Yes
17	Time 16	ABC16	Reciever 16	Subject 16	Size in Bytes 16	ID 16	No

FIGURE 4.5.1: SAMPLE RAW UNCLEANED EMAIL FILE

TABLE 4.5.1: SAMPLE CLEANED FILE TO STUDY THE NUMBER OF INFORMATION IN FORM OF ATTACHMENTS SHARED BETWEEN TEAMS.

Sender Role	Project Party	Date and Time	No. of Attachments
Designer	Owner	Date and Time 1	1
Owner	Designer	Date and Time 2	2
GC	GC	Date and Time 3	1
Owner	Owner	Date and Time 4	3
GC	Designer	Date and Time 5	4
Designer	GC	Date and Time 6	2
Owner	Designer	Date and Time 7	3
GC	Owner	Date and Time 8	5
Owner	GC	Date and Time 9	2
GC	GC	Date and Time 10	2

4.5.1.2 WEB-TOOL DEVELOPMENT

As discussed in detail with table 6, section 4.5.1.1, the formatted email dataset file is use as the input in the model's code. These values are all stored in a temporary database which is created through the code. The code then develops a blank dashboard server which then uses plotly library to display the email exchange data as it is received by owner, designer, and GC. The time

stamps are filtered in accordance with the bi-weekly project meeting dates. The following code

figure 4.5.1.2 highlights the code in detail.

```
# ----------------------
df100['upcoming_meeting_date'] = df100['Meeting Date'].shift(periods=-1)
df100['days_between_meeting']=df100['upcoming_meeting_date']-
df100['Meeting Date']
df100['firstcount']=(df100['Emails to D']+df100['Email to O']+df100['Email to
GC']+df100['PlanGrid']+df100['Unifier'])
df100['secondcount']=df100['firstcount'].shift(periods=1)
df100['days_between_meeting']=df100['days_between_meeting'].astype('str')
def func1(x):
    x=x[:2]
    return x
```

FIGURE 4.5.1.2: FUNCTIONS DEVELOPED TO IMPORT THE EMAIL EXCHANGE DATA IN THE CODE.

The code develops function which import and filters the emails based on whether they are

received by GC, Owner, or Designer. The code then links the dates of the emails with the bi-

weekly meetings and stores in a temporary database. The results of the code and graphical

representations are discussed in section 6.6.2.

4.5.2 PROJECT DOCUMENTATION DATA

4.5.2.1 DATA COLLECTION AND ANALYSIS

Project Documentation data is often the result of planning process of construction and is

pivotal for project management (Kozlovska et. al. 2016). The project documentation software

used for the two mid-sized projects were PlanGrid and Unifier. The researcher was granted

access to these software and imported the data sets into Microsoft excel to study the

information flow. The raw imported files were then cleaned to highlight the timestamps of

information publication, number of pieces of information shared, responsible party for

information exchange. The cleaned excel is then used as in input for the web-based tool.

Project documentation data is used to study the information exchange patterns, calculate DV,

and WIP.

The project documentation websites used for this research had multiple information uploading

options, from the pre-construction phase to the construction execution phase. The websites are

designed to cater the needs of the different phases of the projects and have file uploading

options including bidding documents, contract documents, budget allocation documents,

change orders, RFIs etc. The table 4.5.2 highlights the different types of documents and

information used for calculation of information bits which helps in calculation of WIP and DV.

TABLE 4.5.2: TYPE OF INFORMATION SHARED IN UNIFIER AND PLANGRID.

Type of Document in Project Documentation websites	Use in Project
Project Approvals	Documents related to official approvals or site permits.
Contract Documents	Has documents related to agreed contracts between different subs
Project Specific POs	Special project requirements PDFs
Design Services POs	Special design requirements and Architects reviewed Docs
Bidding Documents	Official bidding record of the project
Budget Adjustments	All adjusted budgets throughout the length of the project are stored here
Budget Allocation	Potential budget allocations for future work
Construction Issues	Active issues on site
Construction Waste Management	Documents related to how waste will be managed on site
Contracting	Contract related issues or legal issues

TABLE 4.5.2 (cont'd)

Misc Costs	Additional costs during execution which could be billed
Insurance	All the insurance required for the project
Owner Services	Documents related to the services and terms provided by the owner
Plan Reviews	Change in drawings or plans
Potential Costs	Potential costs helps in requesting bills
RFIs	Request for information
Submittals	All submittals
Transmittals	All transmittals
Schedule of Values	All schedule of values
Construction Change Directory	All Change orders
Unpublished Documents	Unpublished documents, miscellaneous documents or archival documents which can be reviewed in case of need
Drafts	Documents which are currently been updated or require revision.

Whereas FIGURE highlights the cleaned documentation format in Microsoft excel which is used for the web-based tool.

	Meeting Date	PlanGrid	Unifier
2	1/23/2019	0	19
3	2/11/2019	5	32
4	2/20/2019	0	24
5	2/27/2019	2	10
6	3/6/2019	22	0
7	3/13/2019	10	0
8	3/20/2019	34	36
9	3/27/2019	0	44
10	4/3/2019	0	17
11	4/10/2019	9	48
12	4/17/2019	0	1
13	**4/24/2019**	0	67
14	5/8/2019	0	9
15	5/15/2019	108	38
16	5/22/2019	0	22
17	5/29/2019	0	29
18	6/5/2019	82	37
19	6/12/2019	0	28
20	6/19/2019	0	2
21	6/26/2019	110	5

FIGURE 4.5.2: CLEANED PROJECT DOCUMENTATION DATA

Figure 4.5.2 highlights the cleaned data points which are recorded at the dates of the actual bi-weekly meetings which occurred throughout the length of the project. The types of information tracked on bi-weekly project meetings are explained in detail with figure 8. For example, between January 1st, 2019 to the next meeting date at February 11th, 2019: 0 information was uploaded in software 1 (PlanGrid), and 19 information bits were uploaded in software 2(Unifier). This way, all pieces of information uploaded by the admin are tracked and recorded consistently.

4.5.2.2 WEB TOOL DEVELOPMENT

As discussed in detail with figure 4.5, section 4.5.2.1, the formatted project documentation file

is used as the input in the model's code. These values are all stored in a temporary database

which is created through the code. The code then develops a blank dashboard server which

then uses plotly library to display the project documentation data of the website 1 (PlanGrid)

and website 2 (Unifier) separated based on the bi-weekly project meeting dates. This

separation helped the researcher correlate how much information is being shared within

project teams between two consecutive meeting dates. Figure 4.5.2.2 highlights the code

developed for extracting the data from excel sheet and storing it in database, the results are

then discussed in detail in section 6.6.2.

```python
df100 = df1
# ----------------------
df100['upcoming_meeting_date'] = df100['Meeting Date'].shift(periods=-1)
df100['days_between_meeting']=df100['upcoming_meeting_date']-
df100['Meeting Date']
df100['firstcount']=(df100['Emails to D']+df100['Email to O']+df100['Email to GC'
]+df100['PlanGrid']+df100['Unifier'])
df100['secondcount']=df100['firstcount'].shift(periods=1)
df100['days_between_meeting']=df100['days_between_meeting'].astype('str')
def func1(x):
    x=x[:2]
    return x
```

FIGURE 4.5.2.2: DETAILS OF THE CODE USED FOR INFORMATION EXTRACTION FROM
DOCUMENTATION WEBSITE

4.5.3 MEETING MINUTES DATA

4.5.3.1 DATA COLLECTION AND ANALYSIS

Meeting minutes represent the main discussion points of the bi-weekly project meetings in AEC

projects. The meeting minutes for the two projects used in this research was provided in the

form of PDF documents. Each of the points discussed in the meetings represent an ongoing

issue with the project. Each of these issues were tracked over successive meetings to

understand how long a particular issue lasts, who is responsible for the resolution of the issue,

what were the main discussion related to the issue. Based on this, the meeting minute available

for the two projects were converted to an excel document as represented in figure 4.5.3. Item

code is unique code given to each of the issues in the meeting minutes. Description discusses

the brief explanation of the ongoing issue. Start and end dates are used to understand how

long a particular issue is discussed in the meetings. Days to complete is the difference between

the start date of the issue to the end date of the issue. Finally, Responsible party represents

which one of Owner, Designer, or GC was responsible for resolving the issue.

	A	B	C	D	E	F
1	Item Code	Description	Start Date	End Date	Days to Comple	Responsible Par
2	Code 1	Brief Description 1	Date 1	Date 16	Date 16 - Date 1	GC
3	Code 2	Brief Description 2	Date 2	Date 17	Date 16 - Date 2	GC
4	Code 3	Brief Description 3	Date 3	Date 18	Date 16 - Date 3	O
5	Code 4	Brief Description 4	Date 4	Date 19	Date 16 - Date 4	GC
6	Code 5	Brief Description 5	Date 5	Date 20	Date 16 - Date 5	GC
7	Code 6	Brief Description 6	Date 6	Date 21	Date 16 - Date 6	GC
8	Code 7	Brief Description 7	Date 7	Date 22	Date 16 - Date 7	D
9	Code 8	Brief Description 8	Date 8	Date 23	Date 16 - Date 8	D
10	Code 9	Brief Description 9	Date 9	Date 24	Date 16 - Date 9	D
11	Code 10	Brief Description 10	Date 10	Date 25	Date 16 - Date 10	GC
12	Code 11	Brief Description 11	Date 11	Date 26	Date 16 - Date 11	GC
13	Code 12	Brief Description 12	Date 12	Date 27	Date 16 - Date 12	GC
14	Code 13	Brief Description 13	Date 13	Date 28	Date 16 - Date 13	**GC**
15	Code 14	Brief Description 14	Date 14	Date 29	Date 16 - Date 14	GC
16	Code 15	Brief Description 15	Date 15	Date 30	Date 16 - Date 15	O

FIGURE 4.5.3: FORMATTED MEETING MINUTES DOCUMENT

The figure 4.6 was imported in the web-based tool and was semi-automated to calculate the productivity, average resolution speed, and work in progress.

4.5.4 PROGRESS LOOPS AND INTERVALS

One of the main contributions of this thesis to the literature is the development of progress loops or intervals between different phases of design, planning, and construction. The researcher used archive datasets to figure out how the project progressed (Garcia et al. 2014; Marks et al. 2001). During the design phase, SD, DD, and CD episodes were further divided into monthly time periods based on project progress (i.e., analyses showed cost growth and scope revisions as the key metrics to determine progress loops during the design phase). The whole design phase was divided into seven intervals, each lasting around one month (i.e., SD consisted of 3 intervals, DD consisted of 2 intervals, CD consisted of 5 intervals, and construction consisted of 11 intervals). The CD and the commencement of the building phase were separated by three days. Productivity calculations, which were employed as a measure of sustainability results, were also helped by archival datasets. The breakdown of phases into smaller intervals allowed the researcher to understand information trends and growth at a micro level which helped in accurate identification of bottlenecks. The web-based tool was also programmed to provide outputs based on these intervals.

Project teams working on new product development projects go through episodes (Marks et al., 2001), which are temporal cycles made up of a collection of coordinated actions that contribute, directly or indirectly, to the entire project's progress toward its end goals (Weingart, 1997; Zaheer et al., 1999). Episodes can be characterized as definable periods of time during

which progress accumulates and is evaluated at the end when feedback is provided (Mathieu &

Button, 1992). After analyzing project outcomes, project team members can determine where

the project stands and begin a new cycle, resulting in a series of episodes that are correctly

connected (Marks et al., 2001). For example, an AEC project team that progresses in mechanical

design over an episode may receive feedback on outcomes estimates at the conclusion of the

episode suggesting that the project is overbudget and will be completed beyond the deadline.

The project team members would then have an accurate picture of the project's present

situation and would take appropriate action in the following episode. Marks et al. (2001)

distinguished between two sorts of episodes: action phases, in which project team members do

activities aimed at directly enhancing project progress, and transition phases, in which prior

performance is evaluated and planned choices are made. Projects move through a series of

transition-action stages, with the output of each serving as the input for the next (Marks et al.,

2001). While team members work on AEC projects, progress loops are created between the

time a choice is taken and the time feedback on project results is received, allowing the quality

of previous decisions and progress to be assessed. Progress loops are a cycle of transition-

action-transition phases in which, first, planning decisions are made; second, project team

members perform tasks in accordance with the decisions made in the first stage, resulting in

increased project progress; and third, feedback, or, in other words, project outcomes estimates

updates are obtained, allowing the evaluation of both project progress and the adequacy of

decisions made in the first stage. Following that, AEC project teams enter a new progress loop.

The term "progress" in this article refers to the proportion of a project that has been

completed. Progress loops do not relate to quantitative progress (it is anticipated that progress

will rise, but the amount is unknown), but rather to qualitative progress, or the positive or negative influence of progress on project results. Positive progress loops increase project results compared to the previous estimate, whereas negative progress loops harm them. Neutral progress loops are produced when project outputs remain constant. Progress loops may certainly enhance certain results while wreaking havoc on others. In this instance, priorities between outcomes can be set or a system that assigns weights to each result can be constructed to determine if a progress loop is positive or negative; however, this study does not go any further on this topic. Furthermore, the length between the point when planning choices are taken and the point where feedback is acquired might vary, therefore progress loops can have variable temporal lengths.

The progress loops were identified based on the following protocol developed by the researcher:

1. The meeting minutes, and three week lookahead schedule published by the project teams were studied and analyzed to identify any major milestones coming up which had potential impact of cost or schedule. Such activities or issues marked a potentially important day, which was selected as the end period of the interval. Through analysis of the meeting minutes and three-week schedule, it is identified that each interval within a phase has a duration of around 30-35 days.

2. Once the intervals and the key activities were fixated it was submitted for a review to another researcher in the team with expertise in experience in detecting progress loops) for review. After the review and acceptance of the steps followed for the first phase (SD)

intervals, the researcher followed the same steps to finish development of intervals in each phase.

4.5.5 WEB-BASED TOOL

Meeting minutes data is an important source of information to track all the active issues ongoing during all phases of the project. The meeting minutes file is developed by the researcher over the period of the duration of the two projects used for the study. The meeting minutes extraction is currently being study to be fully automated to save time and produce faster results. The fully automated code will directly extract data from the meeting minutes PDF files using Artificial Intelligence and will not require conversion to excel sheets However, it is beyond the scope of this thesis. Through the code as displayed by the following figure, the data is extracted and is stored in a temporary database which will then be used to study the different trends and calculate WIP, Productivity, and Average Resolution Speed of the teams in resolving these issues.

```
df100['num_of_days']=df100.apply(lambda x: func1(x['days_between_meeting']), axis
=1)
df100['num_of_days']=df100['num_of_days'].replace('Na',0)
df100['secondcount']=df100['secondcount'].fillna(0)
df100['secondcount']=df100['secondcount'].astype('int')
df100['num_of_days']=df100['num_of_days'].astype('int')
df100['dv']=(df100['firstcount']-df100['secondcount'])/df100['num_of_days']
df100['dv']=df100['dv'].replace(df100['dv'][0],0)
df100['sum_of_issues']=(df100['Issues to O']+df100['Issues to GC']+df100['Issues
to D'])
df100['sum_of_issues']=df100['sum_of_issues'].fillna(0)
df100['sum_of_issues']=df100['sum_of_issues'].astype('int')
df100['sum_of_issues_second_meet']=df100['sum_of_issues'].shift(periods=1)
df100['WIP']=(df100['sum_of_issues']-df100['sum_of_issues_second_meet'])
df100['WIP']=df100['WIP'].fillna(0)
df100['Month']=df100['Meeting Date'].dt.month
```

FIGURE 4.5.4: CODE TO EXTRACT MEETING MINUTES ISSUES FROM THE EXCEL DOCUMENT.

FIGURE 4.5.4(cont'd)

```python
df100['Month'] = df100['Month'].replace({1:'January',2:'February',3:'March',4:'Ap
ril',5:'May',6:'June',7:'July',8:'August',9:'September',10:'October',11:'November
',12:'December'})
df1001=df100[['Meeting Date','upcoming_meeting_date','dv','WIP','Month','Phases',
'Comments']]
df1002 =pd.melt(df1001, id_vars=['Meeting Date', 'upcoming_meeting_date','Month']
, var_name=[('dv', 'WIP')], value_name='Value')
df1002.columns=['Meeting Date', 'upcoming_meeting_date', 'Month', 'category','Val
ue']
```

Through this section the researcher discusses the details of the python code developed to

implement the web-based tool. The section is divided into six sub-sections each of which

discuss the different tabs in the web-based tools.

The web-based tool was coded in Visual Studio by importing the python data libraries which are

used to display results in the dashboard created through the code. The libraries imported and

their primary functions are explained below in table 4.5.4:

TABLE 4.5.4: PYTHON LIBRARIES AND THEIR FUNCTIONS

Imported Libraries	Functions
Dash	Used to create dashboards and interfaces for web-tools and applications.
NumPy	Used to work with numbers as arrays. Statistical functions are implemented in the tool using NumPy.
Plotly	Plotly is used to develop interactive and high-quality graphical outputs. For the web-based tool, Plotly is used to graphically represent Team performance and project performance metrics.
Pandas	Pandas is used in this study for analysis, and for bottleneck quantification.
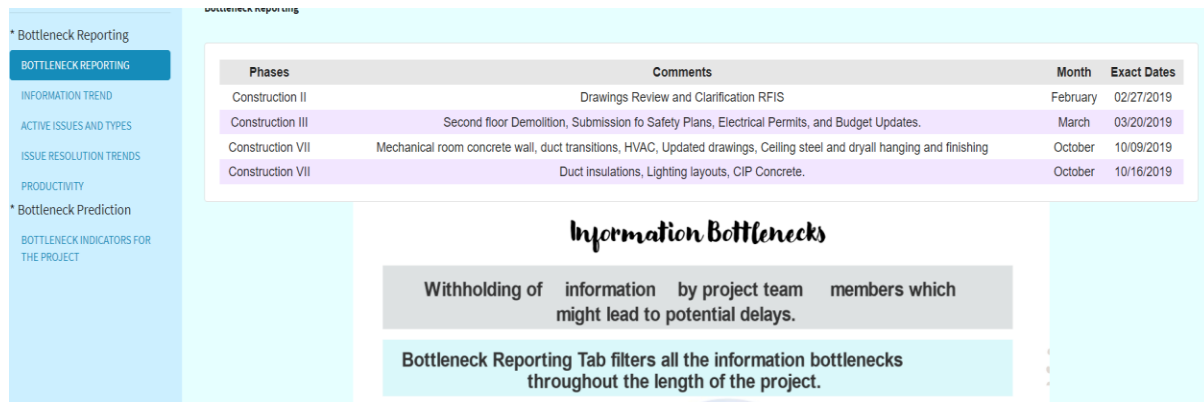
The following sections discuss the tool through individual navigation tabs.

4.6 USABILITY INTERVIEW

4.6.1 BOTTLENECK REPORTING TAB

The web-tool is divided into 2 separate sections, Bottleneck Reporting tab, which reports on

bottlenecks identified during the length of the project by using the calculation and

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quantification defined by the researcher. The bottlenecks are reported using DV and WIP

metrics modified from the definitions provided by Tribelsky and Sacks (2007). DV and WIP

formula as discussed in detail in section 4.1 is coded in python. Using project information

exchange which was in form of meeting minutes, email exchange of information and

information provided through online project documentation software, the code calculates DV

and WIP. It then compares the values of these calculations using the metrics adopted from

Sacks (2010), finally the dates on which the chance of occurrence is high are reported. Figure

4.6.1 is a snapshot of the reporting page of the web-based tool, whereas figure 4.6.1.2 is code

used to quantify DV and WIP.

FIGURE 4.6.1: SNAPSHOT OF THE BOTTLENECK REPORTING PAGE

```python
def funx(x):
    x = float(x)
    if x in(twofive):
        return '0 - 0.25'
    if x in(five):
        return '0.25 - 0.50'
    if x in(sevenfive):
        return '0.50 - 0.75'
    if x in(one):
        return '0.75 - 1'
def funy(y):
    y=float(y)
```

FIGURE 4.6.1.2: SNAPSHOT OF THE DV AND WIP CONDITIONS TO REPORT ON POSSIBLE BOTTLENECKS.

FIGURE 4.6.1.2(cont'd)

```python
    if y in(twofive):
        return '0 - 0.25'
    if y in(five):
        return '0.25 - 0.50'
    if y in(sevenfive):
        return '0.50 - 0.75'
    if y in(one):
        return '0.75 - 1'
df150['dv_range'] = df150.dv.apply(funx)
df150['wip_range'] = df150.WIP.apply(funy)
def fun2(x,y):
    if (x == '0.25 - 0.50')&(y == '0.75 - 1'):
        return 1
    if (x == '0.00 - 0.25')&(y == '0.75 - 1'):
        return 1
    if (x == '0.50 - 0.75')&(y == '0.75 - 1'):
        return 1
```

4.6.2 INFORMATION FLOW OF THE PROJECT

The information exchange of the project is tracked through five different metrics which are used to study the team performance and project performance of the project. The information metrics measured through the next section of the tool are:

- **Email Information:** Tracks the number of emails received by owner, designer, and general contractor on monthly basis. Figure 4.6.2 highlights email information section in the tool. The email information section is coded in python by cleaning the email exchange data set discussed in section 4.5.1 and adding number of emails received by each party per month.

- **Web-Based Project Documentation Data:** tracks the number of updates or information bits uploaded in PlanGrid and Unifier on a monthly basis as discussed in section 4.6.2. The code for this section is developed by adding information shared by each platform per month. Figure 4.6.2 highlights the project documentation data in the tool.

- **Issue Report:** Issue Report is the characterization of issues discussed in the bi-weekly meetings into four different types Pooled, Sequential, Reciprocal, and Intensive. The purpose of these characterization is because each of these types has different implications on the complexity and collaboration requirements of the issues as discussed in section 2.4. The coding for this performed based on the protocol developed by the researcher, and by studying the number of parties involved in resolving a particular issue discussed in bi-weekly meetings. Figure 4.10 shows the snapshot of the tool with Issue Report.

- **Average Days to Complete:** Average Days To Complete is divided into two types, Average days to resolve per expertise role and average days to resolve for each type of issues as discussed in detail in section 4.1. Figure 4.6.2.2 shows a snapshot of the average days to resolve page in the tool.

- **Productivity:** Productivity as defined under section 4.1 is calculated based on each expertise role throughout the length of the project as shown in snapshot 4.6.2.3.
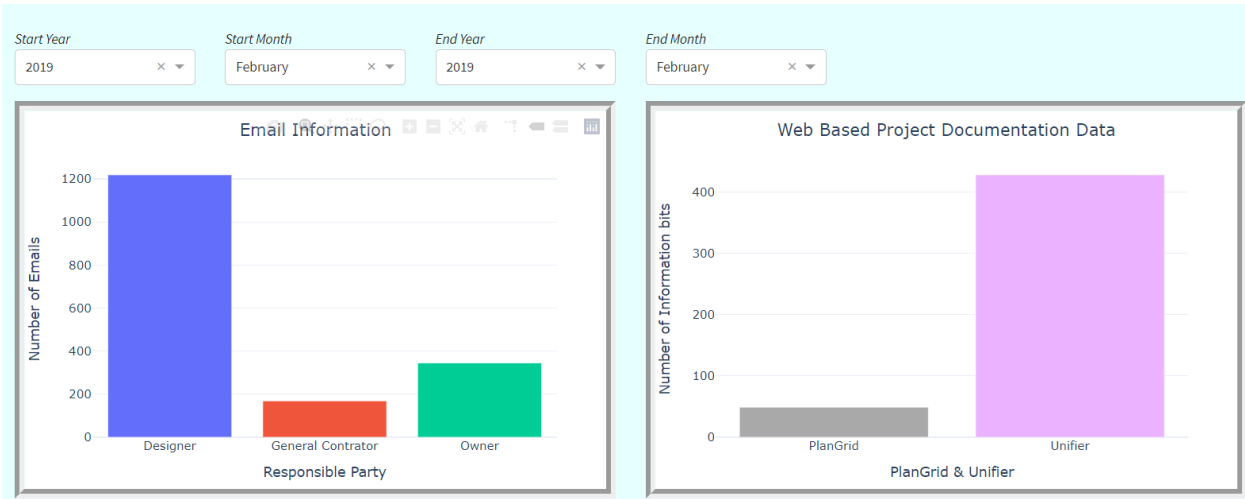
FIGURE 4.6.2: SNAPSHOT OF INFORMATION EXCHANGE PAGE IN THE WEB TOOL

FIGURE4.6.2.2: SNAPSHOT OF AVERAGE DAYS TO RESOLVE PAGE IN THE TOOL

Productivity: Team Performance Metric, illustrating the how productive project teams are in resolving issues. Calculated by total issues resolved over total issues on hand

FIGURE 4.6.2.3: SNAPSHOT OF THE PRODUCTIVITY PAGE IN THE TOOL

4.6.3 BOTTLENECK PREDICTION AND POTENTIAL REMEDIES

Bottleneck Prediction/Potential Remedies provides insights to the users on why the bottleneck has occurred and ways to tackle such type of issues for future projects. The snapshot 4.6.3 highlights how this section is presented in the tool. It used the type of bottlenecks reported by the Bottleneck reporting tool to provide recommendations for tackling these issues. The predictions are provided based on the findings of the IOPT Research Team (iopt4.msu.edu).
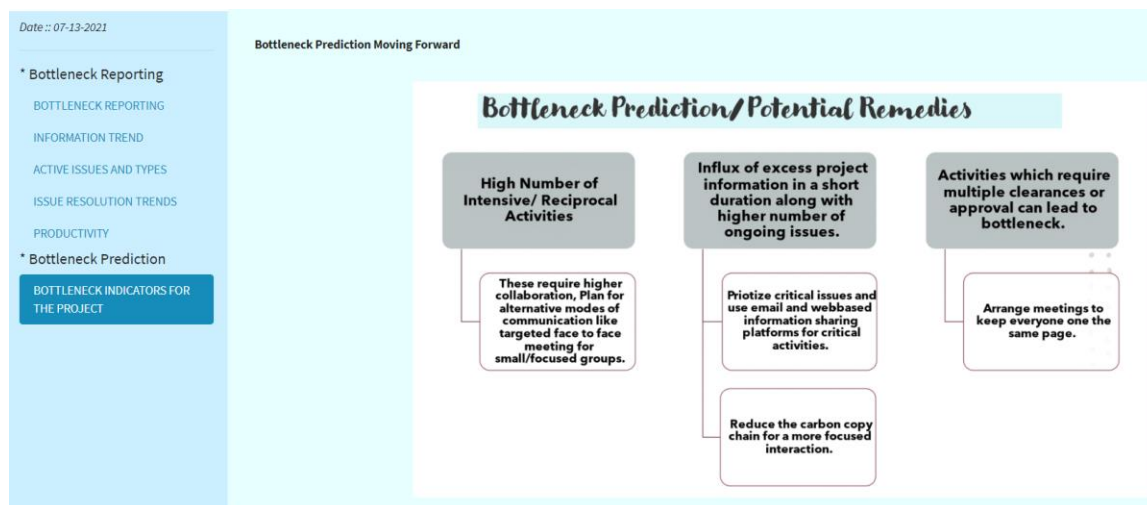
FIGURE 4.6.3: SNAPSHOT OF THE BOTTLENECK PREDICTION/ POTENTIAL REMEDIES

A qualitative assessment of the interview findings is performed since, the sample size of

interview is small and think-aloud protocol was adapted to record the interview feedbacks. The

participants were the Project Managers in charge of the two high profile projects and their

feedbacks were recorded and addressed to improve the baseline model. The interviewees were

given command of the screen and allowed to navigate through the tool, they provided

feedbacks consistently which will be discussed in detail in section 4.3.2. The participants were

selected so they are representative of the target audience of the tool which is management

team of the AEC Projects. Figure 4.7 as adapted from Budiu (2017) was used to ensure

consistency during the development and re-development of the web tool.
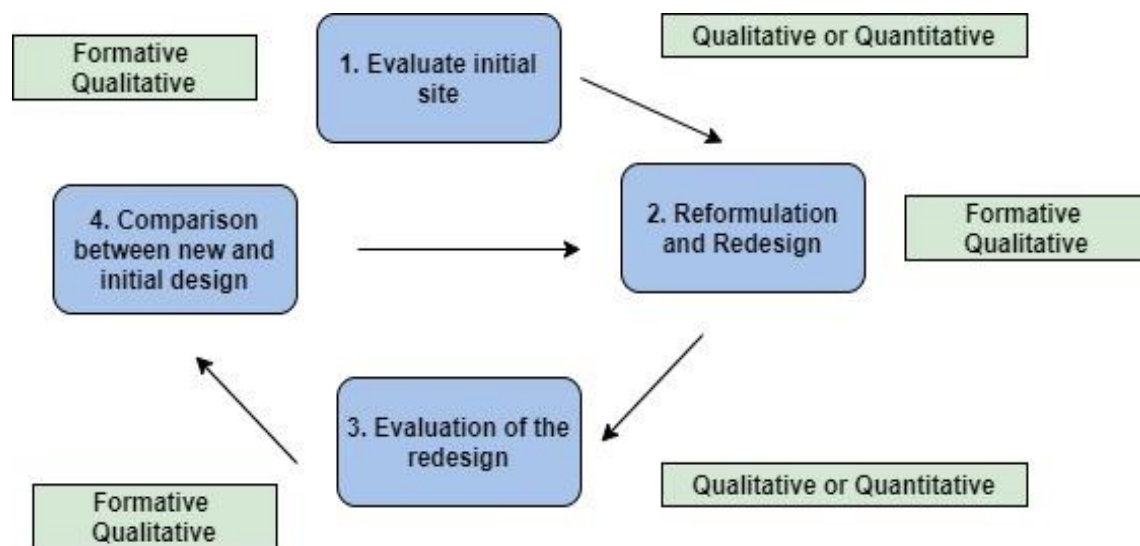
FIGURE 4.7: DESIGN AND THE RE-DESIGN FEATURES OF THE WEB-TOOL.

Through the figure 4.7, the researcher presents the steps in which the qualitative assessments

of the tool will be made. The table 4.6, highlights the different sections in thesis where the 4

steps of qualitative assessments are discussed.

TABLE 4.6 : QUALITATIVE ASSESSMENTS AND SECTION DESCRIPTIONS

Qualitative Assessment Step	Section and Description
1. Evaluate initial site	Section 4.5 addresses the initial requirements for the webtool, and chapter 3 develops the key metrics which are required for implementing the same.
2. Reformulation and Redesign	Section 3.1 discusses the reformulation of the metrics. Section 6.2 discusses the comments received from the interviewees which will help the researcher in redesign.
3. Evaluation of the redesign	The redesign is discussed and presented multiple times with the IOPT4 Research Team
4. Comparison between new and initial design	Section 6.3 discusses the initial and final tool.

4.7 RESEARCH QUALITY

Internal and External validity, inter-coder reliability tests were performed to maintain the quality of the research (Sargent 2013). Internal validity was maintained by using several iterations and conditions in the web-tool while running to ensure consistency. The tool was reviewed by the IOPT4 Research Team (iopt4.msu.edu) several times to ensure external validity. The raw datasets used for the inputs of the tool were coded and extracted using a protocol developed by the team to ensure coding reliability. The interview protocol attached in Appendix A and G went through a detailed Institutional Review Board (IRB) approval to maintain quality and ensure compliance to standards.

4.7.1 ITERATIVE RELIABILITY FOR DETERMINING THE TYPES OF ISSUES

The meeting minutes document for both Project 1 and Project 2 used for this study were distributed to two researchers. Researcher 1 and researcher 2 separated issue types of the meeting minutes based on the protocol developed. The two researchers performed issue

segregation for the first ten meeting minutes for project 1 and project 2 (Sun 2013). After that, results were compared and found out to be similar. The results were then submitted for a review to the researcher 3 with extensive experience with the topic to conduct a final review. After the review and acceptance of the steps followed for the first ten meeting minutes, Researcher 1 followed similar approach to separate all the issues discussed in meeting minutes for both the projects.

The following section presents the protocol used and the steps followed for the development of the protocol for identification of issue types from the meeting minutes issues.

4.7.2 DEVELOPMENT OF PROTOCOL FOR ISSUE TYPES

The protocol for the issue types based on workflows was developed based on the works of Bell and Kozlowski (2002), which defined four different types of activity types – pooled, reciprocal, sequential, and intensive. The four types of workflow interdependencies were separated based on how different nodes or teams collaborate and contribute to finish a task and based on the complexity of a particular task. Appendix H discusses the detailed example of how issue types were identified for each activity type.

Type of Dependency (From Meeting Minutes)

- Pooled- Pooled activities are least interdependent arrangement-work. Activities are performed separately by all team members and then combined into a finished product-within a single organization. (If one organization is involved, it is pooled)

- Sequential-work and activities flow unidirectionally from one member to another-one organization to another. (If two organization is involved, going in one direction, it is sequential)

- Reciprocal-is characterized by work and activities that flow back and forth between team members, one by one, overtime-between different organizations. (If two organization is involved, going in bidirectional, it is sequential)

- Intensive-diagnose, problem solve, and/or collaborate simultaneously as a team to accomplish their task. (If more than two organization is involved, going in bidirectional, it is intensive).

The two researchers followed the above protocol for both the projects, results were then compared and presented to the Researcher 3. After evaluation of both the results, the researcher 1 completed the coding for the rest of the meeting minutes in project 1 and project 2.

4.8 SUMMARY

Through this section the author presented the goals, scope, approach, and methodology of the research. The four major sections in which this thesis is divided is also presented, these sections are development and modifications of metrics from literature, automation of these metrics, development of web-based tool to report on bottlenecks, interviews, and discussion of feedbacks. The researcher through this section, has also presented the detailed flow chart of each step followed in this research. Lastly, the author presented the details of the inputs and outputs of the tool and details about the python coding performed.

CHAPTER 5 RESULTS

This section discusses the usability of the web-tool and discusses the interview findings while also discussing the major changes made in the tool based on the interviewee feedbacks. A Qualitative Analysis is performed of the usability test given the sample size of interview is small and their feedback is used to continuously improve the tool and a comparative study between the initial and final stages of the tool is presented in section 6.3.2.

5.1 INTERVIEW FINDINGS

The get feedback on the usability and adaptability of the tool in AEC teams, the researchers conducted two interviews with industry specialists.

Interview Findings and Feedback:

Through this section the researcher discusses the details of the two interviews which were arranged to discuss and get feedback from AEC project experts about the tool the researcher developed. The questions were designed to address three main questions:

1. The usability of the tool in AEC projects.

2. The adaptability of the tool within AEC teams.

3. The future directions to make the tool even more feasible and easier for use in AEC projects.

Interview 1: Expansion Project in Midwest USA

The interviewee suggested the tool offers great value when studying the project after a particular phase or towards the end in lessons learnt. The tool can help the Project Managers

understand what can be improved in team communications and information shared so that in next project these issues can be tackled. The interviewee appreciated the formatting, and content of the tool. One comment was to use homogenous color in the columns of bottleneck reporting table to maintain consistency. The interviewee also recognized the content of the tool was accurate and easy to understand.

For future studies, the interviewee suggested to make the prediction real time could be of great use the Project Manager in AEC teams. This real-time simulation of ongoing bottlenecks can help the project manager to study the information trends, be pro-active and intervene, therefore helping with the resolution of the information bottlenecks before it happens. The real-time simulation can be achieved by merging the tool with project documentation software, so that all information bits are tied together in one application and tracking becomes less tedious.

The contents of the web-based tool require data set which are usually available to project teams in all types of projects. Although, the formatting of the dataset could vary depending on the type of the project. The researcher received positive feedback regarding the general adaptability of the tool based on the type of dataset used. The interviewee was familiar with the information trend related information so, the navigation became easier and was received well.

Interview 2: Renovation Project in Midwest USA

The second interviewee appreciated the value of the tool in studying the project after completion. According to the subject, some issues which were reported could be managed better in subsequent projects using this tool. The subject also suggested the tool can be used

on a monthly/annual basis by the project managers to study any issues which might have skipped their attention. The subject highlighted this tool could be very useful for the AEC teams when studying their project for in-depth analysis.

The interviewee suggested one way to improve the usability of the project is to use industry specific terms instead of research words. The activity type definitions (Pooled, Sequential, Reciprocal, and Intensive) could be simplified to help the project managers better understand the issues on hand. The subject gave positive feedback on the formatting, clarity, ease of navigation and content of the tool.

The interviewee expressed concern on whether such detail of information could be available for all the projects. Since all construction projects are different in terms of size, scope, and budget. Projects with lower budget might have detailed documentation available. Therefore, the subject suggested this tool could be useful when multiple parties are involved, and project documentation is agreed prior to implementation. Therefore, the ease of adaptability of the tool for smaller budgeted projects could be different to that of high-end projects.

The subject gave positive feedback on information trend metrics such as productivity, average days to resolve, and bottleneck prediction. The interviewee also believed the tool would have helped them study and manage the project better if it was available during the life cycle of the project. The major feedback on improving the tool was through using simpler terms so that it is more comprehensive for AEC team members.

5.2. INTERVIEW FEEDBACK AND MODIFICATIONS IN THE TOOL

The following table 6.3 discusses in detail each of the feedback provided by the interviewee which

participated in the project and then compares the initial and final screenshot of the tool .

TABLE 6.3: COMPARISON BETWEEN INITIAL AND FINAL SCREENSHOT OF THE WEB-BASED TOOL

Interview 1
Feedback 1: Increase the font size of the Definitions added to the homepage of the web-based tool.
Initial Tool Screenshot:

This Tool reports Information Bottlenecks in ACE Projects using Archival Project Data. The Tool Uses project documentation data,email dates,project meeting dates to report on information bottleneck. |
| **Tool after incorporating the Feedback** |

TABLE 6.3 (cont'd)

This Tool reports Information Bottlenecks in ACE Projects using Archival Project Data. The Tool Uses project documentation data,email dates,project meeting dates to report on information bottleneck.

Feedback 2: It is recommended to use homogenous colors through the diagrams in the

model to help the user track the model easily.

Initial Tool Screenshot:

Phases	Comments	Month	Exa
Schematic Design II	Drawings Review and Clarification RFIS	February	02/
Schematic Design III	Announcement of Completion Schedule and Timelines	March	03/
Schematic Design III	Second floor Demolition, Submission fo Safety Plans, Electrical Permits, and Budget Updates.	March	03/
Construction IV	Mechanical room concrete wall, duct transitions, HVAC, Updated drawings, Ceiling steel and dryall hanging and finishing	October	10/
Construction IV	Duct insulations, Lighting layouts, CIP Concrete.	October	10/

Activities based on Team Interdependencies

Pooled | Sequential | Reciprocal | Intensive

Complexity Increases

Tool after incorporating the Feedback

TABLE 6.3 (cont'd)

Feedback 3: The interviewer suggested that to make the model more useful, the tool can be made real-time so that, it can track information from the project documentation websites in real time and bottleneck predictions can be made for upcoming bottlenecks.

Feedback 3 is incorporated in the future directions of work as it is currently beyond the scope of this research.

Interview 2
Feedback 1: It is recommended to improve the definitions or the daigram to make it easier for the AEC construction individuals to understand certain terms which are more research centric.

Initial Tool Screenshot:

TABLE 6.3 (cont'd)

Tool after incorporating the Feedback

Feedback 2: The interviewee expressed concern on whether such detail of information could be available for all the projects. Since, all construction projects are different in terms of size, scope, and budget. Projects with lower budget might have detailed documentation available. Therefore, the subject suggested this tool could be useful when multiple parties are involved, and project

TABLE 6.3 (cont'd)

documentation is agreed prior to implementation. Therefore, the ease of adaptability of the tool for smaller budgeted projects could be different to that of high-end projects.

Feedback 2 will be addressed in the future directions of work.

CHAPTER 6 CONCLUSIONS AND DISCUSSIONS

6.1 INTRODUCTION

This chapter discusses the major findings through this research. Additionally, this chapter concludes the research by discussing its limitations, and provides scope for future research.

6.2 KEY FINDINGS

The research develops a web-tool which reports bottlenecks in AEC projects using archival data. The tool also illustrates team performance and project performance metrics while providing directions and remedies for the bottlenecks occurred. The key findings of the tool are discussed below:

6.2.1 USABILITY AND ADAPTABILITY OF THE TOOL

The web-based tool offers AEC teams a platform to track and record bottlenecks which occurred during the length of the project. This analysis along with future remedies to avoid such bottlenecks could be crucial for the project teams when discussing the key takeaways of the project. The results of the tool based on its usability and adaptability in AEC projects is discussed below:

- The tool uses project documentation data which is readily available for project teams throughout the project duration, this makes the tool easier to use.

- Since the tool is developed as a stand-alone application, it can be used with any system, as long as the data set required for the tool is available in the right format. Therefore, the tool could be highly adaptable in AEC projects.

- From the feedback received from the interviews, the tool offers a realistic and reliable method to identify and record on potential bottlenecks throughout the project duration.

- The tool is not in real time simulation but presents and reports bottlenecks which have already occurred therefore, it can be used at the end of the project as lessons learnt from the particular project.

- The bottleneck remedies section of the tool presents the user with the chance to study each type of bottleneck in detail to make sure such type of issues do not get carried in future projects.

- The tool is also stand-alone application solely developed for the purpose to identify and report on bottlenecks. Therefore, it offers a good integration platform for all types of project information modes (Meeting Minutes, Project Documentation, email Exchange) with a user-friendly application to identify how information flow is tracked and bottlenecks can be tackled.

6.3 RESEARCH CONTRIBUTIONS

This research contributes to the literature on bottlenecks identification and Lean Construction in the following ways:

1. Provides two new metrics: Productivity and Average Days of Issue Resolution for the issues discussed in the bi-weekly AEC Project Meetings.

2. Modifies existing information flow metrics DV and WIP and uses the modified definitions to identify and report Project Bottlenecks.

3. Segregates the issues discussed in meetings in 4 different types: Pooled, Sequential, Reciprocal, and Intensive based on the complexity and collaboration requirements of different issues.

4. Develops a stand-alone web-based tool to report on bottlenecks, which is a unique tool solely dedicated to study the bottlenecks which occur during the lifecycle of an AEC project. The tool reports on bottlenecks, studies information exchange patterns between different groups of the project and provides preventive remedies and feedbacks to the users as lessons learnt for future prospective projects.

5. Tests the usability and adaptability of the tool qualitatively by conducting two expert interviews and improves the tool based on their feedbacks.

6.4 LIMITATIONS

One main limitation of the study is that the projects whose data was used were different in their scope. One was an expansion project while the other was a renovation project in mid-western USA. There have not been studies made to identify if information exchange patterns between team members varies with the size of the project. Other limitation is that the dataset used as an import for the web-based model requires it to be in a specific format based on the protocol developed during the research. These aspects can be addressed in future literature efforts. Additionally, the bottleneck reporting tool uses archival data for its analysis and since it is not merged to operate simultaneously with project documentation websites these projects used, the reporting is not in real-time.

The following can be defined as the limitations of this study:

1. The quantitative tests on the usability of the tool could not be performed given the limitations of the sample size of the interviewees. For most quantitative analysis of usability and adaptability of web-tools and interfaces more than 12 participants are required.

2. The research uses dataset for two projects in Midwest USA only.

3. The simulation and codes developed by the researcher are not in real-time. The study uses archival datasets and reports, provides recommendations on bottlenecks which have already occurred.

6.5 DIRECTION FOR FUTURE RESEARCH

The author provides the following directions of future work for this area:

1. The code developed by the researcher could be used by merging it with any project documentation website which then provides the chance for the users to identify and study project bottlenecks in real-time and not using archival datasets.

2. Quantitative Analysis of the tool could be performed by increasing the sample size of the interviews and performing certain tests like Cronbach Alpha.

3. Artificial Intelligence can be used to automatically read and extract data from the meeting minutes which can save the developer a lot of time and make it easier for the users. To accomplish this direction, a beta version of the tool is currently being planned.

4. The model can be expanded to incorporate wider audience and expertise than just focusing on construction projects only. The web-based tool can be generalized to

incorporate industrial, mechanical, and software projects so that the scope of the tool is

improved.

5. Work can be done in the future to merge this web-based too with document

management tools like Procore, Unifier so that transfer of information is in real time.

6.6 CONCLUSION

The primary objective of the research was to develop and study the usability and adaptability of

a web-based tool dedicated to study and report on bottlenecks which occur during the life cycle

of a AEC project. This was successfully achieved by a combination of Literature review, metrics

development and modifications, coding, expert interviews, and modifications in code based on

the feedback. The data collected was analyzed quantitatively and used to study information

exchange patterns, which helped in identifying bottlenecks. The findings of the research

showed promising signs that such a tool can be adopted by AEC teams and by Project Managers

to study their projects in detail and avoid issues and bottlenecks which could impact on cost or

schedule.

APPENDIX

APPENDIX A: INTERVIEW PROTOCOL

Interview and Survey Questions for Web-Based Tool to Predict Information Bottlenecks

Study Number "STUDY00001064: Network Interventions on Engineering Projects"

The purpose of this document is to provide an outline to the purpose and goals of this study, provide a transcript of the interview questions, and introduce the survey questions which will be used to study the usability of the platform. This report is submitted to IRB as a requirement before conducting interview with industry experts involved with this project.

1. **Introduction:**

This interview and survey is performed as a part of my thesis 'Understanding the Usability of Web-Based Tool in Identifying Information Bottlenecks in AEC Projects'. Through my thesis, I have a developed a web-based tool which imports archival data in the form of project documentation and uses this data to identify which timeframe has high probability of occurrence of bottleneck. Following the development, I want the usability of this tool in AEC projects by interviewing two AEC project personnel to get their feedback and suggested improvements.

2. **Content for the Interview:**

The interview will be conducted via zoom. The interview will be recorded by asking the permission of the interviewees. This would help me to record their insights and use it as suggestions for improving the tool. The tool will be opened in my system with screen control provided to the interviewees. They will be allowed to browse and navigate through the tool. Since, the interview will be recorded, they can add their inputs throughout the length of the

meeting and their feedback will be transcribed after the meeting is over. Once transcribed, the feedback document will be sent to the interviewees to get their consent with the transcription. This document will then be used by the researcher to be included in the results section of the thesis.

3. **Interview Transcript:**

I will be meeting Project Managers of the two projects I have been working closely with for the past two years. Here is the general format of the transcription of the interview to be conducted.

- Hello Mr. A, My name is Pandey, I have been working on your project collecting and analyzing archival data for the past 2 years. For my thesis, using this archival data I came up with a tool. Today I want to show you this tool, allow you to navigate, So I can get your feedback about the usability and adaptability of this tool in AEC projects.

- Based on the consent form, I will also be recording this meeting, This will help me not to miss out on any valuable input from your end. After the meeting, I will be forwarding you a document which summarizes all your feedback and our discussions today for your review and approval. Once approved, I can use the findings of this document in my thesis results. Any of the feedback or data that I have shared will remain confidential.

- The screenshot of the web-based tool has been attached with this protocol:
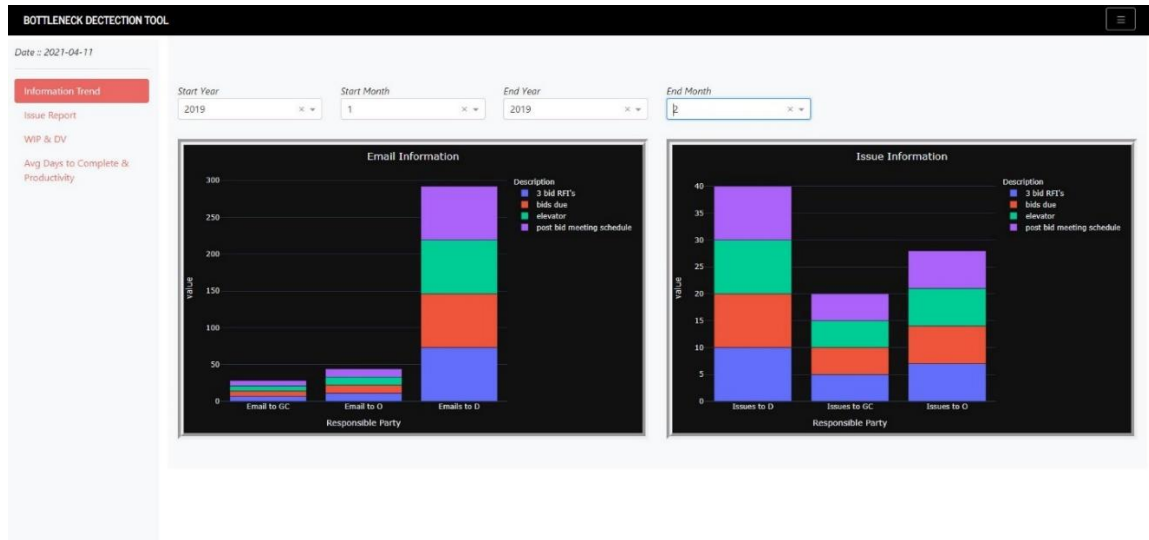
FIGURE A: INFORMATION EXCHANGE AND ISSUES INFORMATION
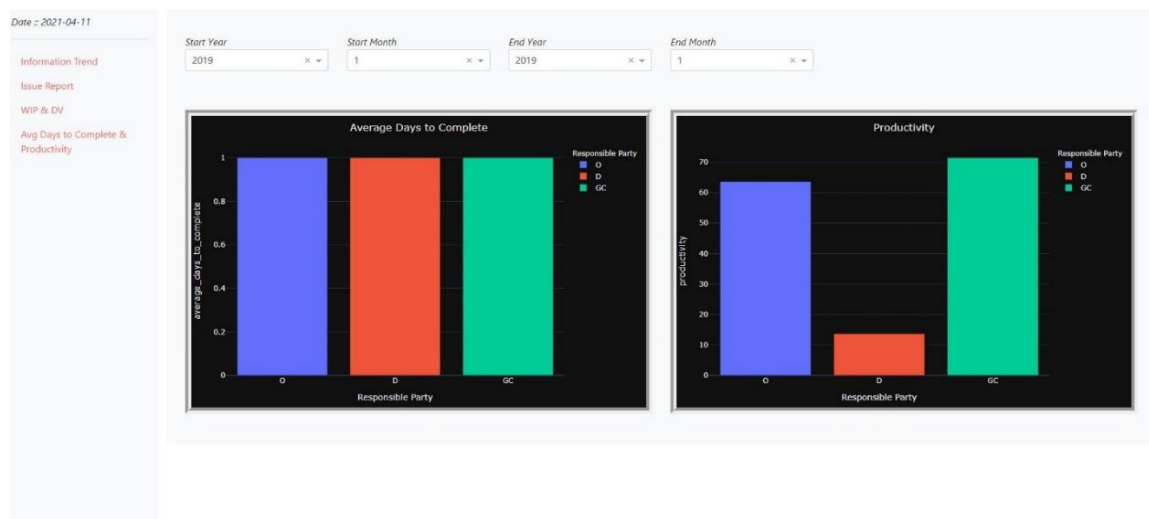
FIGURE B: AVERAGE DAYS TO COMPLETE AND PRODUCTIVITY

- Here are a list of questions which you can answer after you are done navigating the

  tool:

  o Do you think this a useful tool? If so, at what frequency and who do you think

    should be using this?

- How do you think this tool can be improved so, it is more beneficial for the AEC teams?

- Did you feel the content used in the web-based tool is arranged in the right format?

- On a scale of 1-10 how do you rate the clarity of the content? Do you think this information is accurate /representative of your experience with the project?

- Do you have other reflections on this tool, which you think could be useful?

- Do you think this information is accurate /representative of your experience with the project?

- In the projects you have worked on so far, is this technique of identification of information bottlenecks looks applicable? If so, who do you think is suitable to use this identification technique?

- On a scale of 1-10 what is your understanding of information exchange trends in project teams after the presentation?

- On a scale of 1-10, how do you rate the overall experience?

- If you had this tool, do you think this would have been useful in identifying the information bottlenecks?

- Were you able to navigate to other pages easily?

- Do you have additional comments/recommendations to make the webpage even more user friendly?

APPENDIX B: PYTHON CODE

```python
import dash
import dash_bootstrap_components as dbc
import dash_core_components as dcc
import dash_html_components as html
from dash.dependencies import Input, Output, State
from datetime import date
import pandas as pd

import base64
import datetime
import io

import dash
from dash.dependencies import Input, Output, State
import dash_core_components as dcc
import dash_html_components as html
import dash_table
from datetime import date
import dash
import dash_html_components as html
import dash_core_components as dcc
import re
import plotly.graph_objs as go
from plotly.subplots import make_subplots
import pandas as pd
from dash.dependencies import Input, Output
from dash.exceptions import PreventUpdate
import plotly.express as px
import dash_bootstrap_components as dbc
import datetime
import pandas as pd




df = pd.read_excel(r'C:\Users\nishc\Documents\data.xlsx',sheet_name =
'Sheet2')
df['Start Month']=df['Start Date'].dt.month
df['End Month']=df['End Date'].dt.month
df['End Year']=df['End Date'].dt.year
df['Start Year']=df['Start Date'].dt.year

#-----------email and issue file
```

FIGURE C: PYTHON CODE

FIGURE C (cont'd)

```python
df1 = pd.read_excel(r'C:\Users\nishc\Documents\data.xlsx',sheet_name =
 'Sheet3')
df100 = df1
# -----------------------
df100['upcoming_meeting_date'] = df100['Meeting Date'].shift(periods=-
1)
df100['days_between_meeting']=df100['upcoming_meeting_date']-
df100['Meeting Date']
df100['firstcount']=(df100['Emails to D']+df100['Email to O']+df100['E
mail to GC']+df100['PlanGrid']+df100['Unifier'])
df100['secondcount']=df100['firstcount'].shift(periods=1)
df100['days_between_meeting']=df100['days_between_meeting'].astype('st
r')
def func1(x):
    x=x[:2]
    return x
df100['num_of_days']=df100.apply(lambda x: func1(x['days_between_meeti
ng']), axis=1)
df100['num_of_days']=df100['num_of_days'].replace('Na',0)
df100['secondcount']=df100['secondcount'].fillna(0)
df100['secondcount']=df100['secondcount'].astype('int')
df100['num_of_days']=df100['num_of_days'].astype('int')
df100['dv']=(df100['firstcount']-
df100['secondcount'])/df100['num_of_days']
df100['dv']=df100['dv'].replace(df100['dv'][0],0)
df100['sum_of_issues']=(df100['Issues to O']+df100['Issues to GC']+df1
00['Issues to D'])
df100['sum_of_issues']=df100['sum_of_issues'].fillna(0)
df100['sum_of_issues']=df100['sum_of_issues'].astype('int')
df100['sum_of_issues_second_meet']=df100['sum_of_issues'].shift(period
s=1)
df100['WIP']=(df100['sum_of_issues']-
df100['sum_of_issues_second_meet'])
df100['WIP']=df100['WIP'].fillna(0)
df100['Month']=df100['Meeting Date'].dt.month
df1001=df100[['Meeting Date','upcoming_meeting_date','dv','WIP','Month
']]


# -------------------------

# df1  = df1.rename(columns={'Issues to D':'Issues to D', 'Issues to O
':'Issues to O','Issues to GC':'Issues to GC','Emails to D':'Emails to
 D'})
df1['Start Date'] = df1['Meeting Date']
df5 = df.merge(df1, how='inner', on='Start Date')
```

FIGURE C (cont'd)

```python
abc = df5
group = df5.groupby(['Description','Responsible Party','Start Date','E
nd Date','Days to Complete','Start Year','Start Month','End Year','End
 Month'])[['Emails to D','Issues to D','Email to O','Issues to O','Ema
il to GC','Issues to GC']].sum().reset_index()

#----------type of issues----------------

df15 = pd.read_excel(r'C:\Users\nishc\Documents\data.xlsx',sheet_name=
'Types of Issues')
df16=df15[['Recirpocal']]
df16=df16.dropna()
df16['name']='Recirpocal'
df16.columns=['Description', 'name']
df17=df15[['Pooled']]
df17=df17.dropna()
df17['name']='Pooled'
df17.columns=['Description', 'name']
df18=df15[['Intensive']]
df18=df18.dropna()
df18['name']='Intensive'
df18.columns=['Description', 'name']
df19=df15[['Sequential']]
df19=df19.dropna()
df19['name']='Sequential'
df19.columns=['Description', 'name']
df20 =pd.concat([df16,df17,df18,df19],axis=0)
df19.columns=['Description', 'name']
df21=df.merge(df16,how = 'inner',on='Description')
df22=df.merge(df17,how = 'inner',on='Description')
df23=df.merge(df18,how = 'inner',on='Description')
df24=df.merge(df19,how = 'inner',on='Description')
df26 = pd.concat([df21,df22,df23,df24],axis=0)
df27=df26.groupby(['name','Start Month','Responsible Party', 'End Mont
h'])[['Description']].count().reset_index()
print(df27.head(1))

external_stylesheets = 'bootstrap.css'

app = dash.Dash(external_stylesheets=[dbc.themes.JOURNAL])

app.config['suppress_callback_exceptions'] = True
app.config.suppress_callback_exceptions = True

app.css.config.serve_locally = True
```

FIGURE C (cont'd)

```python
app.scripts.config.serve_locally = True

server = app.server

layout_1 = dbc.Container([
    dbc.Row([
        dbc.Col([
            html.I('Start Year'),
            dcc.Dropdown(id='input1', multi=False, value=2019,options=
[{'label':x, 'value':x}
                                    for x in sorted(group['Start Year'].
unique())])],width={'size':2}),

        dbc.Col([
            html.I('Start Month'),
            dcc.Dropdown(id='input2', multi=False, value=1,options=[{'
label':x, 'value':x}
                                    for x in sorted(group['Start Month']
.unique())])],width={'size':2}),

        dbc.Col([
            html.I('End Year'),
            dcc.Dropdown(id='input3', multi=False, value=2019,options=
[{'label':x, 'value':x}
                                    for x in sorted(group['End Year'].un
ique())]
                )],width={'size':2}),

        dbc.Col([
            html.I('End Month'),
            dcc.Dropdown(id='input4', multi=False, value=1,options=[{'
label':x, 'value':x}
                                    for x in sorted(group['End Month'].u
nique())])],width={'size':2}),

        ], no_gutters=False, justify='start',style = {"padding": "2rem
 0rem"}),
    dbc.Row([
        dbc.Col([dcc.Loading(dcc.Graph(id='output', figure={},style =
{"border":"10px groove"}   ,)),],width={'size':6}),
        dbc.Col([dcc.Loading(dcc.Graph(id='output7', figure={},style =
 {"border":"10px groove"}   ,)),],width={'size':6})

        ])], fluid=True,style = {"padding": "2rem 0rem"}   )
```

FIGURE C (cont'd)

```
layout2 = dbc.Container([
    dbc.Row([
        dbc.Col([
            html.I('Start Year'),
            dcc.Dropdown(id='input1', multi=False, value=2019,options=
[{'label':x, 'value':x}
                                        for x in sorted(group['Start Year'].
unique())])],width={'size':2}),

        dbc.Col([
            html.I('Start Month'),
            dcc.Dropdown(id='input2', multi=False, value=1,options=[{'
label':x, 'value':x}
                                        for x in sorted(group['Start Month']
.unique())])],width={'size':2}),

        dbc.Col([
            html.I('End Year'),
            dcc.Dropdown(id='input3', multi=False, value=2019,options=
[{'label':x, 'value':x}
                                        for x in sorted(group['End Year'].un
ique())]
                )],width={'size':2}),

        dbc.Col([
            html.I('End Month'),
            dcc.Dropdown(id='input4', multi=False, value=1,options=[{'
label':x, 'value':x}
                                        for x in sorted(group['End Month'].u
nique())])],width={'size':2}),

        ], no_gutters=False, justify='start',style = {"padding": "2rem
 0rem"}),
    # dbc.Row([
    #     dbc.Col([dcc.Loading(dcc.Graph(id='output', figure={},style
= {"border":"10px groove}  ,)),],width={'size':12})

    #     ]),

    dbc.Row([
        dbc.Col([dcc.Loading(dcc.Graph(id='output5', figure={},style =
 {"border":"10px groove}  ,)),],width={'size':12})

        ], no_gutters=False, justify='start',style = {"padding": "2rem
 0rem"})], fluid=True)
```

FIGURE C (cont'd)

```python
layout3 = dbc.Container([

    dbc.Row([
        dbc.Col([
            html.I('Meeting Month'),
            dcc.Dropdown(id='input5', multi=False, value=2,options=[{'
label':x, 'value':x}
                                        for x in sorted(group['Start Month']
.unique())])]),width={'size':2}),
        ], no_gutters=False, justify='start',style = {"padding": "2rem
 0rem"}),

    dbc.Row([

        dbc.Col([dcc.Loading(dcc.Graph(id='output3', figure={},style =
{"border":"10px groove"}  ,)),],width={'size':6}),
        dbc.Col([dcc.Loading(dcc.Graph(id='output4', figure={},style =
{"border":"10px groove"}  ,)),],width={'size':6})

        ], no_gutters=False, justify='start',style = {"padding": "2rem
 0rem"})

    ], fluid=True)

navbar = dbc.NavbarSimple(
    children=[
        dbc.Button("☰", outline=True, color="secondary", className="mr
-1", id="btn_sidebar"),
        # dbc.NavItem(dbc.NavLink("Page 1", href="#")),
        # dbc.DropdownMenu(
        #     children=[
        #         dbc.DropdownMenuItem("More pages", header=True),
        #         dbc.DropdownMenuItem("Page 2", href="#"),
        #         dbc.DropdownMenuItem("Page 3", href="#"),
        #     ],
        #     nav=True,
        #     in_navbar=True,
        #     label="More",
        # ),
    ],
    brand="Bottleneck Dectection tool",
    brand_href="#",
    color="dark",
    dark=True,
```

FIGURE C (cont'd)

```python
    fluid=True,
)

layout4 = dbc.Container([
    dbc.Row([
        dbc.Col([
            html.I('Start Year'),
            dcc.Dropdown(id='input1', multi=False, value=2019,options=
[{'label':x, 'value':x}
                                    for x in sorted(group['Start Year'].
unique())])],width={'size':2}),

        dbc.Col([
            html.I('Start Month'),
            dcc.Dropdown(id='input2', multi=False, value=1,options=[{'
label':x, 'value':x}
                                    for x in sorted(group['Start Month']
.unique())])],width={'size':2}),

        dbc.Col([
            html.I('End Year'),
            dcc.Dropdown(id='input3', multi=False, value=2019,options=
[{'label':x, 'value':x}
                                    for x in sorted(group['End Year'].un
ique())]
                )],width={'size':2}),

        dbc.Col([
            html.I('End Month'),
            dcc.Dropdown(id='input4', multi=False, value=1,options=[{'
label':x, 'value':x}
                                    for x in sorted(group['End Month'].u
nique())])],width={'size':2}),

        ], no_gutters=False, justify='start',style = {"padding": "2rem
 0rem"}),


    dbc.Row([
        dbc.Col([dcc.Loading(dcc.Graph(id='output1', figure={},style =
 {"border":"10px groove"}  ,)),],width={'size':6}),
        dbc.Col([dcc.Loading(dcc.Graph(id='output2', figure={},style =
 {"border":"10px groove"}  ,)),],width={'size':6})
```

FIGURE C (cont'd)

```python
        ], no_gutters=False, justify='start',style = {"padding": "2rem
 0rem"})


    ], fluid=True)


# the style arguments for the sidebar. We use position:fixed and a fix
ed width
SIDEBAR_STYLE = {
    "position": "fixed",
    "top": 62.5,
    "left": 0,
    "bottom": 0,
    "width": "16rem",
    "height": "100%",
    "z-index": 1,
    "overflow-x": "hidden",
    "transition": "all 0.5s",
    "padding": "0.5rem 1rem",
    "background-color": "#f8f9fa",
}

SIDEBAR_HIDEN = {
    "position": "fixed",
    "top": 62.5,
    "left": "-16rem",
    "bottom": 0,
    "width": "16rem",
    "height": "100%",
    "z-index": 1,
    "overflow-x": "hidden",
    "transition": "all 0.5s",
    "padding": "0rem 0rem",
    "background-color": "#f8f9fa",
}

# the styles for the main content position it to the right of the side
bar and
# add some padding.
CONTENT_STYLE = {
    "transition": "margin-left .5s",
    "margin-left": "17rem",
    "margin-right": "1rem",
    "padding": "1rem 1rem",
```

FIGURE C (cont'd)

```python
        "background-color": "#f8f9fa",
}

CONTENT_STYLE1 = {
    "transition": "margin-left .5s",
    "margin-left": "1rem",
    "margin-right": "1rem",
    "padding": "1rem 1rem",
    "background-color": "#f8f9fa",
}

date =date.today()
sidebar = html.Div(
    [
        # html.H2("Sidebar", className="display-4"),
        html.I('Date :: {}'.format(date)),
        html.Hr(),
        # html.P(
        #       "A simple sidebar layout with navigation links", classNa
me="lead"
        # ),
        dbc.Nav(
            [
                dbc.NavLink("Information Trend", href="/page-
1", id="page-1-link"),
                dbc.NavLink("Issue Report", href="/page-2", id="page-
2-link"),
                dbc.NavLink("WIP & DV", href="/page-3", id="page-3-
link"),
                dbc.NavLink("Avg Days to Complete & Productivity", hre
f="/page-4", id="page-4-link"),
                # dbc.NavLink("WIP", href="/page-3", id="page-5-
link"),
                # dbc.NavLink("DV", href="/page-3", id="page-6-link"),

            ],
            vertical=True,
            pills=True,
        ),
    ],
    id="sidebar",
    style=SIDEBAR_STYLE,
)

content = html.Div(
```

FIGURE C (cont'd)

```
    id="page-content",
    style=CONTENT_STYLE)

app.layout = html.Div(
    [
        dcc.Store(id='side_click'),
        dcc.Location(id="url"),
        navbar,
        sidebar,
        content,
    ],
)

@app.callback(
    [
        Output("sidebar", "style"),
        Output("page-content", "style"),
        Output("side_click", "data"),
    ],

    [Input("btn_sidebar", "n_clicks")],
    [
        State("side_click", "data"),
    ]
)
def toggle_sidebar(n, nclick):
    if n:
        if nclick == "SHOW":
            sidebar_style = SIDEBAR_HIDEN
            content_style = CONTENT_STYLE1
            cur_nclick = "HIDDEN"
        else:
            sidebar_style = SIDEBAR_STYLE
            content_style = CONTENT_STYLE
            cur_nclick = "SHOW"
    else:
        sidebar_style = SIDEBAR_STYLE
        content_style = CONTENT_STYLE
        cur_nclick = 'SHOW'

    return sidebar_style, content_style, cur_nclick

# this callback uses the current pathname to set the active state of t
he
```

FIGURE C (cont'd)

```python
# corresponding nav link to true, allowing users to tell see page they
  are on
@app.callback(
    [Output(f"page-{i}-link", "active") for i in range(1, 4)],
    [Input("url", "pathname")],
)
def toggle_active_links(pathname):
    if pathname == "/":
        # Treat page 1 as the homepage / index
        return True, False, False
    return [pathname == f"/page-{i}" for i in range(1, 4)]


@app.callback(Output("page-
content", "children"), [Input("url", "pathname")])
def render_page_content(pathname):
    if pathname in ["/", "/page-1"]:
        return [layout_1]
    elif pathname == "/page-2":
        return [layout2]
    elif pathname == "/page-3":
        return [layout3]
    elif pathname == "/page-4":
        return [layout4]
    # If the user tries to reach a different page, return a 404 messag
e
    return dbc.Jumbotron(
        [
            html.H1("404: Not found", className="text-danger"),
            html.Hr(),
            html.P(f"The pathname {pathname} was not recognised..."),
        ]
    )



@app.callback(
    Output("output", "figure"),
    Input("input1", "value"),
    Input("input2", "value"),
    Input("input3", "value"),
    Input("input4", "value"),
)
def func(start_year,start_month,end_year,end_month):
    df = group[(group['Start Year']==start_year)&(group['End Year']==e
nd_year)&(group['Start Month']==start_month)&(group['End Month']==end_
month)]
```

FIGURE C (cont'd)

```python
    dff =pd.melt(df, id_vars=['Description','Responsible Party','Start
 Year','Start Month','End Year','End Month','Start Date','End Date','D
ays to Complete'], var_name=[('Emails to D','Issues to D','Email to O'
,'Issues to O','Email to GC','Issues to GC')], value_name='value')
    dff.columns = ['Description','Responsible Party','Start Year','Sta
rt Month','End Year','End Month','Start Date','End Date','Days to Comp
lete','colnames','value']
    dff = dff[(dff['colnames']!='Issues to D')&(dff['colnames']!='Issu
es to O')&(dff['colnames']!='Issues to GC')]
    dff=dff.groupby(['Description','Responsible Party','Start Month','
End Month','Start Year','End Year','colnames'])[['value']].sum().reset
_index()
    return px.bar(dff, x='colnames', y='value',template = 'plotly_dark
',color='Description',title='Email Information', height=480)\
    .update_layout(showlegend=True,margin=dict(t=50, b=50, l=50, r=50)
,title_x=0.5,xaxis=dict(title=dict(text='Responsible Party',font=dict(
size=14))))

@app.callback(
    Output("output7", "figure"),
    Input("input1", "value"),
    Input("input2", "value"),
    Input("input3", "value"),
    Input("input4", "value"),
)
def func(start_year,start_month,end_year,end_month):
    df = group[(group['Start Year']==start_year)&(group['End Year']==e
nd_year)&(group['Start Month']==start_month)&(group['End Month']==end_
month)]
    dff =pd.melt(df, id_vars=['Description','Responsible Party','Start
 Year','Start Month','End Year','End Month','Start Date','End Date','D
ays to Complete'], var_name=[('Emails to D','Issues to D','Email to O'
,'Issues to O','Email to GC','Issues to GC')], value_name='value')
    dff.columns = ['Description','Responsible Party','Start Year','Sta
rt Month','End Year','End Month','Start Date','End Date','Days to Comp
lete','colnames','value']
    dff = dff[(dff['colnames']!='Emails to D')&(dff['colnames']!='Emai
l to O')&(dff['colnames']!='Email to GC')]
    dff=dff.groupby(['Description','Responsible Party','Start Month','
End Month','Start Year','End Year','colnames'])[['value']].sum().reset
_index()
    return px.bar(dff, x='colnames', y='value',template = 'plotly_dark
',color='Description',title='Issue Information', height=480)\
```

FIGURE C (cont'd)

```python
        .update_layout(showlegend=True,margin=dict(t=50, b=50, l=50, r=50)
,title_x=0.5,xaxis=dict(title=dict(text='Responsible Party',font=dict(
size=14))))

@app.callback(
    Output("output5", "figure"),
    Input("input2", "value"),
    Input("input4", "value"),
)
def func1011(startmonth,endmonth):
    df28=df27[(df27['Start Month']==startmonth)&(df27['End Month']==en
dmonth)]
    return px.bar(df28, x='name', y='Description',color = 'Responsible
 Party',template = 'plotly_dark',title='Issue Report', height=480)\
        .update_layout(showlegend=True,margin=dict(t=50, b=50, l=50, r=50)
,title_x=0.5,xaxis=dict(title=dict(text='Types of Issues',font=dict(si
ze=14))))

@app.callback(
    Output("output3", "figure"),
    Input("input5", "value"),
)
def func100(month):
    df12=df1001[df1001['Month']==month]
    return px.bar(df12, x='Meeting Date', y='WIP',color = 'Meeting Dat
e',template = 'plotly_dark',title='WIP', height=480)\
        .update_layout(showlegend=True,margin=dict(t=50, b=50, l=50, r=50)
,title_x=0.5)

@app.callback(
    Output("output4", "figure"),
    Input("input5", "value"),
)
def dv(month):
    df12=df1001[df1001['Month']==month]
    return px.bar(df12, x='Meeting Date', y='dv',color = 'Meeting Date
',template = 'plotly_dark',title='DV', height=480)\
        .update_layout(showlegend=True,margin=dict(t=50, b=50, l=50, r=50)
,title_x=0.5)

@app.callback(
    Output("output1", "figure"),
    Input("input1", "value"),
    Input("input2", "value"),
    Input("input3", "value"),
```

FIGURE C (cont'd)

```python
    Input("input4", "value"),
)
def func1(start_year,start_month,end_year,end_month):
    owner = abc[(abc['Responsible Party']=='O')&(abc['Start Year']==st
art_year)&(abc['End Year']==end_year)&(abc['Start Month']==start_month
)&(abc['End Month']==end_month)]
    owner=owner[['Responsible Party','Email to O','Issues to O','Days
to Complete']]
    owner['average_days_to_complete']=owner['Days to Complete'].mean()
    owner['total_email']=owner['Email to O'].sum()
    owner['email']=owner['Issues to O'].sum()
    owner['productivity'] = (owner['email']/owner['total_email'])*100
    owner  =owner[['Responsible Party','total_email','productivity','a
verage_days_to_complete']]
    owner=owner[0:1]
    gc = abc[(abc['Responsible Party']=='GC')&(abc['Start Year']==star
t_year)&(abc['End Year']==end_year)&(abc['Start Month']==start_month)&
(abc['End Month']==end_month)]
    gc=gc[['Responsible Party','Email to GC','Issues to GC','Days to C
omplete']]
    gc['average_days_to_complete']=gc['Days to Complete'].mean()
    gc['total_email']=gc['Email to GC'].sum()
    gc['email']=gc['Issues to GC'].sum()
    gc['productivity'] = (gc['email']/gc['total_email'])*100
    gc  =gc[['Responsible Party','total_email','productivity','average
_days_to_complete']]
    gc=gc[0:1]
    d = abc[(abc['Responsible Party']=='D')&(abc['Start Year']==start_
year)&(abc['End Year']==end_year)&(abc['Start Month']==start_month)&(a
bc['End Month']==end_month)]
    d=d[['Responsible Party','Emails to D','Issues to D','Days to Comp
lete']]
    d['average_days_to_complete']=d['Days to Complete'].mean()
    d['total_email']=d['Emails to D'].sum()
    d['email']=d['Issues to D'].sum()
    d['productivity'] = (d['email']/d['total_email'])*100
    d  =d[['Responsible Party','total_email','productivity','average_d
ays_to_complete']]
    d=d[0:1]
    frames = [owner, d, gc]
    result = pd.concat(frames)
    # pie_fig = px.pie(result, names=result['Responsible Party'], valu
es='average_days_to_complete' ,height = 480,hole = .3,template = 'plot
ly_dark',color = 'Responsible Party' , title='Average Days to Complete
')\
```

FIGURE C (cont'd)

```python
    #           .update_layout(showlegend=True,margin=dict(t=50, b=50, l
=50, r=50),title_x=0.5).update_traces(textposition='inside',  textinfo
='label+percent+value')
    # return pie_fig
    return px.bar(result, x='Responsible Party', y='average_days_to_co
mplete',color = 'Responsible Party',template = 'plotly_dark',title='Av
erage Days to Complete', height=480)\
    .update_layout(showlegend=True,margin=dict(t=50, b=50, l=50, r=50)
,title_x=0.5)


@app.callback(
    Output("output2", "figure"),
    Input("input1", "value"),
    Input("input2", "value"),
    Input("input3", "value"),
    Input("input4", "value"),
)
def func3(start_year,start_month,end_year,end_month):
    owner1 = abc[(abc['Responsible Party']=='O')&(abc['Start Year']==s
tart_year)&(abc['End Year']==end_year)&(abc['Start Month']==start_mont
h)&(abc['End Month']==end_month)]
    owner1=owner1[['Responsible Party','Email to O','Issues to O','Day
s to Complete']]
    owner1['average_days_to_complete']=owner1['Days to Complete'].mean
()
    owner1['total_email']=owner1['Email to O'].sum()
    owner1['email']=owner1['Issues to O'].sum()
    owner1['productivity'] = (owner1['email']/owner1['total_email'])*1
00
    owner1  =owner1[['Responsible Party','total_email','productivity',
'average_days_to_complete']]
    owner1=owner1[0:1]
    gc1 = abc[(abc['Responsible Party']=='GC')&(abc['Start Year']==sta
rt_year)&(abc['End Year']==end_year)&(abc['Start Month']==start_month)
&(abc['End Month']==end_month)]
    gc1=gc1[['Responsible Party','Email to GC','Issues to GC','Days to
 Complete']]
    gc1['average_days_to_complete']=gc1['Days to Complete'].mean()
    gc1['total_email']=gc1['Email to GC'].sum()
    gc1['email']=gc1['Issues to GC'].sum()
    gc1['productivity'] = (gc1['email']/gc1['total_email'])*100
    gc1  =gc1[['Responsible Party','total_email','productivity','avera
ge_days_to_complete']]
    gc1=gc1[0:1]
```

FIGURE C (cont'd)

```python
    d1 = abc[(abc['Responsible Party']=='D')&(abc['Start Year']==start
_year)&(abc['End Year']==end_year)&(abc['Start Month']==start_month)&(
abc['End Month']==end_month)]
    d1=d1[['Responsible Party','Emails to D','Issues to D','Days to Co
mplete']]
    d1['average_days_to_complete']=d1['Days to Complete'].mean()
    d1['total_email']=d1['Emails to D'].sum()
    d1['email']=d1['Issues to D'].sum()
    d1['productivity'] = (d1['email']/d1['total_email'])*100
    d1  =d1[['Responsible Party','total_email','productivity','average
_days_to_complete']]
    d1=d1[0:1]
    frames = [owner1, d1, gc1]
    result = pd.concat(frames)
    # pie_fig = px.pie(result, names=result['Responsible Party'], valu
es='productivity' ,height = 480,hole = .3,template = 'plotly_dark',col
or = 'Responsible Party' , title='Productivity')\
    #         .update_layout(showlegend=True,margin=dict(t=50, b=50, l
=50, r=50),title_x=0.5).update_traces(textposition='inside',  textinfo
='label+percent+value')
    # return pie_fig
    return px.bar(result, x='Responsible Party', y='productivity',colo
r = 'Responsible Party',template = 'plotly_dark',title='Productivity',
 height=480)\
    .update_layout(showlegend=True,margin=dict(t=50, b=50, l=50, r=50)
,title_x=0.5)



if __name__ == "__main__":
```

APPENDIX C: INTERVIEW FINDINGS

Interview Findings and Feedback:

Through this section the researcher discusses the details of the two interviews which were

arranged to discuss and get feedback from AEC project experts about the tool the researcher

developed. The questions were designed to address three main questions:

1. The usability of the tool in AEC projects.

2. The adaptability of the tool within AEC teams.

3. The future directions to make the tool even more feasible and easier for use in AEC

   projects.

Interview 1: Expansion Project in Midwest USA

The interviewee suggested the tool offers great value when studying the project after a

particular phase or towards the end in lessons learnt. The tool can help the Project Managers

understand what can be improved in team communications and information shared so that in

next project these issues can be tackled. The interviewee appreciated the formatting, and

content of the tool. One comment was to use homogenous color in the columns of bottleneck

reporting table to maintain consistency. The interviewee also recognized the content of the tool

was accurate and easy to understand.

For future studies, the interviewee suggested to make the prediction real time could be of great

use the Project Manager in AEC teams. This real-time simulation of ongoing bottlenecks can

help the project manager to study the information trends, be pro-active and intervene,

therefore helping with the resolution of the information bottlenecks before it actually happens.

The real-time simulation can be achieved by merging the tool with project documentation

software, so that all information bits are tied together in one application and tracking becomes

less tedious.

The contents of the web-based tool require data set which are usually available to project

teams in all types of projects. Although, the formatting of the dataset could vary depending on

the type of the project. The researcher received positive feedback regarding the general

adaptability of the tool based on the type of dataset used. The interviewee was familiar with the information trend related information so, the navigation became easier and was received well.

Interview 2: Renovation Project in Midwest USA

The second interviewee appreciated the value of the tool in studying the project after completion. According to the subject, some issues which were reported could be managed better in subsequent projects by the use of this tool. The subject also suggested the tool can be used on a monthly/annual basis by the project managers to study any issues which might have skipped their attention. The subject highlighted this tool could be very useful for the AEC teams when studying their project for in-depth analysis.

The interviewee suggested one way to improve the usability of the project is to use industry specific terms instead of research words. The activity type definitions (Pooled, Sequential, Reciprocal, and Intensive) could be simplified to help the project managers better understand the issues on hand. The subject gave positive feedback on the formatting, clarity, ease of navigation and content of the tool.

The interviewee expressed concern on whether such detail of information could be available for all the projects. Since, all construction projects are different in terms of size, scope, and budget. Projects with lower budget might have detailed documentation available. Therefore, the subject suggested this tool could be useful when multiple parties are involved, and project documentation is agreed prior to implementation. Therefore, the ease of adaptability of the tool for smaller budgeted projects could be different to that of high-end projects.

The subject gave positive feedback on information trend metrics such as productivity, average

days to resolve, and bottleneck prediction. The interviewee also believed the tool would have

helped them study and manage the project better if it was available during the life cycle of the

project. The major feedback on improving the tool was through using simpler terms so that it is

more comprehensive for AEC team members.

APPENDIX D: EMAIL CLEANING PROTOCOL

1) There are two modes of extraction of emails. The email data should include **received time, sender e-mail, receiver e-mail, sender name/surname, receiver name/surname, email subject line, email size, message ID, filenames of attached files**
    a. Server
        i. Protocol to extract:
            1. 'Sender' and 'Receiver' data per email include at least one individual from the attached roster (roster.xlsx)
            2. 'Receiver' data per email includes at least two individuals from the roster, regardless of the sender.
            3. The information we seek is a CSV file with each row representing an email with headers - sender email address, receiver email addresses, subject, timestamp, and email size. A sample excel file is attached ('sample_template.xlsx').
            4. Please do not eliminate non-consenting individuals. We are supposed to strike them out per the study protocol.
        ii. Cleaning emails using subject lines: use step 1 below for small datasets and step 2 for large datasets
            1. Manual: line-by-line delete irrelevant emails as deduced from subject lines
            2. Automation: prepare a set of whitelisted subject line words that are relevant to the project (name of project, contractors, keywords such as construction etc.); delete all emails that does not contain at least one whitelisted word in the subject line
    b. Personal Laptops
        i. Protocol to extract: run the macro on folders relevant to the project
        ii. In the absence of folders relevant to project run Step 1.a.ii.2 on the extracted emails
2) Prepare a diary of all unique individuals appearing in the emails, accounting for duplicate names and emails of the same individual. Label this file diary.xlsx. This file

would be of the format where each row corresponds to a unique individual. 'ID' represents a unique individual, 'e1', 'e2',… are email addresses with which the person appear in the email dataset and 'n1', 'n2',… are names with which the person appear in the email dataset. Clean the diary by keeping only individuals that are relevant to the project in the ID. Others such as marketing, group-emails, relatives constitute blacklisted emails/names.

ID	e1	e2	n1	n2

3) Remove duplicate emails based on emails that have duplicated received time, sender ID, and formatted subject line (formatted subject lines are subject lines after removing prefixes such as Re:, Fwd:, [EXTERNAL] etc.
4) Prepare a final cleaned email communication dataset in the format

date	size	subject	sender ID	receiver 1 ID	receiver 2 ID	…..	received last ID

5) To obtain edge weight for a given pair of nodes in a given date range of interest:
   a. Find the number of emails exchanged between the pair in the given date range
   b. Find the number of business days, business weeks, and business months in that date range
   c. Edge weight is 3, 2, and 1 respectively if the number of emails exceed business days, business weeks, and business months; 0 otherwise

APPENDIX E: IRB APPROVAL LETTER

MICHIGAN STATE
U N I V E R S I T Y

Modification / Update APPROVAL
Pre-2018 Common Rule

April 15, 2021

To: Sinem Mollaoglu

Re: **MSU Study ID:** STUDY00001064
       IRB: Social Science / Behavioral / Education Institutional Review Board
       Principal Investigator: Sinem Mollaoglu
       Category: Expedited 7
       Submission: Modification / Update MOD00003837
       Submission Approval Date: 4/15/2021
       Effective Date: 4/15/2021
       Study Expiration Date: 9/22/2021

Title: Understanding Impacts of Social Network Interventions on Engineering
Project Outcomes
Proposal Number: 32578

**Office of
Regulatory
Affairs**
Human Research
Protection Program

4000 Collins Road
Suite 136
Lansing, MI 48910

517-355-2180
Fax: 517-432-4503
Email: irb@ora.msu.edu
www.hrpp.msu.edu

This submission has been approved by the Michigan State University (MSU) SIRB.
The submission was reviewed by the Institutional Review Board (IRB) through the
Non-Committee Review procedure. The IRB has found that this study protects the
rights and welfare of human subjects and meets the requirements of MSU's Federal
Wide Assurance (FWA00004556) and the federal regulations for the protection of
human subjects in research (e.g., pre-2018 45 CFR 46, 28 CFR 46, 21 CFR 50, 56,
other applicable regulations).

This letter notes approval of changes to the data collection materials.

Institutional restrictions to in-person human subject research activities conducted by
MSU employees, MSU students, or agents of MSU are in place, but MSU is
phasing in human research that has the potential for in-person interactions with
participants, using a Tier approach. Restrictions to in-person interactions with
human research participants by MSU employees, MSU students, or agents of MSU
are in place until the activity is permitted under a Tier and a Human Research Plan
for a Safe Return is approved. Visit http://hrpp.msu.edu/COVID-19/index.html for
the restrictions, Tiers, forms, and the process.

How to Access Final Documents
To access the study's final materials, including those approved by the IRB such as
consent forms, recruitment materials, and the approved protocol, if applicable,
please log into the Click™ Research Compliance System, open the study's
workspace, and view the "Documents" tab. To obtain consent form(s) stamped with
the IRB watermark, select the "Final" PDF version of your consent form(s) as

MSU is an affirmative-action,
equal-opportunity-employer.

applicable in the "Documents" tab. Please note that the consent form(s) stamped with the IRB watermark must typically be used.

Continuing Review: IRB approval is valid until the expiration date listed above. If the research continues to involve human subjects, you must submit a Continuing Review request at least one month before expiration.

Modifications: Any proposed change or modification with certain limited exceptions discussed below must be reviewed and approved by the IRB prior to implementation of the change. Please submit a Modification request to have the changes reviewed. If changes are made at the time of continuing review, please submit a Modification and Continuing Review request.

New Funding: If new external funding is obtained to support this study, a Modification request must be submitted for IRB review and approval before new funds can be spent on human research activities, as the new funding source may have additional or different requirements.

Immediate Change to Eliminate a Hazard: When an immediate change in a research protocol is necessary to eliminate a hazard to subjects, the proposed change need not be reviewed by the IRB prior to its implementation. In such situations, however, investigators must report the change in protocol to the IRB immediately thereafter.

Reportable Events: Certain events require reporting to the IRB. These include:
- Potential unanticipated problems that may involve risks to subjects or others
- Potential noncompliance
- Subject complaints
- Protocol deviations or violations
- Unapproved change in protocol to eliminate a hazard to subjects
- Premature suspension or termination of research
- Audit or inspection by a federal or state agency
- New potential conflict of interest of a study team member
- Written reports of study monitors
- Emergency use of investigational drugs or devices
- Any activities or circumstances that affect the rights and welfare of research subjects
- Any information that could increase the risk to subjects

Please report new information through the study's workspace and contact the IRB office with any urgent events. Please visit the Human Research Protection Program (HRPP) website to obtain more information, including reporting timelines.

Personnel Changes: Key study personnel must be listed on the MSU IRB application for expedited and full board studies and any changes to key study personnel must to be submitted as modifications. Although only key study personnel need to be listed on a non-exempt application, all other individuals

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engaged in human subject research activities must receive and maintain current human subject training, must disclose conflict of interest, and are subject to MSU HRPP requirements. It is the responsibility of the Principal Investigator (PI) to maintain oversight over all study personnel and to assure and to maintain appropriate tracking that these requirements are met (e.g. documentation of training completion, conflict of interest). When non-MSU personnel are engaged in human research, there are additional requirements. See HRPP Manual Section 4-10, Designation as Key Project Personnel on Non-Exempt IRB Projects for more information.

Prisoner Research: If a human subject involved in ongoing research becomes a prisoner during the course of the study and the relevant research proposal was not reviewed and approved by the IRB in accordance with the requirements for research involving prisoners under subpart C of 45 CFR part 46, the investigator must promptly notify the IRB.

Site Visits: The MSU HRPP Compliance office conducts post approval site visits for certain IRB approved studies. If the study is selected for a site visit, you will be contacted by the HRPP Compliance office to schedule the site visit.

For Studies that Involve Consent, Parental Permission, or Assent Form(s):

Use of IRB Approved Form: Investigators must use the form(s) approved by the IRB and must typically use the form with the IRB watermark.

Copy Provided to Subjects: A copy of the form(s) must be provided to the individual signing the form. In some instances, that individual must be provided with a copy of the signed form (e.g. studies following ICH-GCP E6 requirements). Assent forms should be provided as required by the IRB.

Record Retention: All records relating to the research must be appropriately managed and retained. This includes records under the investigator's control, such as the informed consent document. Investigators must retain copies of signed forms or oral consent records (e.g., logs). Investigators must retain all pages of the form, not just the signature page. Investigators may not attempt to de-identify the form; it must be retained with all original information. The PI must maintain these records for a minimum of three years after the IRB has closed the research and a longer retention period may be required by law, contract, funding agency, university requirement or other requirements for certain studies, such as those that are sponsored or FDA regulated research. See HRPP Manual Section 4-7-A, Recordkeeping for Investigators, for more information.

Closure: If the research activities no longer involve human subjects, please submit a Continuing Review request, through which study closure may be requested. Human subject research activities are complete if there is no further interactions or interventions with human subjects and/or no further analysis of identifiable private information.

For More Information: See the HRPP Manual (available at hrpp.msu.edu).

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Contact Information: If we can be of further assistance or if you have questions, please contact us at 517 355 2180 or via email at IRB@msu.edu. Please visit hrpp.msu.edu to access the HRPP Manual, templates, etc.

Expedited Category. Please see the appropriate research category below for the full regulatory text.

Expedited 1. Clinical studies of drugs and medical devices only when condition (a) or (b) is met.
(a) Research on drugs for which an investigational new drug application (21 CFR Part 312) is not required. (Note: Research on marketed drugs that significantly increases the risks or decreases the acceptability of the risks associated with the use of the product is not eligible for expedited review.)
(b) Research on medical devices for which (i) an investigational device exemption application (21 CFR Part 812) is not required; or (ii) the medical device is cleared/approved for marketing and the medical device is being used in accordance with its cleared/approved labeling.

Expedited 2. Collection of blood samples by finger stick, heel stick, ear stick, or venipuncture as follows:
(a) from healthy, nonpregnant adults who weigh at least 110 pounds. For these subjects, the amounts drawn may not exceed 550 ml in an 8 week period and collection may not occur more frequently than 2 times per week; or
(b) from other adults and children, considering the age, weight, and health of the subjects, the collection procedure, the amount of blood to be collected, and the frequency with which it will be collected. For these subjects, the amount drawn may not exceed the lesser of 50 ml or 3 ml per kg in an 8 week period and collection may not occur more frequently than 2 times per week.

Expedited 3. Prospective collection of biological specimens for research purposes by noninvasive means.
Examples: (a) hair and nail clippings in a nondisfiguring manner; (b) deciduous teeth at time of exfoliation or if routine patient care indicates a need for extraction; (c) permanent teeth if routine patient care indicates a need for extraction; (d) excreta and external secretions (including sweat); (e) uncannulated saliva collected either in an unstimulated fashion or stimulated by chewing gumbase or wax or by applying a dilute citric solution to the tongue; (f) placenta removed at delivery; (g) amniotic fluid obtained at the time of rupture of the membrane prior to or during labor; (h) supra- and subgingival dental plaque and calculus, provided the collection procedure is not more invasive than routine prophylactic scaling of the teeth and the process is accomplished in accordance with accepted prophylactic techniques; (i) mucosal and skin cells collected by buccal scraping or swab, skin swab, or mouth washings; (j) sputum collected after saline mist nebulization.

Expedited 4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the

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safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.) Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject's privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual.

Expedited 5. Research involving materials (data, documents, records, or specimens) that have been collected, or will be collected solely for nonresearch purposes (such as medical treatment or diagnosis). (NOTE: Some research in this category may be exempt from the HHS regulations for the protection of human subjects. 45 CFR 46.101(b)(4). This listing refers only to research that is not exempt.)

Expedited 6. Collection of data from voice, video, digital, or image recordings made for research purposes.

Expedited 7. Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies. (NOTE: Some research in this category may be exempt from the HHS regulations for the protection of human subjects. 45 CFR 46.101(b)(2) and (b)(3). This listing refers only to research that is not exempt.)

Expedited 8. Continuing review of research previously approved by the convened IRB as follows:
(a) where (i) the research is permanently closed to the enrollment of new subjects; (ii) all subjects have completed all research-related interventions; and (iii) the research remains active only for long-term follow-up of subjects; or
(b) where no subjects have been enrolled and no additional risks have been identified; or
(c) where the remaining research activities are limited to data analysis.

Expedited 9. Continuing review of research, not conducted under an investigational new drug application or investigational device exemption where categories two (2) through eight (8) do not apply but the IRB has determined and documented at a convened meeting that the research involves no greater than minimal risk and no additional risks have been identified.

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APPENDIX F: EXAMPLE OF IDENTIFICATION OF ISSUE TYPE.

This appendix discusses and provides an example of how each issue type is decided based on

the activity discussed in the project meetings.

The four types of issues are pooled, sequential, reciprocal, and intensive. They can be defined

as:

     i.   Pooled: Pooled issues are least interdependent where work and activities is

            distributed separately by members of the team. This type of interdependency is

            common for low complexity tasks and require minimal collaborations.

     ii.   Sequential: In sequential issues work and tasks flow unidirectionally between team

            members based on their expertise. Usually, collaboration is not required as

            information follows its defined path based on the functionality of the team

            members. Sequential type issues are also common for low complexity tasks.

     iii.   Reciprocal: Reciprocal issues are those which involves back and forth of information

            between team members till the issue is resolved. Usually, team members of two

            different expertise coordinate closely to resolve such issues and thus it involves

            large amount of information and communication. Such issues are common for high

            complexity tasks which requires rechecks, and reworks.

     iv.   Intensive: Intensive issues are usually of highest complexity. Due to their complexity,

            there is often no regular pattern which is followed by team members. Such issues

are goal oriented, and the project teams of various expertise collaborate for their resolution. Intensive issues are usually high complexity tasks.

Sample of Type of Issue discussed in project meeting:

- GC to send work scope to Designer for Graphics package next week for monthly coordination meeting. – In this example, two parties GC and designer are involved in exchange of information. The package that will be sent is a transmittal rather than a submittal therefore, it does not require information to be sent back to the GC by the designer. The flow is unilateral and is flowing through a sequential manner, therefore this issue is Sequential in manner.

- GC reviewed their concept estimate that was provided, based on meetings between the design team and GC, an initial concept estimate of @$ X million total project costs was shown based on best information available. After a number of CCL items were reviewed and approved, the current concept estimate indicates @$ Y M total project cost. A few items of note, related to contingencies; the current project costs noted above, includes no Design Contingency and a fixed Construction Contingency in the amount of $Z M. GC is still reviewing allowances and assumptions and will update the estimate over this phase. – For this example, it is clear to notice that since this is a budget related issue, more than 2 parties are involved in the process. For example, design team provides information to GC, GC gets other information from other potential sub-contractors and then provides that information to the owner of the project. Based on the comments received from the owner the GC re-coordinates and

changes the budget or cost associated with the project by further coordinating it with

the designer and sub-contractors, therefore based on the definition of the issue types,

this issue is intensive in nature as it requires information exchange and coordination

between multiple parties and the information exchange is not unilateral in nature.

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