GEORGIA DOT RESEARCH PROJECT RP 20-20

Final Report

TACIT KNOWLEDGE MODEL TO SUPPORT KNOWLEDGE CAPTURE AND TRANSFER IN GDOT

Office of Performance-based Management and Research
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16. Abstract:
The research team has undertaken a comprehensive study of Tacit Knowledge Management (TKM) within the Georgia Department of Transportation (GDOT) and compared it to other state DOTs. Through document analysis, surveys, and a case study of the I-85 Highway Bridge Collapse, the team has developed a final draft of the GDOT Tacit Knowledge Model (TKM). The TKM is designed to help decision-makers in emergency situations by representing and organizing critical knowledge in a structured and accessible way. The I-85 Highway Bridge Collapse was chosen as a case study to develop the first basic TKM structure. The team evaluated the TKM with input from subject matter specialists in a chosen GDOT department or office and modified the framework as necessary based on the feedback. The TKM was developed with the aim of improving the sharing of Tacit Knowledge within GDOT and ensuring quick and informed decision-making in emergency situations. The TKM includes best practices, lessons learned, and different forms of knowledge representation such as storytelling, graphs, sketches, and video clips. The model provides a comprehensive and structured approach to managing Tacit Knowledge, leading to better outcomes for public health and safety. Deployment of the TKM will involve ongoing evaluation to identify areas for improvement and maximize its effectiveness. In conclusion, the research team has developed a crucial tool for managing Tacit Knowledge within GDOT, helping to ensure quick and informed decision-making in emergency situations. The TKM provides a structured approach to organizing and sharing Tacit Knowledge, leading to better outcomes for public health and safety. The deployment of the TKM will involve ongoing evaluation to identify areas for improvement and maximize its effectiveness, making it an invaluable resource for GDOT.

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GDOT Research Project 20-20

Final Report

TACIT KNOWLEDGE MODEL TO SUPPORT KNOWLEDGE CAPTURE AND TRANSFER IN GDOT

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

K. * SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2000)

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LIST OF ABBREVATIONS

COP	Communities of Practice
CSS	Cascading Style Sheets
GDOT	Georgia Department of Transportation
HTML	Hypertext Markup Language
ICT	Information and Communication Technology
KBS	Knowledge Based Systems
KM	Knowledge Management
KSU	Kennesaw State University
KSURT	Kennesaw State University Research Team
NCHRP	National Cooperative Highway Research Program
NTKN	National Transportation Knowledge Network
ONA	Organizational Network Analysis
OPD	Office of Program Delivery
PDP	Plan Development Process
SACM	Self-Associated Concept Mapping
SME	Subject Matter Expert
SOP	Standard Operating Procedures
TK	Tacit Knowledge
TKL	Tacit Knowledge Life Cycle
TKM	Tacit Knowledge Management
TKS	Tacit Knowledge Sharing
TMC	Traffic Management Center

1. EXECUTIVE SUMMARY

This is a comprehensive study of Tacit Knowledge Management (TKM) within the Georgia Department of Transportation (GDOT). The existing TKM was compared to other state DOTs. Through document analysis, surveys, and a case study of the I-85 Highway Bridge Collapse, a final draft of the GDOT TKM was developed. The TKM was designed to help decision-makers in emergency situations by representing and organizing critical knowledge in a structured and accessible way.

The I-85 Highway Bridge Collapse was selected as a case study to establish the inaugural framework for the TKM structure. SUBJECT MATTER EXPERTS (An individual with qualifications and experience in a particular field or work process) from a designated department within the Georgia Department of Transportation (GDOT) contributed expertise to the evaluation process of the TKM and provided feedback throughout the process to provide adjustments to the framework. The primary objective behind the development of the TKM was to enhance the dissemination of tacit knowledge within GDOT, facilitating prompt and well-informed decision-making during emergency scenarios.

The TKM encompasses a wide array of knowledge representation techniques, including storytelling, graphs, sketches, and video clips, along with the incorporation of best practices and lessons learned. This model offers a comprehensive and methodical approach to the management of tacit knowledge, resulting in improved outcomes pertaining to public health and safety. The implementation of the TKM will entail continuous evaluation to identify areas for refinement and to maximize its overall effectiveness.

The TKM provides a structured approach to organizing and sharing tacit knowledge, leading to better outcomes for public health and safety. The deployment of the TKM will involve ongoing evaluation to identify areas for improvement and maximize its effectiveness, making it an invaluable resource for GDOT.

2. INTRODUCTION

The purpose of this report is to present the outcome of the project on Tacit Knowledge Management for the Georgia Department of Transportation (GDOT). The research team was tasked with understanding the tacit knowledge life cycles, processes, and tools used by different GDOT departments, to share knowledge and make decisions. The team also aimed to develop a TKM specific to the I-85 Highway Bridge Collapse case study. The report presents the results of all nine tasks completed during the project.

Jeremy Daniel, a Subject Matter Expert (SME) from the Construction Office provided the most recent TKM for the study. In the development process, initial collaboration occurred between Sam Harris and Mathew Glasser from the Traffic Operations Office and Bill Duvall from the Bridge Repair Office. To collect the data required from the GDOT subject matter experts, a list of questions was provided over the course of several meetings with the necessary teams. Extensive discussions regarding the challenges associated with the current system led to the creation of an enhanced version of the TKM. Valuable feedback on this updated framework was provided by Donn Digamon, the State Bridge Engineer. The next version of the Tacit Knowledge Representation for the I-85 incident used tacit knowledge collection elements including storytelling, graph, sketches, and a video clip. During the process of filling the database, it incorporated and stored the implicit knowledge gathered in the structured form designed for tacit knowledge. This structure was created within the Tacit Knowledge Management (TKM) framework and was organized within individual categories such as know-how, lessons learned, and best practices.Adhering to the designated timelines, significant advancements were accomplished in every task, focusing on enhancing the foundational structure of the Tacit Knowledge Model (TKM). This progress was achieved through collaboration and knowledge acquisition from SMEs spanning various departments and offices.

A key aspect of this endeavor involved the creation and implementation of a computerized tool designed to facilitate the systematic sharing of knowledge. By leveraging established tools within the organization, the aim is to streamline the integration and adoption process, ensuring a seamless transition to the new knowledge sharing mechanism. "With the direction of GDOT, the KSU team concentrated their efforts on the

Bridge Construction Office to complete the GDOT Tacit Knowledge Model and the TKM for GDOT based on the case study of the I-85 Bridge Collapse (TKM)." For instance, the Bridge Construction office was chosen to complete the GDOT Tacit Knowledge Model and the TKM for GDOT based on the case study of the I-85 Bridge Collapse (TKM).

As requested by GDOT, this paper is a compilation of previously submitted reports that summarize the progress achieved in each phase of the project. Each task report focuses on a specific objective and provides a detailed account of the research team's methodologies employed and the knowledge acquired throughout the study.

3. PROBLEM STATEMENT

This research is focused on Tacit Knowledge Management at the GDOT and references important aspects mentioned in the National Cooperative Highway Research Program (NCHRP) Research Report 867, “Keeping What You Paid For – Retaining Essential Consultant – Developed Knowledge Within DOTs” [1]. For example, GDOT has some knowledge capture and transfer requirements, specifically when the outsourced work is specialized and/or utilizes methods from established standards and procedures. GDOT implemented different Knowledge Management (KM) aspects in this study. The scope of this research is to capture tacit knowledge and create methods to transfer it.

Tacit knowledge presents a formidable challenge due to its intrinsic nature, as individuals possess knowledge beyond what they can explicitly communicate [2]. In response, certain organizations are actively engaged in concerted efforts to identify, store, and leverage tacit knowledge, with the aim of managing it independently from individual employees. This strategic approach ensures that valuable knowledge resources remain accessible and preserved, unaffected by the departure of employees at the end of the workday or their eventual retirement [2].

KM is an umbrella term for a variety of methods of preserving and enhancing the knowledge of an organization’s employees and effectively implementing that knowledge as a productive asset [3]. An important capability for competition is the understanding and management of tacit knowledge as an intangible asset [4]. There are differences between data, information, knowledge, and knowledge types [4]. Data is symbolic representations

lacking inherent context and relationships, which can be attributed with meaning that varies depending on the specific context in which they are interpreted. Such meanings can pertain to words or numerical values, further emphasizing the significance of contextual understanding and interpretation in data analysis. [5]. Information is structured data that has a particular meaning. It only exists when data relationships are recognized within a specific context [6]. Knowledge is the combination of relevant data and information, linked together in a proper format that can be used to support decisions [6].

Knowledge is a collection of information, the sum of what is known, and is the body of truth using data and principles acquired by humanity [7]; however, there remains a need to not only differentiate data from information but also to make distinctions between different knowledge types such as explicit and tacit knowledge [8]. GDOT has presented important advances exploring the types of knowledge, for example, explicit and tacit. It is important to identify the Tacit Knowledge Life Cycle (TKL) in GDOT to create the right methods and tools to capture and to transfer this important knowledge type. In this regard, GDOT made important advances and developed techniques to capture both types of knowledge and learning methods. However, the knowledge and data collected still needs to be identified, organized, and categorized in order to capture and transfer complex experiences gained from previous projects. This can be approached through KM where a model is described as a single entity that can be used for providing logical solutions for the procedures as intended [9]. For GDOT, this is a strategic research approach related to managing assets in the most efficient way with the Research Technical Advisory Group serving as the Asset Management. To do this, it is important to explore and understand the different types of knowledge at various levels and areas in organizations [9].

Several researchers have studied the diverse types of knowledge that humans use to make decisions [10]. For example, the National Transportation Knowledge Network (NTKN) is committed to support and guide the nation's transportation knowledge networks in their efforts to organize, share, and preserve transportation information, data, and knowledge for their stakeholders [11]. This research will emphasize two main knowledge types. The first is explicit knowledge, which consists of formal policies and procedures with basic facts and storable document sets [12]. Normally, explicit knowledge has been articulated and captured in the form of procedures, tables, diagrams, graphs and so on [12].

Alternatively, tacit knowledge is a complex type of knowledge that is difficult to manage and consists of personal relationships, practical experience, and shared values [13]. It constitutes the major part of what is known and, as such, is often difficult for organizations to fully benefit from this valuable asset [14]. The hypothesis of this research is that tacit knowledge can be captured using different knowledge-type representations such as video clips, storytelling, sketches, and patterns, among others. Once tacit knowledge is successfully captured, it can be effectively contained and shared through computerized methodologies. However, the process of knowledge elicitation, which involves extracting knowledge from individuals, presents inherent challenges. Reliable techniques for retrieving knowledge from people, particularly when it comes to tacit knowledge, are scarce and limited in their availability. [14].

Recently, various tools incorporating novel software, information, and communication technologies have emerged, along with Knowledge Based Systems (KBS), with the primary objective of facilitating knowledge transfer. Nevertheless, a crucial prerequisite for the effective utilization of these tools in knowledge management is the establishment of appropriate knowledge structure definitions [15]. These definitions elucidate the specific roles and contributions of each knowledge type within the broader project context, enabling seamless integration and application of knowledge throughout the project lifecycle. [16]. The research presented in this work explores a knowledge model to support capture through an experimental software application, which demonstrates how it can be transferred.

4. IMPORTANT ASPECTS OF LITERATURE REVIEW

The literature review plays a crucial role in establishing the baseline of Tacit Knowledge within and outside the DOT. The Kennesaw Research Team undertook collaborative surveys, both within and outside GDOT, resulting in a total of 73 responses received. Task 1 report provides a comprehensive overview of these survey responses, highlighting various aspects related to Tacit Knowledge. The Literature Review milestone within Task 1 offers a detailed examination of each aspect, delving into the connectivity of

GDOT departments, the communication of information, the types of knowledge shared, and the key decision-makers involved.

Task 2 builds upon the insights gained from the literature review, providing a thorough understanding of the interconnections between GDOT departments, the mechanisms of information dissemination, the nature of knowledge sharing, and the individuals who play pivotal roles in decision-making processes. This comprehensive overview outlined in Task 2 explains the various functionalities and dynamics at play within GDOT, contributing to a deeper comprehension of the organization's knowledge ecosystem.

5. GOAL

To create a knowledge model that will capture, identify, organize, and categorize tacit knowledge in order to reuse complex experiences gained from previous projects in GDOT. The purpose of this model is to improve the agency's efficiency by providing a TKM that transfers complex skills between GDOT departments, which the agency's current computer-based system cannot capture. In addition, as the number of outsourced projects in the agency increases, this research will provide a tacit knowledge framework to transfer the outsourced tacit knowledge from external consultants to GDOT to avoid loss of institutional knowledge and improve the agency's internal Knowledge Management System.

6. OBJECTIVES

The objective of this research was to analyze the I-85 Highway Bridge Collapse and repair period to get a better understanding of how the transmission of knowledge and information led the bridge to fully recover in a span of three months. The project will:

- Acquire a better understanding of KM initiatives and results inside the Department of Transportation (DOT) by studying and analyzing previous DOT KM project results.
- Learn how different GDOT departments are connected and what information and knowledge types are shared with each other. In addition, the project shall study current systems such as "Experience U."
- Analyze the I-85 Highway Bridge Collapse case study and the communication flow with the outsourced agencies involved.
- Define and create a model that captures the valuable tacit knowledge implemented at the I-85 Highway Bridge Collapse study.
- Evaluate the findings and utilize them for one department or area.
- Finalize the Tacit Knowledge Model structure for selected GDOT areas.
- Develop the KM tool that can be implemented for selected GDOT areas.

7. SIGNIFICANCE OF RESEARCH

Tacit Knowledge in GDOT is an important and intangible asset. When external consultants perform specialized projects building experiences between GDOT experts and themselves, the generated knowledge could be lost if the experiences are not captured and transmitted within the GDOT organization. Developing a customized knowledge model that captures and transfers the outsourced knowledge needed for future implementation that will support the organization's overall efficacy. Departments within the agency will be able to utilize the KM system and learn from each other's experiences in a variety of business functions such as construction, maintenance, design, and operations to maximize time and effort spent on special projects. GDOT benefits from this knowledge model as it can assist in developing internal capabilities allowing them to not only record external agency performances, but also allows the agency to reuse their developed knowledge on what, how, and why previous projects were completed to properly resolve any previous, future, or current issues that demand expertise. Applying this knowledge model will save GDOT considerable time and resources that can instead be redirected to other business

opportunities. The tacit knowledge that currently exists in the minds of employees in several different functions of the organization can be stored within a novel knowledge system that can be transferred throughout the GDOT organization. This research will assist GDOT in capturing tacit knowledge as well as relaying the results on their current computerized systems.

In the case of the I-85 Highway Bridge Collapse, the recovery effort required the involvement of almost all GDOT departments such as communication, procurement, and construction that collectively brainstormed the steps that needed to be taken in order to have the bridge functional in the fastest and most efficient way possible. However, due to the magnitude of this situation, GDOT did not have the adequate amount of resources to fully grasp the impact of the bridge collapse and was unable to account for all the associated primary and secondary factors. The proposed TKM will have the ability to make GDOT aware of certain aspects within the decision-making process that could minimize the risk and damage associated.

8. RESEARCH SCOPE

This research explores knowledge modeling to capture tacit knowledge for GDOT operations. The research considers four phases.

In Phase I, previous DOT KM projects were studied to analyze significant advances in this knowledge area and identify the key components of their results. This enables further identification of the strengths and weaknesses of the current GDOT Knowledge Management System. This first phase explores the GDOT organizational structure to identify the offices associated with each relevant department, the key decision makers within each department, as well as the key processes utilized by each department. This process assists in determining the communication methods used in GDOT and the type of information shared between GDOT departments for better preparation of tacit knowledge modeling.

Phase II of this research studies the I-85 Highway Bridge Collapse to define and create a model that captures the collective experiences of the bridge collapse period. It

explores how the GDOT team collaborated internally and externally with stakeholders, the key developments made by decision makers during the collapse and repair period, and the essential processes that were key in mobilizing those involved including any new processes that were implemented. This will identify the innovative ideas within the GDOT areas that significantly increase the knowledge shared between the team that were critical in the rebuild.

Phase III entails a comprehensive evaluation of the findings obtained during the research process and utilizes it at a specific GDOT department or area to consolidate specific benefits within that department or area via defined scenarios. The objective is to consolidate and maximize the specific benefits derived from the research within that particular department or area, employing predefined scenarios as a framework for implementation.

Phase IV of the research consists of developing a new tool with the potential of being implemented throughout the entire organization. Phase III and Phase IV depend on the results of Phase II.

9. WORK PLAN AND SCHEDULE:RESEARCH PROJECT TIMELINES:

Table 1. Research Project Timelines

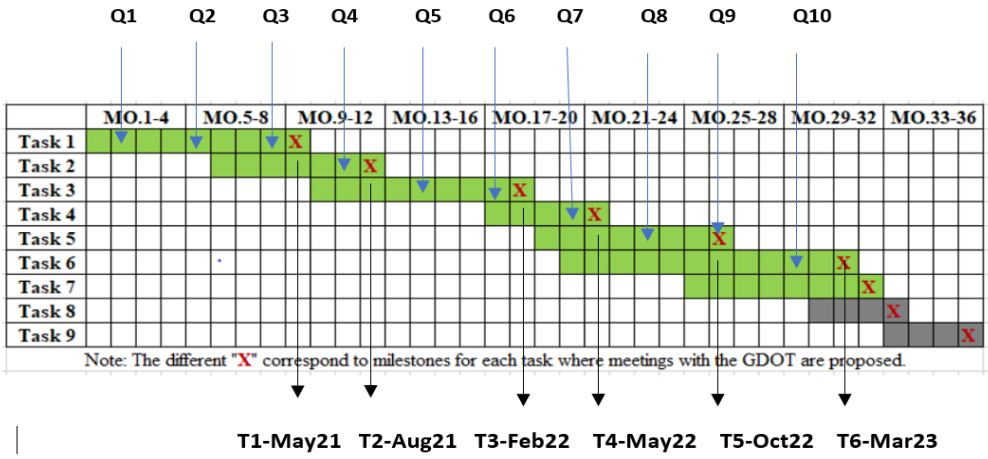

Table 1 demonstrates the Timelines of Quarterly and Task Reports respectively.

- Q indicates the Quarterly Report
- T indicates the Task Report

TASK REPORTS

This project was segmented into nine tasks with each task lasting four months. Task reports were created to describe the goal, efforts, and conclusion of work for each task. The task reports were submitted to GDOT at the end of each four-month block to inform them of the progress made. It clearly defines the milestones and deadlines met for the project. This final report is a collection of all nine task reports submitted to GDOT.

9.1 TASK 1: STRENGTHS AND WEAKNESSES OF KM IN DOT

Timeline: August 26th, 2020, to April 26th, 2021

9.1.1 Task 1 Description:

Acquire an understanding of KM initiatives and results inside DOT by studying and analyzing previous DOT KM projects results. In addition, analyze GDOT Knowledge Management Systems such as "Experience U."

9.1.2 Task 1 Deliverables:

Technical report identifying how the strengths and weaknesses of previous DOT KM projects related to Tacit Knowledge (TK) managing systems are implemented in other organizations.

9.1.3 Task 1 Milestone:

Have a clear understanding of previous DOTs KM efforts (Month 09).

9.1.4 Task 1 Report:

Executive Summary:

Knowledge is a critical asset that plays a vital role in an organization's success or failure. To remain competitive in the market and increase customer value, knowledge management has become a key aspect for modern organizations. The Georgia Department of Transportation (GDOT) recognizes the importance of managing knowledge assets,

especially tacit knowledge, and has commissioned this research team to create a Tacit Knowledge Model to identify, store, and categorize tacit knowledge for future reference.

Task 1 of the proposal involved exploring the knowledge management activities of GDOT and other state DOTs, such as VDOT, Caltrans, TxDOT, and PennDOT. The research team utilized surveys, case studies, and technical reports to analyze KM initiatives, tools, and previous knowledge management projects. The report includes a comprehensive literature review of tacit knowledge life cycle models, which cover knowledge capture, storage, mapping, sharing, transfer, and representation for both inside and outside DOT case studies.

The research team analyzed the survey results to gain a clear understanding of GDOT's current KM system and how a new Tacit Knowledge Model can help manage knowledge assets more effectively in the future. Task 1 has provided the research team with insights into how GDOT currently manages tacit knowledge and what can be done to improve and modify it, as compared to other state-of-the-art techniques.

The findings of Task 1 will form the foundation for the development of the GDOT Tacit Knowledge Model (TKM). The TKM aims to provide a structured and comprehensive approach to managing tacit knowledge and ensuring quick and informed decision-making in emergency situations. The model will include best practices, lessons learned, and different forms of knowledge representation such as storytelling, graphs, sketches, and video clips. The deployment of the TKM will involve ongoing evaluation to identify areas for improvement and maximize its effectiveness, making it an invaluable resource for GDOT.

In conclusion, Task 1 helped the research team gain a deeper understanding of the current KM practices at GDOT and other state DOTs. This knowledge will serve as a basis for the development of the TKM, which aims to improve the sharing of tacit knowledge within GDOT and ensure better outcomes for public health and safety.

INTRODUCTION OF LITERATURE REVIEW

The team defined the Tacit Knowledge Management baseline for both inside and outside DOTs in Task 1. CalTrans, WDOT, TxDOT, VDOT, PennDOT, and NCHRP (National Cooperative Highway Research Program) documentation were researched for

inside DOT applications. For general information on Tacit Knowledge Management, recent conference papers and research papers published were accessed. A Tacit Knowledge Management survey was sent to GDOT personnel as well as other DOT across the States after conducting an analysis of the Experience U software. The research team identified the advantages, disadvantages, and suggestions for the future knowledge management program based on the survey responses. The study team finished all Task 1 activities on April 26 (the ninth month of the project).

Knowledge Management (KM) has become the center of attention for many corporations and organizations. There are several motivations behind the growth of knowledge management at the Department of Transportation (DOT) across the country. First, veteran employees who are about to retire have so much knowledge accrued over their years in industry that is not easily passed on to the next generation. Second, DOT has shifted its focus from manufacturing to operations. Third, because of the hiring freeze due to economic impact, DOT relies on external contractors to do the project and after the project ends, pass the knowledge to the in-house staff. However, there are three types of knowledge: explicit, implicit, and tacit knowledge.

Explicit knowledge answers the "who, what, where, why, and how" questions, while tacit knowledge refers to the idea that people know more than what they can express verbally [17,18]. Implicit knowledge is the bridge between explicit knowledge and tacit knowledge [19], in other words, it is knowledge without being articulated. The focal point of this research is to understand the current ecosystem of the Tacit Knowledge Management and Tacit Knowledge Management Model by studying the initiatives that DOT across the United States has taken to preserve Tacit Knowledge (TK) as an effort to increase efficiency and effectiveness in DOT projects. Moreover, this research would study what other scholars and authors did to differentiate, transfer, capture, implement, approach, and model Tacit Knowledge (TK).

Besides studying Tacit Knowledge Management and its Model, this project focused on GDOT Knowledge Management Software: Experience U. Specifically, the research team introduced the software and its capabilities. Next, the team conducted the strengths and weaknesses of DOT KM initiatives. The goal is to understand the system inside the Georgia Department of Transportation (GDOT) and understand how other organizations

are facing KM problems by identifying key methods, techniques, and tools from previous projects and how they were implemented.

INSIDE GDOT AND OUTSIDE GDOT TACIT KNOWLEDGE MANAGEMENT SURVEY

The Kennesaw Research Team distributed the Tacit Knowledge Management survey to VDOT, TxDOT, Caltrans, PennDOT, and internal GDOT back in February 2021. A total of 73 responses were received. The team has analyzed the responses and provided a summary of the findings below.

Based on the survey, organizations both inside GDOT and outside GDOT are familiar with Knowledge Management Practices. There are formal and informal knowledge-based repositories where the state employees can search and retrieve information as needed. There are several tools that DOT uses as a part of KM efforts.

Formal

- SharePoint
- LAP Processes
- Experience U
- MS Teams and Stream Video
- Critical Skill Gap Matrix
- PDP
- ROADS (ProjectWise Flowcharts)
- AECOM Bridge Program SharePoint site
- Facilitated Team Alignment sessions
- Program Delivery
- Falcon
- Drupal
- SPOL
- Knowledge Mapping, Measuring Intellectual Capital
- Wiki page
- Right of Way manual

Informal

- Directives, memos, memorandum of understandings, desk manuals, contact lists, workflow diagram, project documents, documentation of processes and history, lesson learned.

- Peer and Supervisor Interaction
- Exit Interviews, Knowledge retention interviews.
- Process documents for specific tasks
- SOPs, video tutorials, and annual updates to demonstrate how a particular function should occur.
- Cross-training
- After Action Review

Offices that responded to the survey

Inside GDOT

- Program Delivery
- OPD (Office of Program Delivery)
- Office of Bridge Design and Maintenance
- Traffic Operations
- Construction
- District 4 - District Maintenance
- Innovative Delivery
- District 5 – Training
- Equal Employment Opportunity Office
- Program Delivery/Program Control
- State Utilities
- Local Grants
- Procurement
- District 2 Office
- District 3 Office
- Office of Environmental Services
- Office of Performance-based Management and Research
- Design Policy and Support
- Finance
- Human Resources
- TIA office
- Equipment Management

Outside GDOT

- VDOT – Virginia Transportation Research Council- VDOT Research Library
- Caltrans – Enterprise Data and Geospatial Governance Program
- Caltrans – Human Resources/Talent Management Branch
- Caltrans – Division of Research, Innovation and System Information
- PennDOT Bureau of Planning and Research Division

- Texas DOT, Strategic Planning

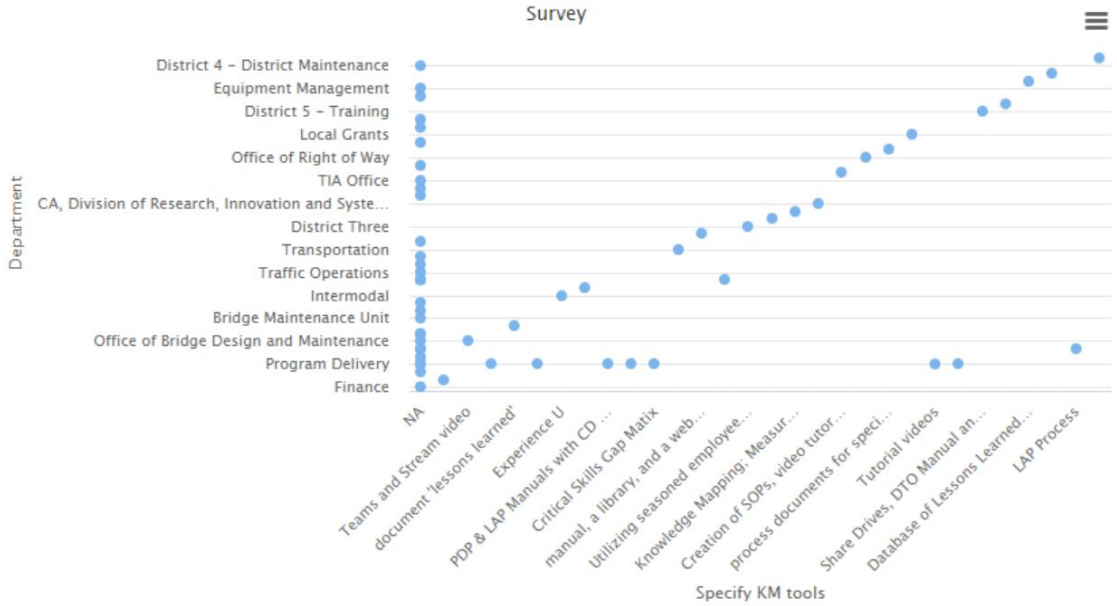

Figure 1. Chart. KM tools used in the GDOT Department

Figure 1 summarizes how the different GDOT departments manage/store/capture knowledge through the specified KM tools as per the survey, the team has created a graph by using mining tools. X axis is "Specify KM tools" and Y axis "Department." It can be seen that many of the responders have responded as "NA" shown as a vertical line in the graph. The linear regression line (diagonal) specifies the KM tools against the GDOT departments.

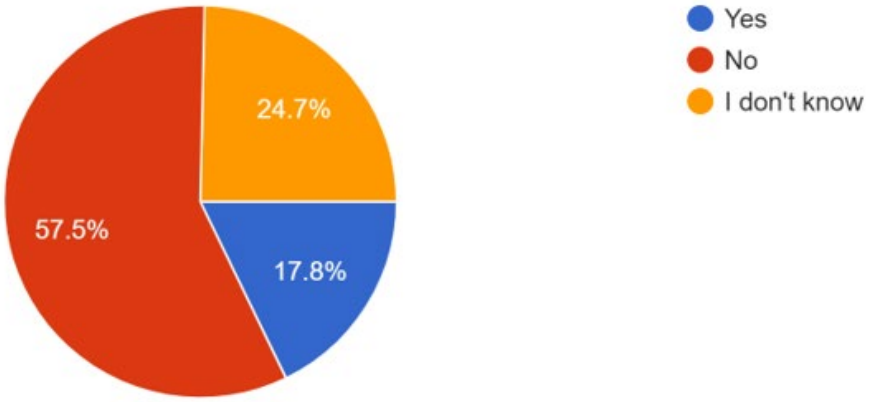

Figure 2. Graph. Percentage of GDOT areas which have dedicated Knowledge Management Person

Figure 2 highlights that a majority (57.5%) of the surveyed individuals reported a lack of dedicated personnel or departments responsible for overseeing the Knowledge Management (KM) program within their organizations. This indicates that a sizable portion of the surveyed organizations currently do not have a designated team focused on managing their knowledge assets.

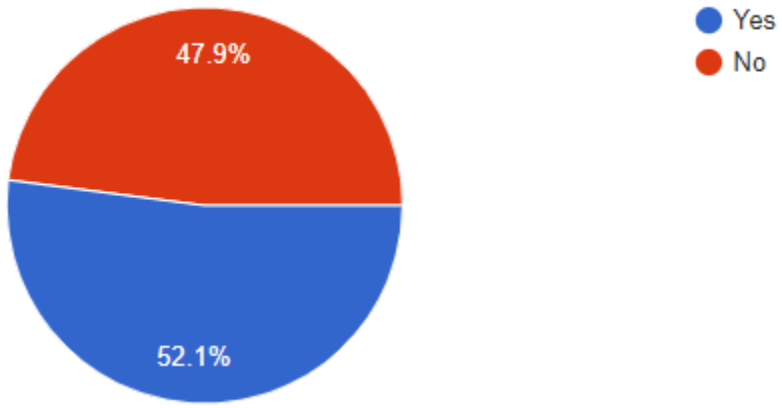

Figure 3. Graph. Percentage of People Within DOT Involved in Informal or Formal KM Program

Figure 3 shows that nearly one out of two people who participate in the survey engage in DOT KM program at varying levels. This means that DOTs are aware of the importance of knowledge management in their workforce.

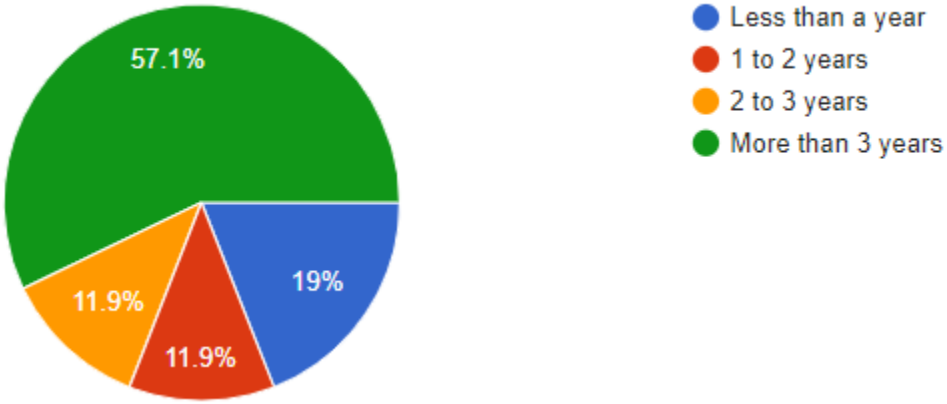

Figure 4. Graph. The Amount of Time DOT People Engage in The Knowledge Management Program

Figure 4 showed that 57.1% of participants have worked on the KM program for more than three years. This means KM programs have proved to be useful and it is worth exploring to discover useful aspects to apply to this research.

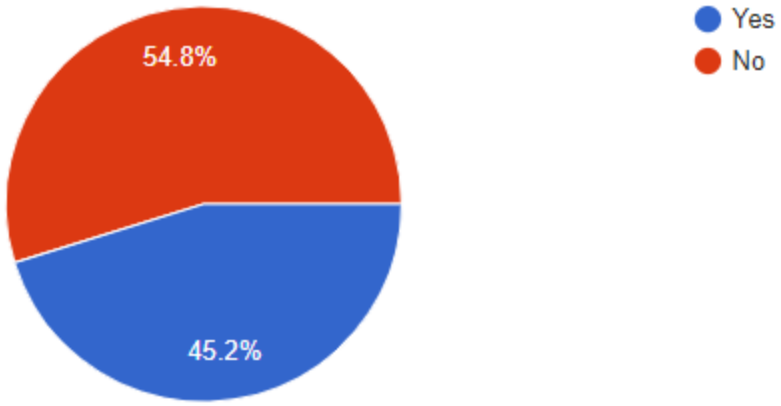

Figure 5. Graph. Percentage of People Who Know KM Tools

Figure 5 indicates more than half of DOTs employees surveyed know about at least one KM tool.

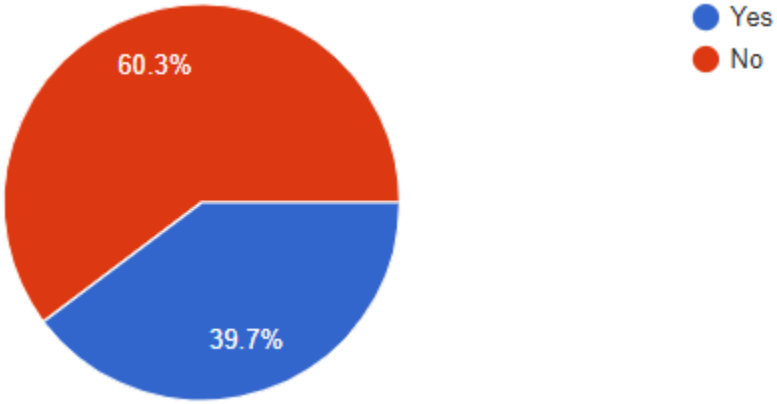

Figure 6. Graph. Percentage of Knowledge Management Implementation Within DOTs

Figure 6 is positively showing that the level of KM implementation within DOTs is at 60.3%

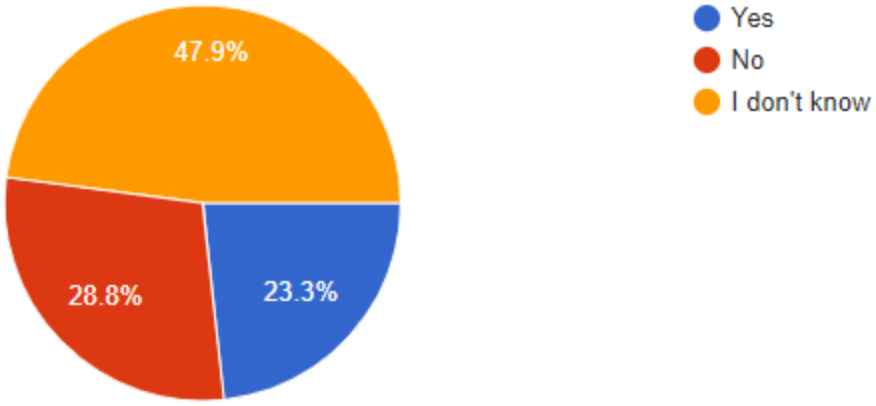

Figure 7. Graph. Percentage of Groups in Charge of The Knowledge Management Program

Figure 7 shows that about half of the surveyed DOT staff does not know which group is in charge of the KM program.

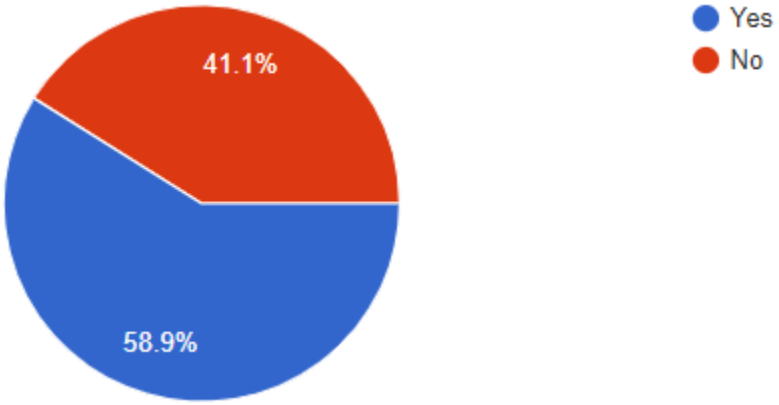

Figure 8. Graph. Percentage of DOT Staff Who Capture Tacit Knowledge

Figure 8 depicts 60% of DOT staff demonstrate understanding of Tacit Knowledge.

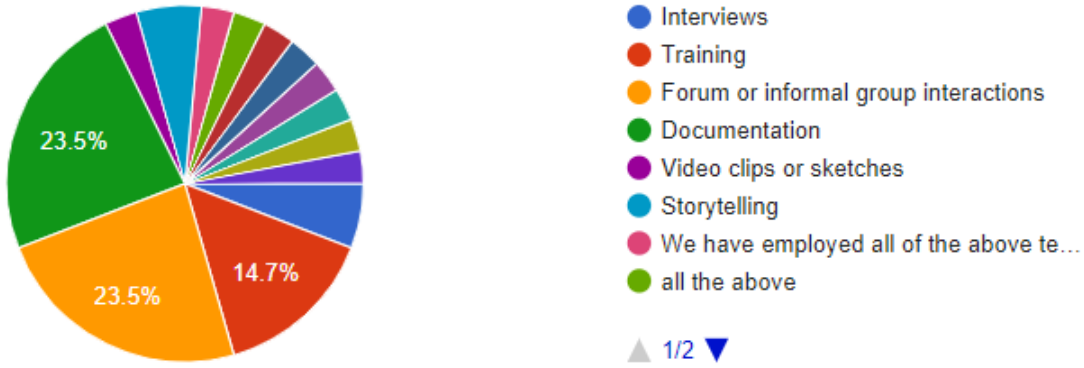

Figure 9. Graph. Best Methods to Capture Tacit Knowledge According to DOT Staff

According to Figure 9, three popular ways to capture Tacit Knowledge within DOTs are: (1) Documentations (2) Forum or informal group interactions and (3) Training. However, it should be noted that documentation is a method to store explicit knowledge (how- to guides, instructions, etc.), not tacit knowledge.

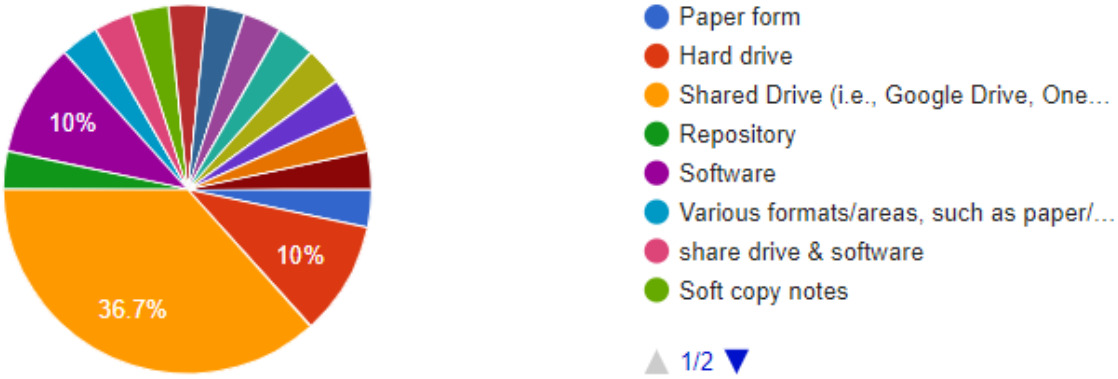

Figure 10. Graph. Tacit Knowledge Repositories

According to Figure 10, a shared drive is among the easiest/most widely used means to store tacit knowledge.

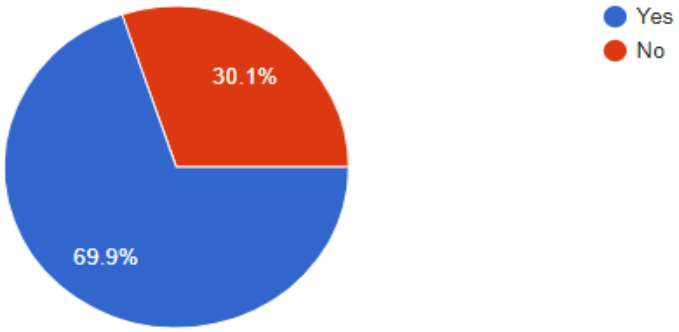

Figure 11. Graph. DOT Staff Know Where to Retrieve Knowledge

Figure 11 shows that most DOT staff know where to find the organizational knowledge (explicit and tacit knowledge) whenever they need.

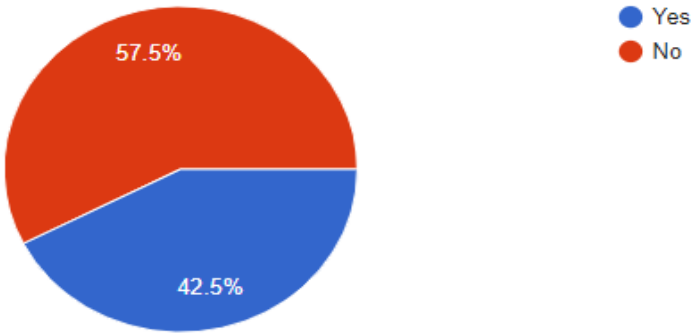

Figure 12. Graph. Familiarity with Community of Practices

Figure 12 is Community of Practice is a commonly known concept for transferring knowledge, tacit knowledge included, for both inside and outside DOTs. This indicates that DOT personnel are familiar with the technique.

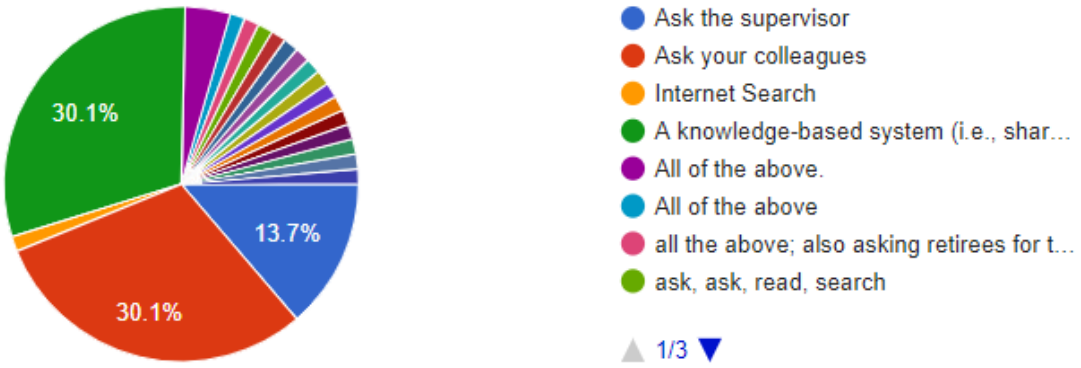

Figure 13. Graph. Approach to Retrieve Stored Knowledge

Figure 13 shows three most common ways to retrieve knowledge within DOT areas are (1) Knowledge Based system (2) Ask colleagues and (3) Ask the supervisor.

Figure 14. Graph. Technological Barriers which stop people from locating Tacit Knowledge

Figure 14 shows Almost 40% of respondents said that due to the information being disorganized, they have a difficult time locating the knowledge.

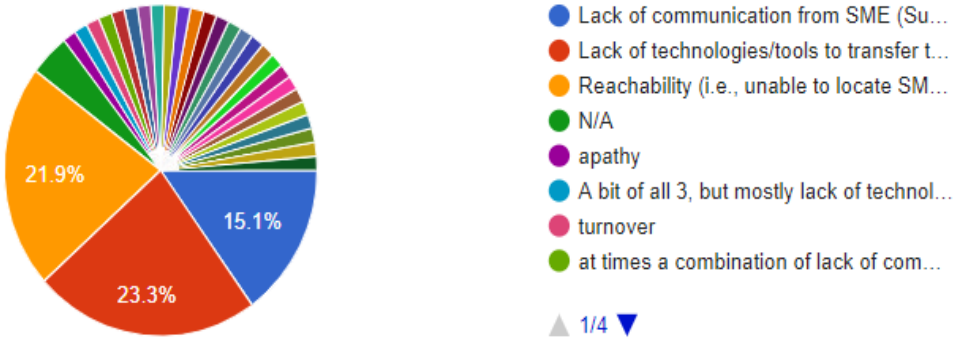

Figure 15. Graph. Human-Related Obstacles That Stop People from Capturing Tacit Knowledge

Figure 15 shows the human-related obstacles such as (1) Reachability (2) Lack of tools and (3) Lack of communication stop the respondents from capturing/retrieving tacit knowledge.

A one-on-one meeting with Texas DOT Knowledge Management Lead, Benjamin Anyacho, provided insight into the Texas DOT Knowledge Café. According to Anyacho, Knowledge Café is a way to transfer Tacit Knowledge among Texas DOT staff. The software/repository from the survey is used as a part of specialized software (ProjectWise, SPOL, Drupal, etc.) and is impractical for a tacit knowledge repository.

Knowledge management within surveyed Texas DOTs does not fall on one single individual. There are DOTs who have recognized the need for a knowledge management program and focused on developing the program. However, when the main person who was in charge of the program leaves the organization, the knowledge management program dies out, for example, VDOT. Moreover, there is a lack of concentration on Tacit Knowledge Management efforts. Most DOTs are not aware of Tacit Knowledge and there is no formal procedure for capturing and transferring the knowledge.

LITERATURE REVIEW ABOUT KNOWLEDGE MANAGEMENT FROM OUTSIDE AND INSIDE DOT

Tacit Knowledge Management

Tacit Knowledge Management (TKM) is described as an "inter-organizational collaborative" process of capturing, storing, and transferring tacit knowledge via social communication and interactions between a group of people [20]. In an organizational context, it means the company recognizes the tacit knowledge, finds ways to extract, implement, and reuse the knowledge, to ensure the competitive advantage of the company [21]. In other words, TKM is the key to collaboration, problem-solving, idea implementation, or policies and procedure execution [22]. One of the common ways to reuse tacit knowledge is converting tacit knowledge into explicit knowledge; however, this method is not ideal due to the significant loss of valuable knowledge during the transfer [23]. The majority of the research focuses on general knowledge management, without emphasis on Tacit Knowledge Management. This project offers an opportunity for both GDOT and academia to discover important Tacit Knowledge Management aspects.

Texas DOT described KM as "an umbrella term for a variety of techniques for building, leveraging and sustaining the know-how and experience of an organization's employees" [25]. Although DOT recognizes and incorporates both tacit and explicit knowledge types, they consider Knowledge Management non-exclusive to tacit management. DOT Knowledge Management consists of Knowledge Capture, Knowledge Transfer, Knowledge Strategic Planning, and Knowledge Implementation, and considers Knowledge Management as the process of maintaining the organization's knowledge during its operation and record its employee and partners' experience to support the company's strategic operation [24].

By adopting KM practice, DOTs hope to (1) decrease the need to "reinvent the wheel" when there are new employees, allowing experienced staff to get the new hires accustomed to the jobs within a shorter timeframe and increase productivity. (2) Reduce the transition friction- as known as loss of knowledge during the transferring process (3) bringing back established knowledge from outsourcing, and public-private partnerships to in-house staff [25].

There are a few techniques to embed KM in DOT operations [25].

- Workforce planning: revisit the differences between the existing skills and required skills and what needs to be done to get the required skills.
- Communities of practice: learning among groups for experts in the field.
- Expertise directories: knowing who to go to for information.
- Experienced employee knowledge capture.
- Project management methodologies: help employees learn and document previous experiences.
- Information management method for effectively retrieving information whenever needed.

The goal for State DOT Knowledge Management [25]

- Improve organizational efficiency and effectiveness.
- Strengthen organizational resilience.
- Strengthen workforce capabilities.
- Leverage external expertise.
- Foster learning and innovation.
- Reduce vulnerability to employee transitions.

The office was established by Dr. Maureen Hammer, director of the Knowledge Management and Technology Transfer Office, and located in Charlottesville, Virginia. She focuses on establishing communities of practice (CoPs). She notices that 80% of the managers are about to retire and the first two CoPs are: Quality Assurance and Right-of-Way. CoPs' decisions can affect procedures, policies, and contracts, which eventually create new knowledge. There are about 20 members in each CoP [26,27].

The department utilized MS SharePoint to initiate discussion posts and encourage knowledge sharing. Once knowledge is recognized, it is categorized and moved to a more permanent site, which is VDOT Lesson Learned and VDOT Lesson Learned Interface is the user

interface of the software. VDOT Lesson Learned aims to encourage a culture of sharing knowledge by construction field staff. Its purpose is to capture lessons from previous experiences that are shared across the agency [26,27].

Figure 16. Screenshot. VDOT Lesson Learned Interface [26,27]

Figure 16 shows the role of the department is to coordinate knowledge management within each CoP. In other words, the department acts as a "KM Hub Central." There are seven members within the knowledge management division who maintain a broad knowledge [26,27].

In addition to the development of the KM Community of Practice, VDOT has undertaken experimentation with various knowledge mapping techniques, employing organization network analysis. The process initiates by requesting district leadership to make informed decisions regarding information sharing and identifying the most critical information using knowledge mapping. This tool aids in identifying areas requiring succession planning and facilitates network-building efforts. Subsequently, meetings are arranged with resident engineers and department representatives to establish priorities and conduct interviews with experts. Organizational network analysis is employed during these interactions, providing a visual representation of communication patterns, leadership dynamics, knowledge transfer, and the roles individuals hold within a network or group. This analysis proves valuable in gathering insightful information about the organization's knowledge flow and communication dynamics. One of the first questions asked is, "If you were to leave tomorrow, what would be essential for your successor to know?" The final product is a map of who is responsible for processing what types of knowledge [17,18].

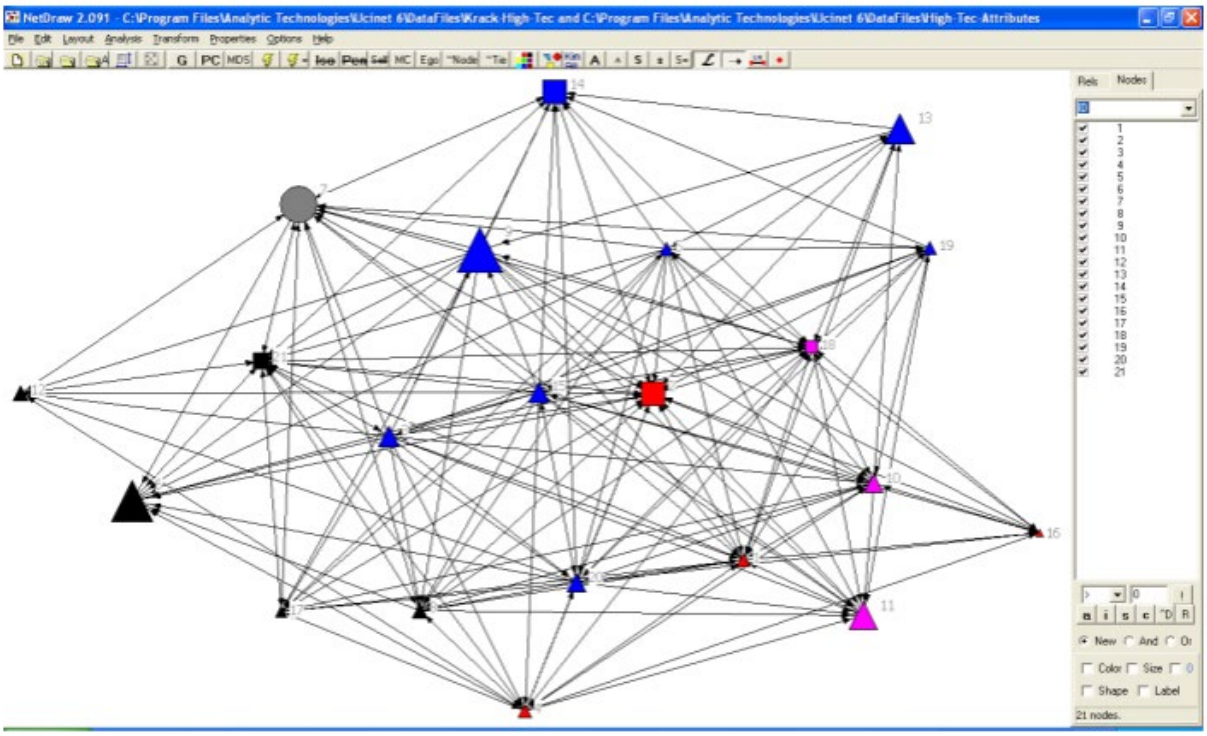

Figure 17. Screenshot. UCINET Software [26,27]

Figure 17 is the interface of UCINet. VDOT uses UCINet, an organizational network analysis (ONA) program, along with a web-based questionnaire developed by the University of Virginia. This tool is used to map knowledge sharing amongst a group of individuals providing managers with visual images of how employees connect and how knowledge is transferred amongst them. UCINet is used in conjunction with Netdraw. By defining the input and output of the system, the software can map out the information flow among different entities, therefore, support Social Network Analysis [26,27].

However, there are a few things Virginia came across when adapting knowledge management in its operation.Within the communities of practice, there should be dedicated experts who take the leadership role in knowledge recognition, knowledge capture, and knowledge sharing. Employees who are about to retire are great candidates for this position [26,27].

Reflection and Summary

According to the literature review, VDOT is aware of the importance of knowledge management (KM) and has a clear vision of their KM goals. However, they have not gone into depth about the differences between explicit knowledge management and tacit knowledge management. It is true that knowledge management requires capturing, transferring, and implementing the knowledge but the methods are different and to be successful in managing either Tacit or Explicit requires different techniques. In recent times, the concept of managing tacit knowledge has gained momentum as numerous organizations are actively working to enhance their knowledge management by integrating tacit knowledge management practices.

Tacit Knowledge Types

From Outside

According to Hao, J. et. al., there are three types of tacit knowledge ranging from weak to strong. Weak knowledge means the knowledge can be easily transferred to explicit knowledge and strong knowledge is almost impossible to be transferred to explicit knowledge [28].

- *Relational Tacit Knowledge* is tacit knowledge transfer among a group of people via communication and relationship, preferably within the "Elite Group." People within this group tend to have a challenging time explaining their understanding of a subject and sometimes do not realize the key knowledge that leads to their success. A common mistake that happens among people who have relational tacit knowledge is called Mismatched Saliences. This means they unconsciously hide knowledge from each other during the sharing process. [28]
- *Somatic Tacit Knowledge* is tacit knowledge that has to do with human bodies (i.e.: learning how to ride a bike, learning how to play tennis) or it is also known as muscle memory. One can observe and try to learn a process, but he/she would be unlikely to succeed right after the first try. Somatic Tacit Knowledge can only be acquired by practice and the level of explicit instructions is inevitably limited. Somatic Tacit Knowledge by imitation is more effective than verbal instructions. [28]
- *Collective Tacit Knowledge* is tacit knowledge within social/community settings. For instance, one has been driving on a rural road but gradually learns how to drive on a busy urban road, he/she will eventually 'get used to it' with little to no explicit instructions.

Collective Tacit Knowledge in companies can be described as "culture" or "organizational behaviors." [28]

Tacit knowledge can further also be divided into two parts such as technical and cognitive. Technical knowledge refers to the ‘know-how’ aspect whereas cognitive tacit knowledge refers to experience, mental state, and observations [42]. Tacit knowledge is important to understand and implement knowledge management in an organization for three reasons:

- Problem-solving techniques
- Problem-finding applications
- Prediction and anticipation of relevant actions

From Inside

According to [9] DOTs have recognized several types of knowledge.

- Descriptive knowledge: addresses the question “what”? – for example: “what projects similar to this have been done over the past five years?"
- Causal knowledge: address the question "why”- for example: “why was this pavement mix type selected?”
- Procedural knowledge: addresses the question “how” – for example: “how to build a bridge efficiently? What are the steps involved?”
- Social knowledge: address the question “who” – for example: “who is the best person to talk to about how to handle a particular customer concern?”
- Explicit knowledge: the knowledge that has not been categorized yet. Documents and procedures are two examples of explicit knowledge.
- Tacit knowledge: knowledge held by SMEs in the form of intuition, know-how, skills, and experiences.

CalTrans has a clear definition of explicit knowledge and implicit knowledge. Explicit knowledge can be acquired through formal training and manuals while tacit knowledge is acquired through rotational programs, multimedia, face-to-face interactions. General TKQ Step offers a better explanation of their advancements in the field of knowledge management [29].

Reflection and Summary

DOTs have a clear distinction between different knowledge types, including tacit knowledge. There are many variations of knowledge such as Descriptive, Causal, Procedural, Social Knowledge, etc. There are some tacit knowledge types explored inside and outside DOT. There is an opportunity to define the different tacit knowledge types for GDOT.

Tacit Knowledge Capture/Transfer

From Outside

The best TK capturing method is done face-to-face [28]. Formal events such as training or conferences or informal events are where tacit knowledge transfer can take place [28]. Within a team, individuals must be ready to share their understanding of the subject matter and how to perform the skills. Another way to acquire tacit knowledge is by combining multiple knowledge assets to achieve TK. TK should be organized and categorized for the ease of distribution and reusability by the members [28].

Another technique used to retrieve tacit knowledge is by using patterns [22]. Behavioral interviews can be used to articulate knowledge. Another way is to simulate the artificial situation or made-up scenarios and ask the employees to apply tacit knowledge. This kind of knowledge can be retrieved and used for evaluation.

The pattern method used for accumulating and transferring tacit knowledge consists of two main concepts:

- The pattern structure is a structure divided into pieces in which the content will be displayed.
- The pattern instance is a piece of knowledge that is categorized down into the parts of the pattern structure. The pattern structure is shown in the below table that can be modified and changed as per the organization's requirement.

Table 2 – Pattern Template [22]

Element	Description
Pattern Name	The name of the pattern.
Problem	An existing problem that needs to be solved.

Context	Description of the situation and things or people involved.
Forces	Interests of key characters.
Solution	Solution found.
Rationale	A statement that explains why the solution is used and how it works.
Resulting Context	The situation arises after applying the solution.

The pattern method described in Table 2 is effective although it does not always provide the quality of knowledge transfer. This patterning method can be more beneficial where the knowledge transfer is more formalized and structured. Therefore, this method is suitable to enable tacit knowledge transfer exchange in virtual project teams. Other methods of extracting tacit knowledge are storytelling, expert interview, analogies, and repertory grid. Expert interviews and repertory grids are widely used tacit knowledge extraction techniques.

Expert Interview: In this process, experts answer a set of questions to articulate tacit knowledge. The expert interview is typically one of three types: unstructured, semi-structured, and structured. The unstructured interview does not have any pre-defined or planned questions and allows the SME to provide what knowledge they have gained over their career in a relaxed manner. The semi-structured interview is a combination of flexible and pre-planned questions where the SME has the freedom to answer the questions, while not specifically adhering to a strict list. This feature provides a guided conversation while allowing both parties to expand on topics as necessary. Structured interviews are strictly based on predefined questions.

Repertory Grid: One of the powerful ways to extract tacit knowledge using a structured interview with the help of analysis tools. This method was previously used to find out the personality traits of different people. With time, this method evolved to extract tacit knowledge

mainly in finance, software, construction, and healthcare. Personal construct theory (PCT) needs to be investigated to fully grasp the repertory grid. PCT works with the constructs (pattern) that are built in the expert's mind based on personal experience.

There are three types of Tacit Transferring:

- *Tacit Knowledge Sharing*: TK are shared among a group and there is no need to convert tacit knowledge into explicit. This can be done via Community of Practices, expert interviews, job shadowing, etc.
- *Tacit Knowledge Quantization*: The Amount of Time DOT People Engage in The Knowledge Management Program explains that organizations can find a group of experts that matches the organizational requirement, converts tacit knowledge into smaller explicit knowledge, and organizes them in a way that is easy to understand. Moreover, machines must be able to import knowledge into the system.

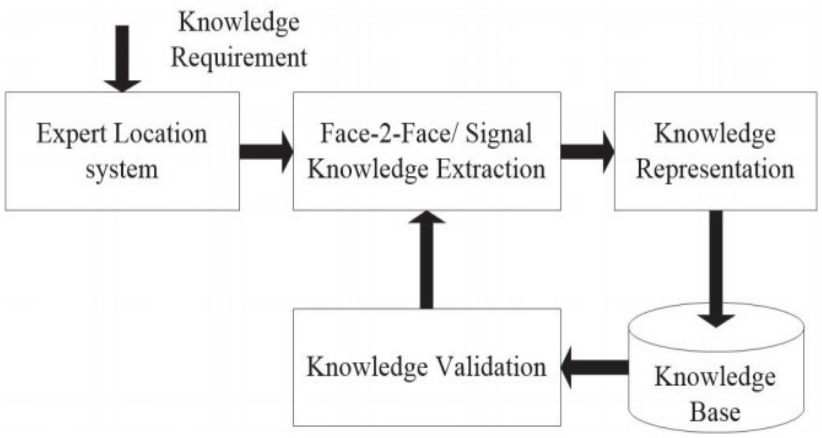

Figure 18. Flowchart. General TKQ Step [28]

Figure 18 represents the flowchart of the general TKQ step where there will be knowledge representation and knowledge base and knowledge validation.

Tacit Knowledge Generation: TK is impossible to update during the interaction with the outside environment. Tacit Knowledge Generation is the highest level of TKM and includes machine-learning and it can automatically learn new knowledge from the model-environment interaction [28].

From Inside

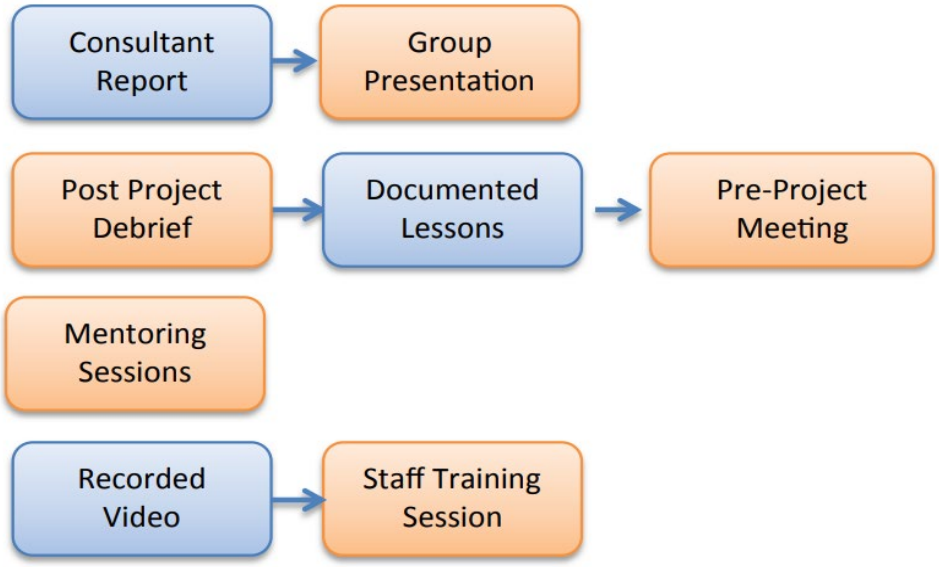

Figure 19. Flowchart. Knowledge capture and learning sequences. [24]

Figure 19 shows knowledge capture and learning techniques in DOTs, which are categorized into two types: (1) recorded information (blue boxes) such as consultant reports, documented lessons, or recorded video, and (2) individual person-to-person interaction (orange boxes) such as group presentation, post-project debriefs, mentoring sessions, or staff training session [24].

- **Knowledge Capture:** Professionals may be interviewed and asked to explain useful lessons and techniques they've learned. These lessons and techniques can be recorded and made available to others [24]. This is called "knowledge capture" which, in turn, results in the transformation into codified data of human intelligence [25].
- **Knowledge Transfer:** An experienced project manager may be asked to mentor or collaborate with others as they approach a mission or project. This enables "knowledge transfer" from person to person [25]

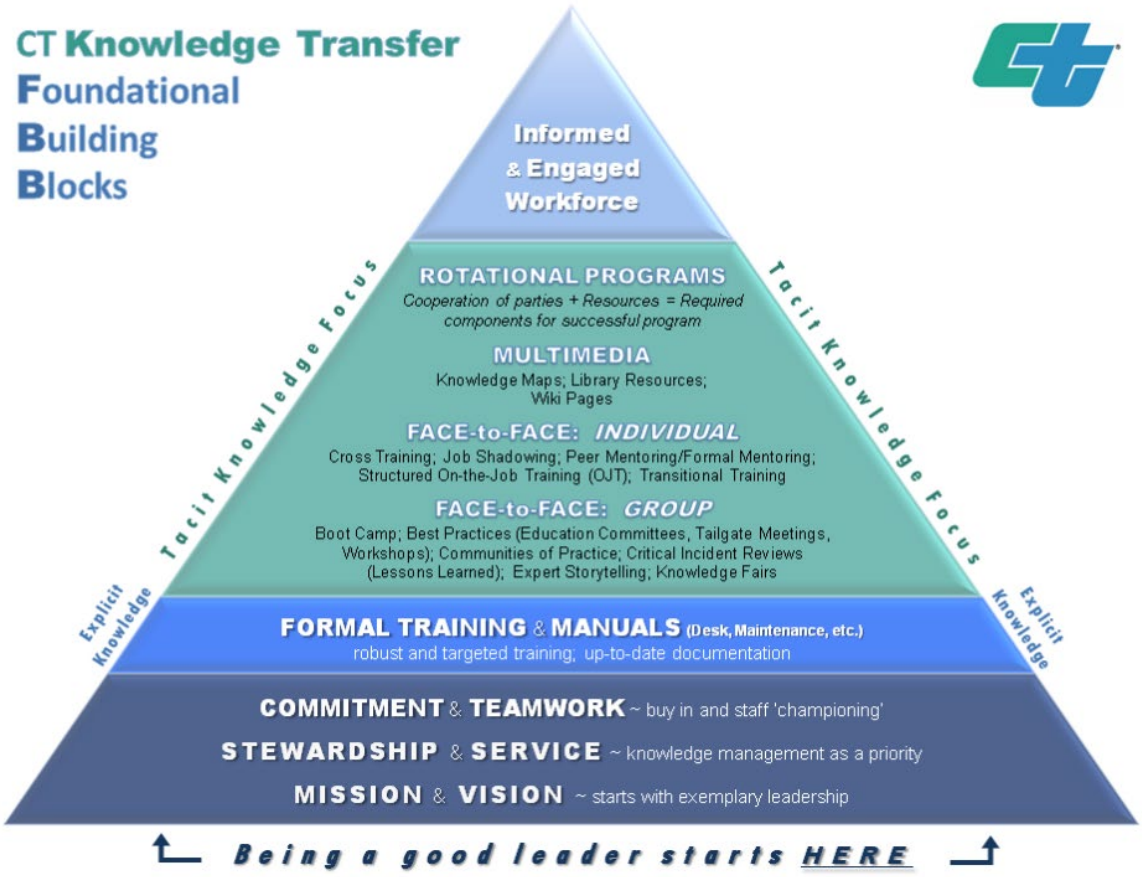

Figure 20. Diagram. CT knowledge Transfer

Figure 20, Caltrans, Tacit Knowledge can be transferred by (1) Rotational Program, (2) Multimedia, (3) Face-to-face: individual, and (4) Face-to-face: group according to Percentage of Knowledge Management Implementation Within DOT. It is clear understanding of Caltrans Knowledge transfer program for an "Informed & Engaged Workforce." Moreover, there is a clear distinction of tacit knowledge vs explicit knowledge and followed by methods to capture/transfer.

Reflection and Summary

Researchers mentioned that the best technique of tacit knowledge capture is performed face-to-face. Whereas DOT stated lessons and strategies may be documented and made accessible to others. The transfer of knowledge seeks to coordinate, produce, capture, or spread knowledge and to ensure that it is accessible to future users. The transfer of knowledge refers to the exchange or distribution of knowledge and the availability of inputs to solve problems.

Caltrans is the leading DOT agency to specifically produce methods for differentiating and transferring tacit knowledge. Several Tacit knowledge capture methods were identified such as patterns, storytelling, repertory grid, and sketches. Along with this, Tacit knowledge sharing, quantization, and generalization are also three main types of knowledge transfer identified.

Tacit Knowledge Sharing (TKS)

From Outside

TKS includes tacit knowledge transfer, tacit knowledge diffusion, and tacit knowledge exchange. It demonstrates how tacit knowledge is transferred within or between organizations and it is important to turn tacit knowledge into explicit knowledge [30].

Influencing Factors of TKS

Organizations should have sufficient TKS productive conditions and resources. TKS can result in positive or negative aspects. For example, confidence, community, well-being, social ties, etc. [30]. The influencing factors have key problems. The factors are at various levels and overlap with one another, so that "community" requires some degree of "trust." [30].

TKS is a way to understand and analyze the sharing process. There are two research streams of the TKS. First, a theoretical model should be developed to analyze the TKS mechanism. Secondly, a framework should be developed to incorporate TKS support tools [28,31].

Trust and communication are necessary to build relationships among coworkers to exchange knowledge face-to-face or through social networks. Information and communication technology (ICT) such as extranets, intranets, email, databases, and conferences play a big role in providing access to channels where community members share their knowledge and experience [20]. Online discussion forums, wikis, and blogs are effective tools for transferring tacit knowledge. The following methods and practices can be used to achieve the goal.

- Employee engagement and management meetings
- Different types of knowledge transfer sessions, mentoring, and coaching
- report of the past failure and root cause analysis
- Developing the knowledge databases
- Job rotation in various workstations

- Regular meetings of different department team members and assigning a scenario to work on
- Analysis of the reports prepared by the contractors and the people involved

From Inside

DOT identifies that the requirements for sharing knowledge are trust and respect between individuals. Personal interactions and relationships take time and should be carefully managed [31]. DOT recommends showing appreciation when their employees perform an exchange of knowledge. Moreover, GDOT considers the inclusion of information-sharing skills in the employee's annual performance assessment [31]. The Community of Practice is similar to Collective Tacit Knowledge in the sense that knowledge is learned in a social/community setting. CoPs are used to promote knowledge sharing and learning among DOT staff. CoPs' programs gather employees from the same geographical business function together to learn how to solve issues and how to collaborate. This program involves top managers to create an environment where employees are comfortable in sharing knowledge [31]. The program has been implemented at VDOT, FTA, Alberta Transportation, and especially GDOT. Specifically, in the GDOT projects such as roundabouts, GISs, and environmental issues, there are two CoPs assigned and they would meet monthly and identify common problems and summarize lessons learned [31].

Reflection and Summary

Researchers and GDOT have the same view on tacit knowledge sharing. Knowledge sharing is an activity in which knowledge (namely, data, skills, or expertise) is shared by individuals, friends, peers, families, networks, or within or between organizations. Rewards encourage knowledge sharing and it should be incorporated in the performance assessment. CoP is one important factor that can be utilized for knowledge sharing in GDOT. All the methods for knowledge sharing are required and implemented into the TKM to have a strong knowledge sharing experience in GDOT.

How to Reuse Tacit Knowledge

From Outside

TK should be converted to a machine-readable format. It can be either symbol-based (ontology) or can be a number-based representation. Moreover, tacit knowledge visualization offers descriptive details and can assist in the decision-making process and reusing of knowledge [32]. TK reasoning and computation synchronize the explicit and tacit knowledge to create a decision support system [32]. The problem with TK reasoning and computation is the conversion of tacit knowledge into a language that computer software understands (e.g., production rule, Boolean logic, general TK steps, and ontology framework). One possible approach to implement ontology into GDOT project is breaking down components of GDOT contractors, experienced workers, and subject matter experts into unitsand storing them.

How to Implement

The text emphasizes the importance of socialization, the knowledge transfer process through direct experiences, communications, reflection, and interactions. Although there are still some imperfections, TK is implemented in Robotic Arms to perform non-invasive surgeries. Research on TK Robotic Strategies Approach confirmed that using robotic grinding and polishing would increase the speed by 20%. TKM has been implemented across Manufacturing, Healthcare, and Operation industries. [32]

From Inside

DOT defines reusing knowledge as leveraging, adapting, and reusing analytics already developed, shared by others, and benefiting from the help of a much wider group of specialists outside transportation culture inside or outside the department [25]. The recipient can reuse exported data by using the spreadsheet, then processing it and creating a database for analyzing potential results to refine statistical software with information for new items [25]. PennDOT Knowledge Management system offers a way to effectively retrieve the information and reuse it [27]. The effectiveness of a KM program can be gauged by the extent of knowledge reuse within an organization [43]. Note that knowledge reuse is “looking at significant events and how they were handled and making this information available for future use.” Reusing knowledge captured is a must due to recent year budget cuts to state DOTs, which requires the jobs traditionally performed by in-house DOTs staff to be performed by contractors. It is not wise to hire the same contractors to perform similar jobs, therefore, it is necessary for developing the consultant's captured knowledge to be reused by in-house staff [24].

Reflection and Summary

According to the literature review, sources outside GDOT use sorted spreadsheets that link to databases for analysis or create statistical software with information for new objects so recipients may reuse the exported data. However, inside GDOT, TK needs to be translated into a machine-readable format. It can be either symbol-based (ontology) or a number-based representation. Knowledge Models are not efficient if they only track and hold knowledge. The act of reusing the knowledge gained is where the benefit of TKM systems come from.

Tacit Knowledge Model

From Outside

A knowledge model is only as good as the system it is contained in. The knowledge model is a formatted collection of storyboards, interviews, and documents that integrates the many knowledge types into a human-readable or machine-readable model. There are different tools to design a knowledge model, for example, IDEF0, UML, DMN, ontologies [44,45]. Task 2 investigates knowledge model definitions according to the information system standards. This research describes the Tacit Knowledge Model on how the tacit knowledge can be captured and reused for company value [33].

There are several ways to create Tacit Knowledge Model:

- Research shows that the Automated Knowledge Acquisition framework can be used for TKMs in service departments for manufacturing companies consist of:
  - ⇨ Input layer gaining from day-to-day activities.
  - ⇨ Knowledge Identification: providing context about which type of activities support which business function.
  - ⇨ Knowledge Acquisition: uploading voice recordings from employee interviews.
  - ⇨ Knowledge Transformation: transforming spoken word into a text format that can be read by everyone.
  - ⇨ Knowledge Comparison: using Euclidean distance to compare the knowledge captured to the standard procedure.
  - ⇨ Knowledge Validation: examine the validity and credibility of the knowledge.
  - ⇨ The framework coordinates the use of “Structured domain text (ontology), The ontology concept with the use of the Web Ontology Language and the Natural Language Processing”.

- Another technique that can be used is socio-technique. It evaluates the effectiveness of KM activities (knowledge sharing, knowledge transfer, knowledge integration, and collaboration) in social settings [33]. It can be used for KM to design and utilize computer software and enhance process automation and document management systems. This technique uses Knowledge Process Tools, which are backed by IT and they make sure that the process is followed by principle and the tools are capable of creating, collecting, sharing, and transferring knowledge to the organization [33].
- Knowledge Transfer Effectiveness Model consists of Knowledge characteristics, sources characteristics, recipient characteristics, transfer mechanism to ensure the effectiveness of tacit knowledge transfer. [33].
- Agent-based modeling and simulation approach: consist of output and input, agent, attribute, behavior, and determination (employees, or KM source), Model simulation, provide parameter (parameterization), the use of software (either to measure the result or decide what is the best output) and last is validation to see the simulation represent the actual state of the situation [33].

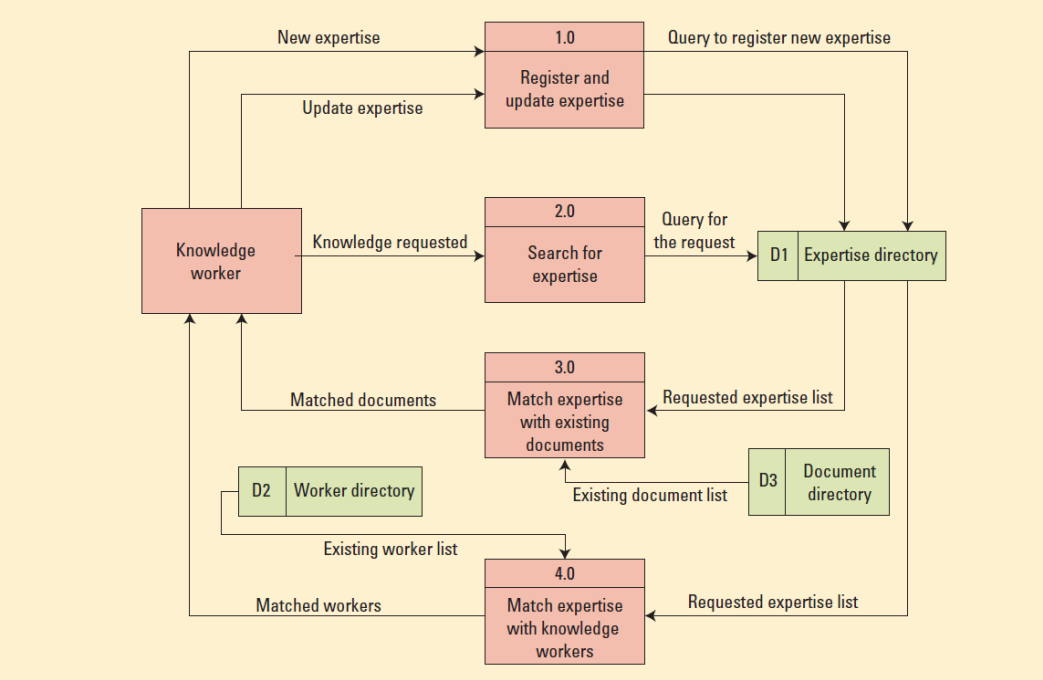

Figure 21. Flowchart. Dataflow diagram of a knowledge management system [39]

Figure 21 represents the dataflow diagram of the knowledge management system where it represents the new expertise and updating the expertise with the match expertise of the knowledge workers.

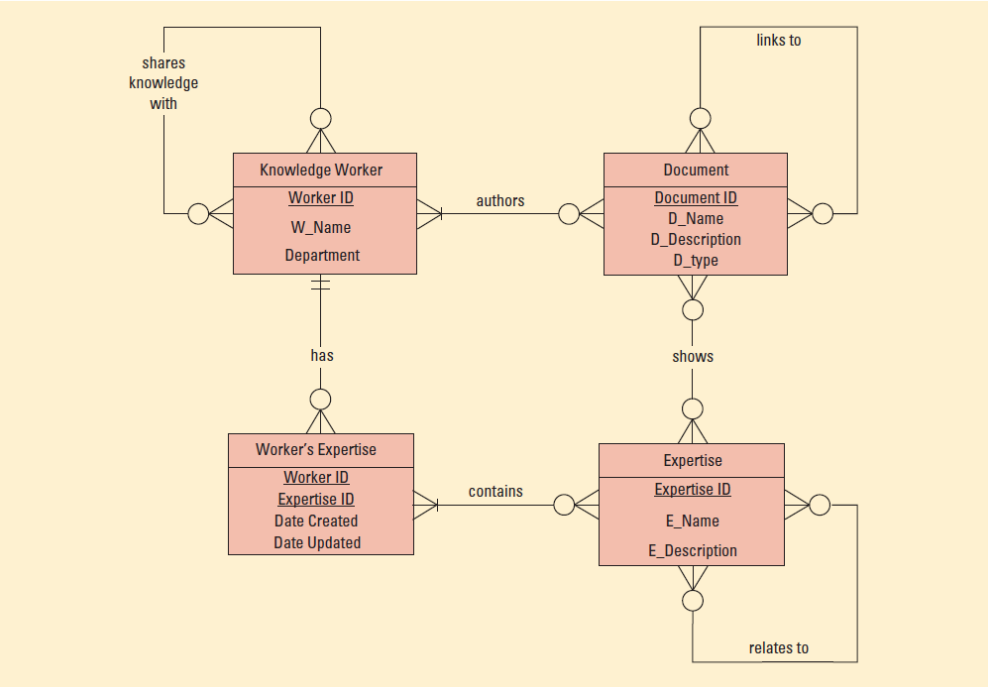

Figure 22. Flowchart. The relational data model of the knowledge management system [39]

Figure 22 shows the relational data model where four entities have been created. The Expertise entity stores a list of expertise keywords and descriptions. The Knowledge Worker entities store information about knowledge workers. The Document entity stores the features of each document. The Worker's Expertise entity matches up a worker with their expertise keywords, which can be included and modified.

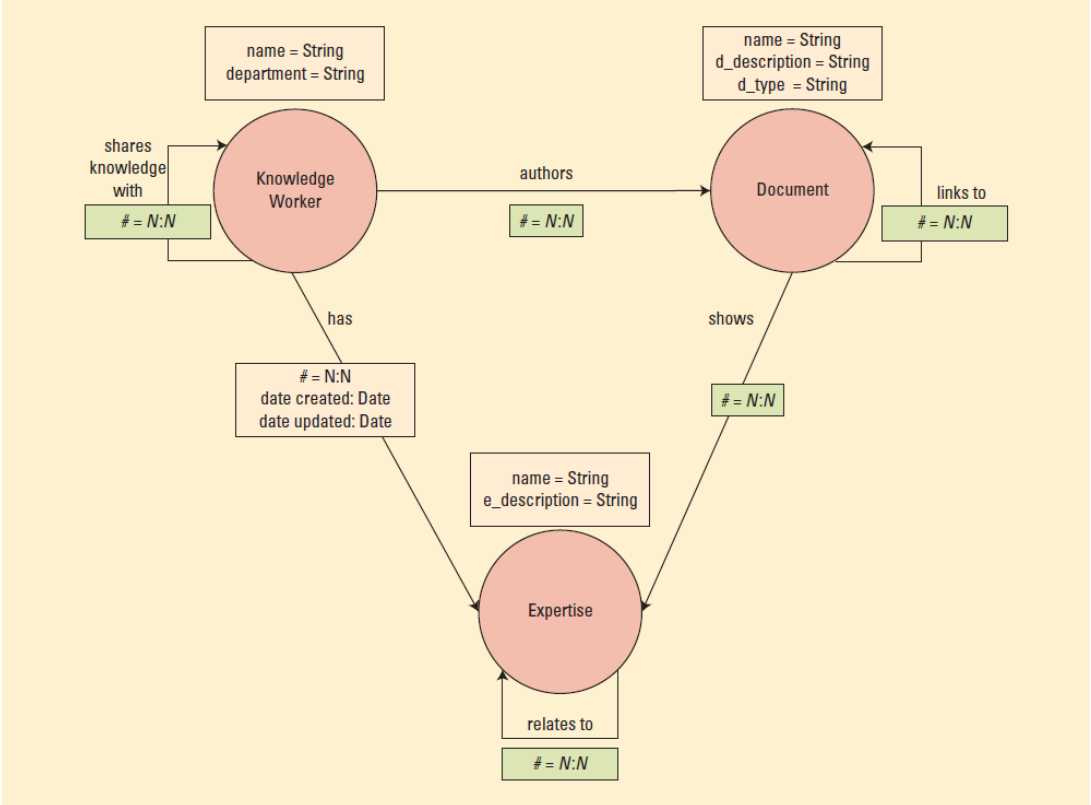

Figure 23. Flowchart. The property graph data model of the KMS [23]

Figure 23 is about the property graph data model of the KMS which is a relational data model can be easily transformed into a property graph data model. An example of which is displayed in Tacit Knowledge Repositories [39]. This is because a many-to-many relationship can be implemented, and it does not require a separate model.

From Inside

Spy Pond Partners LLC [25] presents a four-step method to create an effective "Tacit Knowledge Management" program for use by DOT.

a. Assess Risks and Opportunities
    i. **Senior Leadership Workshops:** senior engineers get together and decide which knowledge is at risk and come up with a plan to preserve them.
    ii. **In-depth knowledge survey**: (1) learn how employees familiarize themselves/ where they can find information to support their business needs. Where an employee can go to for information (2) current means of

knowledge sharing (3) finding the differences in knowledge which already been captured vs knowledge required to perform the tasks

iii. **Knowledge Risk Assessment:** a scoring system to prioritize from high priority knowledge capture to low priority knowledge capture.

b. Develop a KM Strategy
   i. Implement in Agency Strategic Plans
   ii. Define clear goals
   iii. Include strategies such as KM Leadership and Direction, Social Learning & Community, Knowledge Codification & Dissemination, Succession and Talent Management to target People, Process, and Information Management/Technology.

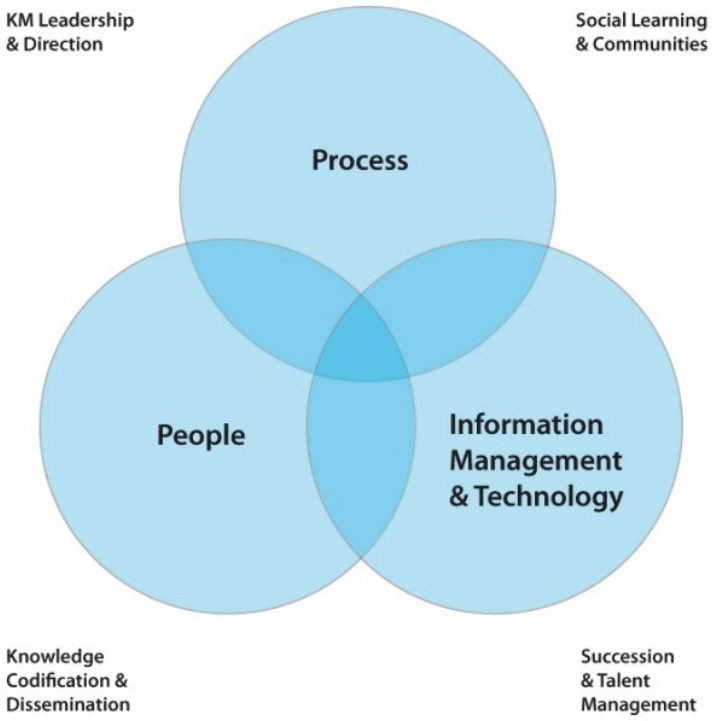

Figure 24. Diagram. KM Strategies [25]

Figure 24 shows the required collaboration among "Process, People, and Information Management & Technology" to create a successful KM program.

iv. Develop KM LEAD

c. Create a KM Implementation Plan

i. KM Techniques

1. KM Leadership & Direction
2. Social Learning & Communities
3. Knowledge Codification & Dissemination
4. Succession & Talent Management

ii. Defining Roles and Responsibilities for KM Implementation

AGENCY-WIDE KM ELEMENTS	KM LEAD	HUMAN RESOURCES	IT	RESEARCH/ LIBRARY	DIVISION/ OFFICE MANAGER
KM LEADERSHIP & DIRECTION					
Strategic Planning and Policy Development	●	○	○	○	○
KM Education/Training	●	○			
Knowledge Assessment	●				○
Knowledge Mapping/ Social Network Analysis	●		○	○	
KM Metrics	●			○	
SOCIAL LEARNING & COMMUNITIES					
Communities of Practice	○		○		●
Peer Reviews	○				●
After Action Reviews	○				●
Social Networking and Collaboration Platforms	○		●		
Expertise Locator/ Smart Org Charts	○	●	○		
Recognition & Rewards for Collaboration	○	○			●
KNOWLEDGE CODIFICATION & DISSEMINATION					
Lessons Learned Repository	●			○	○
Organizational Narratives/ Storytelling	●				○
Knowledge Books/ Continuity Books	○				●
Business Process Documentation/Automation	○		○		●
Contractor Knowledge Transfer	○				●
Content Management/ Portals/Wikis	○		●		○
Common Vocabulary/ Content Classification	○			●	○
Personalization/ Role-Based Subscriptions	○		●		
SUCCESSION & TALENT MANAGEMENT					
Talent Tracking	○	●			
Desk-Side Reviews	○				●
Mentoring, Shadowing and Job Rotation	○	●			○
Phased Retirements	○	●			○
Leadership Training	○	●			○

Figure 25. Diagram. KM Program in WisDOTPlan [25]

Figure 25 is created by WisDOT, and it shows how to capture/implement Knowledge management aspects within the agency.

d. Monitor Results (4 metrics to consider when measuring KM efforts: Costs, outputs, exposure/use, and outcomes)

i. Approaches to Measurement

1. Cost: time and money spent to support KM activities
2. Outputs: can be policies, training as the result of KM implementation
3. Exposure/Use: tracking employees' involvement in KM activities by using sign-in sheets or automated methods built into systems.
4. Outcome: can be tangible or intangible. Achieved by employee interview, survey, or estimate cost savings for the organization.

ii. How to measure KM results. Define KM Outputs, Exposure/Use, Impacts/Outcome for each Agency-Wide KM Element. See the US Navy: "Metrics Guide to Knowledge Management Initiatives" for an example of how to measure KM results.

AGENCY-WIDE KM ELEMENTS	KM OUTPUTS	EXPOSURE/USE	IMPACTS/OUTCOMES
KM LEADERSHIP & DIRECTION			
Strategic Planning and Policy Development KM Education/Training Knowledge Assessment Knowledge Mapping/Social Network Analysis KM Metrics	• Completion of KM strategy • Completion of KM implementation milestones	• Number and percent of individuals participating in KM planning & implementation	• Awareness of KM strategies and resources
SOCIAL LEARNING & COMMUNITIES			
Communities of Practice (CoPs) Peer Reviews After Action Reviews (AARs) Social Networking and Collaboration Platforms Expertise Locator/Smart Org Charts Recognition & Rewards for Collaboration	• Number of CoPs coordinated • Number of briefings conducted on AARs • Modifications to recognition programs	• Number of posts on collaboration site • Number of participants in CoPs • Number of AARs completed	• Employee satisfaction • Employee retention • Reported benefits from collaboration (stories)

Figure 26. Diagram. KM Implementation Plan Results [25]

Figure 26 shows how state DOTs can measure the effectiveness of KM programs.

iii. KM Outcomes (Expertise Locator System, After-Action Reviews,

Lesson Learned Repository, Collaboration Platforms, Organizational Narratives/ Continuity Books/ Knowledge Books, Communities of Practice.

Reflection and Summary

According to the literature review, organizations outside GDOT have a clear understanding of the tacit knowledge life cycle that is used to create a Tacit Knowledge Model, whereas GDOT has a preliminary model, which can become the foundation for the Tacit Knowledge Model. However, GDOT should choose between knowledge types to come up with a knowledge model specifically for each type. Currently. Organizations outside DOT have a stronger approach to develop a Tacit Knowledge Model. This research presents a combination of both methodologies to provide the best TKM for the task.

Tacit Knowledge Management Framework

A knowledge framework is a pictorial or graphical representation of ideas to express some thoughts. Frameworks are useful to explain some concept ideas or projects. The framework shows the overall program, from top to bottom and several models can be created from a framework [44]. There are different types of frameworks. For example, at Enterprise Engineering Integration there are different frameworks based on PERA, CIMOSA, and Zachman architectures. Delphi is a good framework example [44].

From Outside

There are several methods used to articulate Tacit Knowledge Management, such as Stakeholder collaboration, Artificial Intelligence (SACM-Self Associated Concept Mapping), and the Delphi method [33].

- **Stakeholder Collaboration** creates an environment where stakeholders can comfortably share knowledge or ask their peers to create user stories and convert user stories into scenarios. In the end, all user stories are converted to use cases and distributed to the community [35].

- **Artificial Intelligence (SACM-Self Associated Concept Mapping)** can utilize process automation and gamification ("applying game mechanics in a non-game environment like marketing, training, health, and social change). This framework can discover, understand, articulate, and update knowledge. Gamification rewards users with clear and short-term rewards, these rewards are designed to motivate and engage users by providing them with positive reinforcement for their actions and progress. Therefore, users are encouraged to achieve goals. As a result, using Artificial Intelligence assists in increasing feedback loops [35].
- **Delphi Method** consults a group of experts and repeatedly asks them questions to find the knowledge that needs capturing. This framework eliminates the negative group effects such as pressure in confrontation and group members becoming dominant by keeping the identity of participants anonymous. The desired result from this method is to extract rich data and valuable ideas. This method includes four steps: selecting applicants, collecting data, analyzing data, and assessing the quality of the research [36].
- **The Community of Practice** is a collective of individuals who actively engage in knowledge creation and sharing through discussions centered around real-life scenarios. Comprising experts with similar backgrounds or areas of expertise, a CoP serves as a valuable platform for individuals seeking solutions to their specific challenges and problems [37].
- **The Intranet and Extranets** is a system that allows people to collaborate and share their knowledge regarding processes, projects, and future improvements. Although Tacit Knowledge is not always clearly communicated, person-to-person and person-to-organizations interaction can maximize results [38].

From Inside

The referenced report mentioned a framework developed to capture essential consultant-developed knowledge within DOTs [24].

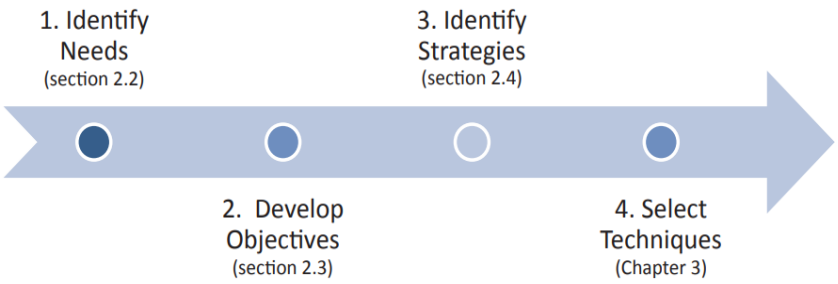

Figure 27. Flowchart. Process for planning consultant knowledge transfer activities [24]

Figure 27 includes these following steps:

- **Identify Needs:** the need for knowledge capture and learning is varied and follows a case-by-case basis. It can be to mitigate the risks or expose in-house staff to new techniques and future practices.
- **Develop Objectives:** (1) Remembering what was done and why, (2) Improving future practice based on experience, and (3) Developing seasoned program managers and project engineers.
- **Identify Strategies:** based on the three objectives, three strategies match each other. For example, if the objective is "Improving Future Practice Based on Experience", according to Table 2, the best corresponding strategies will be "Identifying and Learning Lessons".

Purpose/Need for Knowledge Capture and Learning	Strategies		
	Documentation and Handoff Processes	Identifying and Learning Lessons	Mentoring and Interaction
Remembering What Was Done and Why			
Improving Future Practice Based on Experience			
Developing Seasoned Program Managers and Project Engineers			

Figure 28. Diagram. Matching Needs to Strategies

Figure 28 represents the need of the knowledge capture and learning and the strategies are mentioned like documentation, identifying and mentoring with interaction.

- **Select Techniques**: Three common techniques are: (1) documentation and handoffs (2) capturing and learning lessons (3) mentoring and interaction. The frameworks are mentioned in Bloom's Taxonomy [24].

Bloom's Taxonomy is the framework layed out in a table. Each column represents the cognitive processes and the rows represent the type of knowledge. The knowledge types in this framework are "factual (terminologies and of specific details that are needed to understand a topic, event, or situation)" [24]; conceptual (understanding of how to do something understanding of techniques, procedures, (how-to, instructions); and meta-cognitive "(knowledge about cognition itself-knowing what is known; knowing how to teach others; understanding what level of thinking is required for different tasks" [24].

The cognitive process comprises the following "remembering (recalling relevant knowledge from long-term memory), understanding (Constructing meaning from inputs (written, auditory, visual) through interpretation, classification, inference, comparison, or summarization) applying (executing or implementing a procedure) analyzing (breaking a body of information down; understanding how the parts relate to the whole, understanding structure, and interrelationships) evaluating (making judgments based on criteria and standards) and creating (developing or producing something new by reorganizing known elements into a new pattern or structure)" [24]. Tables 3, 4, and 5 are a graphical representation of Bloom's Taxonomy modified to serve KM within GDOT.

Table 3. Learning objectives: remembering what was done and why.

	Remembering	Understanding	Applying	Analyzing	Evaluating	Creating
Factual						
Conceptual						
Procedural						
Meta-Cognitive						

Table 4. Learning objectives: improving future practice based on experience.

	Remembering	Understanding	Applying	Analyzing	Evaluating	Creating
Factual						
Conceptual						
Procedural						
Meta-Cognitive						

Table 5. Learning objectives: developing seasoned program managers and project engineers.

	Remembering	Understanding	Applying	Analyzing	Evaluating	Creating
Factual						
Conceptual						
Procedural						
Meta-Cognitive						

[24]

Tables 3, 4, and 5 show the corresponding knowledge types to be applied and the cognitive processes involved in each objective**.** The columns are the cognitive processes, and the rows are the types of knowledge. Depending on the learning objective, the organization will match the cognitive processes with the knowledge type accordingly.

GDOT identified three main objectives for Tacit Management Framework;

- Learning objective 1: Remembering what was done and why [24]
- Learning objective 2: Improving future practice based on experience [24]
- Learning objective 3: Developing seasoned program managers and project engineers [24]

Halikowski, J. S., et al. mentioned KM Maturity Ladder. It is said that the more mature the KM programs get, the more embedded in the organization they become. The main KM technique that the report mentioned is Community of Practice (CoP) [43].

Table 6. Diagram. FAA CoP Maturity Continuum [43]

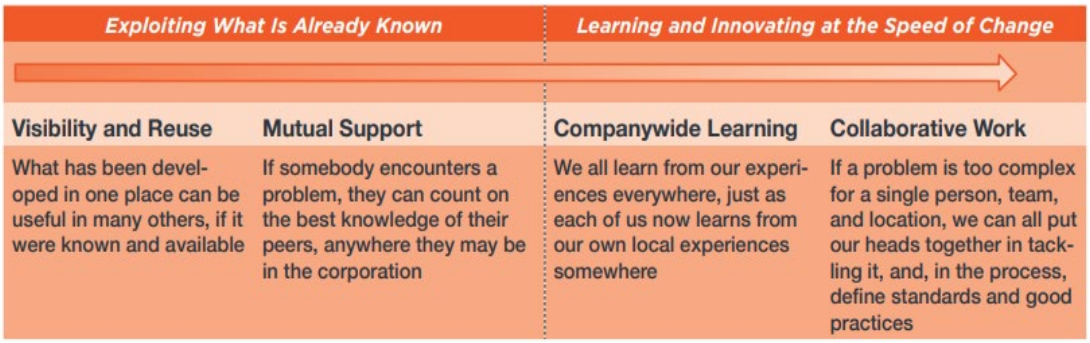

Table 6 displays diverse levels of maturity within CoP programs. This framework encompasses two primary objectives. Firstly, the goal of "Exploiting What Is Already Known" is characterized by visibility and resource utilization. Secondly, the objective of "Learning and Innovating at the Speed of Change" is associated with Companywide Learning and Collaborative Work practices. The articulation of these goals and their corresponding methodologies holds significant importance in the context of crafting a dedicated Tacit Knowledge Model/Framework tailored to the specifics of GDOT. Notably, this technique has found implementation in various transportation entities including GDOT, WisDOT, KDOT, and Alberta Transportation [25].

WisDOT created a KM Tools Matrix as an example of how the KM initiative is implemented. The goal is to create networks that help the employee to learn, develop, and assist in sharing information.

Table 7. WisDOT KM Tools Matrix

Topic and tasks	Brief description	Might be good for	Resources
Documenting process			
Writing down processes	Incumbent writes down steps in key tasks	Stable, routine tasks; quick reference	Low
Videotaping processes	Incumbent is videotaped performing key tasks	Quick capture, including context	Low
Formalizing process			
Formalizing process	Manually require steps be completed in certain way	More complex tasks	Low
Automating process	Automation requires steps be completed in certain way	Highly complex tasks with many players	Med
Expert decision system	Incorporates expert judgment; provides decision	Complex decisions that can be modeled	High
Experiencing together			
Double-filling key positions	New employee and retiring employee work together	Critical positions with sole complex knowledge	Low
Cross-training	Train employees to do a range of overlapping work	Positions with sole knowledge	Med
Communities of practice	Employees with similar work regularly communicate	Positions scattered throughout agency	Med
Sharing experience			
Exit interviews	HR or supervisor asks questions of departing employee	All departing employees	Med
Expert interviews	Interviewer asks questions of knowledgeable employee	Employees with extensive specific knowledge	Med
Last lectures	Departing employee gives open-ended talk	Departing employees with extensive tacit knowledge	Med
Storytelling	Current employees share stories of challenges faced	Current employees with extensive tacit knowledge	High
Developing leaders			
Rotation program	Selected employees work in one or more new areas	Employees showing leadership promise	High
Leadership program	Selected employees receive agency exposure	Employees showing leadership promise	High

Table 7 shows the knowledge management tasks and their descriptions for implementation in transportation departments. Specifically, last lectures and storytelling are two methods being used to capture tacit knowledge according to WisDOT.

Reflection and Summary

Research materials mention several frameworks which can be used across industries while the GDOT method emphasizes the framework to achieve learning objectives and is only applicable to the transportation industry. However, the two frameworks both include key steps aimed at enhancing organizational knowledge and enabling success at a business level, as well as increasing employee efficiency and a deeper understanding of the market, clients, suppliers, products, and services. Bloom's taxonomy and FAA CoPs Maturity Continuum proves to be a baseline for developing Tacit Knowledge Framework for GDOT project.

Knowledge Management Life Cycle

From Outside

Knowledge should be continuously re-evaluated and updated over some time to maintain the integrity, value, and credibility of Tacit Knowledge [31].

VDOT Lesson Learned Interface shows a Tacit Knowledge Management Life Cycle that includes several phases such as:

- **Identify/Create:** identifying or creating knowledge is initiated in response to a knowledge request, following the elimination of analogous pre-existing knowledge. Organizations can facilitate the identification or creation of novel knowledge through various means, including expert interviews, prototyping, information and workflow analysis, competency assessments, and process mapping. These activities can be effectively orchestrated using management software to streamline the process and enhance knowledge development [40].
- **Store:** using knowledge audits, maps, models, and taxonomies for efficient knowledge preservation. The stored knowledge requires meticulous organization and categorization to ensure its accessibility and ease of reuse [40].
- **Share:** the distribution of knowledge both inside and outside the organization. This can be done by coaching, mentoring, apprenticeship programs, storytelling, narratives, and anecdotes [41].

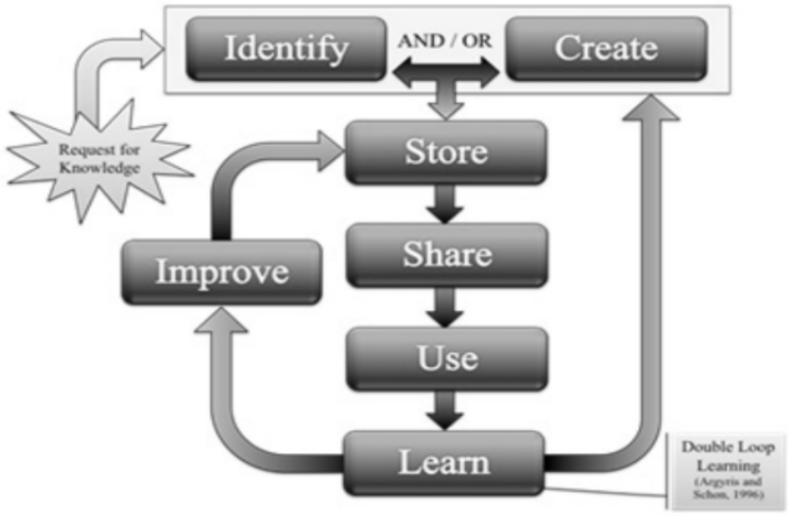

Figure 29. Chart. Knowledge Management Life Cycle [37]

Figure 29 shows the use, learn and improve concepts of the knowledge management life cycle.

- **Use:** integrating Tacit Knowledge into company projects to yield positive outcomes. Nonetheless, owing to the intricate nature of tacit knowledge, it's essential to acknowledge that not all facets of it may be documented or effectively put into practical use.
- **Learn:** studying previous TKM endeavors, leading to the generation of novel knowledge and process enhancements. Through this, employees accumulate valuable experience and insights.
- **Improve:** updating existing TKMs and keep them current for reusing purposes in the future [40].

The scope of Knowledge Management is the information used to provide support for infrastructure and applications, resolve Incidents, Problems and fulfill Service Requests, for example:

- Application Runbooks, Application Information Documents (AIDs), and Application Support Control Plans (ASCPs)
- Knowledge Transfer session recordings
- Policies, procedures, and best practices relating to support topics
- Methods to resolve Incidents, including previous resolutions and workarounds
- Known errors
- Service Desk scripts
- Self-help articles
- Frequently Asked Questions (FAQs)
- Support team contacts and routing

From Inside

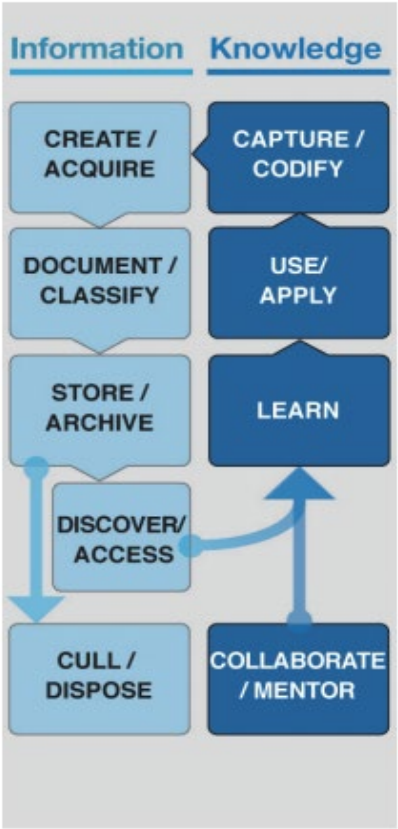

Figure 30. Chart. The Information and Knowledge Life Cycle

Figure 30 consists of these following components researched by Spy Pond Partners [25]:

- Create/acquired: new knowledge being recognized
- Document/classify phase stores the knowledge in retrievable form, categorized with keywords, and add description
- Store/archive: store in database and available for a long period. Available for employee's retrieval
- Discover/access: the process of continuously re-evaluating the information to see if it is still relevant or not
- Cull/Dispose: eliminate outdated and irrelevant information

DOT organizations such as Caltrans have designed a model for knowledge management life cycle, including Tacit and Explicit knowledge [13].

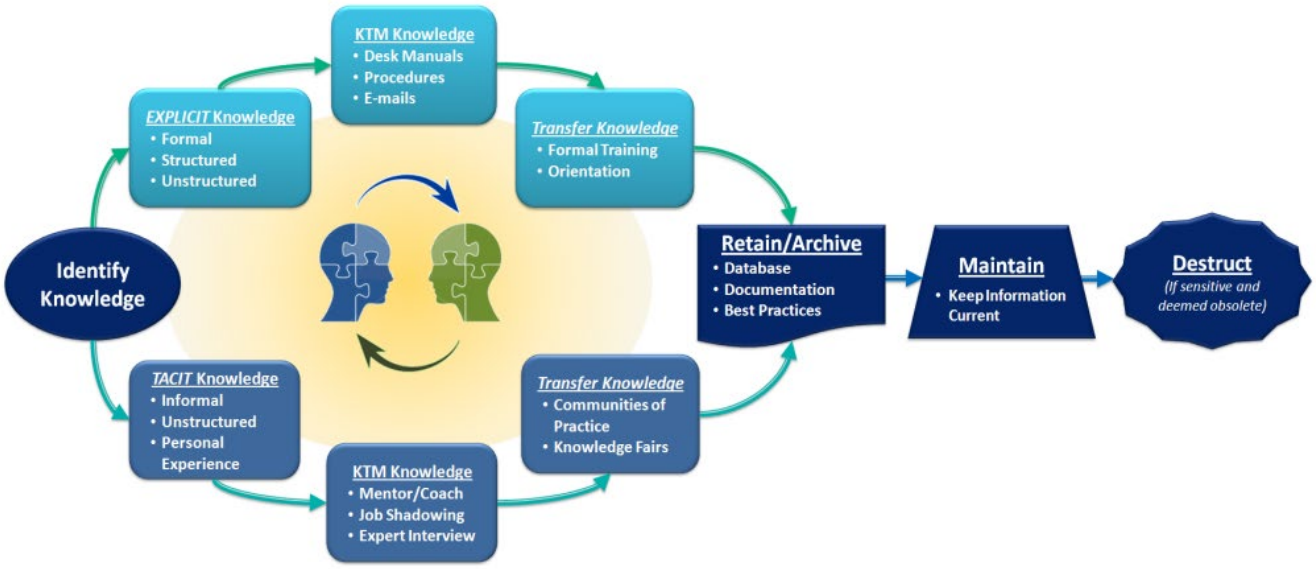

Figure 31. Chart. Caltrans Knowledge Transfer Guidebook- Knowledge Life Cycle [29]

Figure 31 shows that Caltrans is strong not only recognizing different types of knowledge but also having a clear understanding of knowledge transfer, knowledge retain/archive, knowledge maintenance and knowledge destruction. In PennDOT, the knowledge life cycle is the key in KM maintenance since once knowledge is consistently being shared and re-evaluated, they can grow their knowledge base [41].

Reflection:

According to the literature review, the reflection is the entire life cycle of big data, including the creation of data, data collection, use of data, and exchange of data. However, there is a higher level of detail from outside GDOT. In order to maintain the meaning and reputation of tacit knowledge, it is imperative to engage in ongoing evaluation and periodic revision. Knowledge that has become outdated or irrelevant should be subject to re-evaluation and, if necessary, disposal. Given that individuals may have divergent approaches to performing tasks, it is crucial to continually revisit knowledge to ensure its integrity and validity. This iterative process of evaluation and revision is essential for preserving the reliability and relevance of tacit knowledge.

Summary:

The survey of literature emphasizes the importance of reflection throughout the big data life cycle, encompassing data production, collection, usage, and interchange. However, it emphasizes the importance of moving beyond GDOT and engaging in continual review and periodic updating to retain the value and reputation of tacit knowledge. Outdated or irrelevant knowledge should be re-evaluated and discarded, and frequent assessment is required owing to the many ways that individuals may take. This constant process of examination and updating is critical for maintaining the reliability and usefulness of tacit knowledge.

EXPERIENCE U SOFTWARE

Strengths

- One-stop-shop for GDOT employees
    - ⇨ "Experience U" serves as the primary resource that comes to mind for employees when they have work-related needs. The overarching objective of this initiative is to enhance organizational awareness and empower staff by providing a centralized platform to identify, comprehend, and establish connections with managers and subject matter experts. Furthermore, the software endeavors to leverage information and knowledge across the existing multi-generational workforce. By facilitating seamless access to resources and expertise, "Experience U" fosters a collaborative environment that transcends generational boundaries and facilitates effective knowledge sharing and transfer.
- User-friendly
    - ⇨ The software interface is designed to be user-friendly. GDOT staff can select the icon which corresponds to Organizational Chart, Chat, FAQs, etc., and the software redirects the users to where they want to be. Moreover, users can select on the interactive map to know which region their project belongs to. The application comes with a mobile version. Therefore, GDOT staff can use the software on the go on their smart devices.
- Encourage learning activities
    - ⇨ By implementing the application, GDOT encourages its employees to learn and ask questions to acquire explicit and tacit knowledge. Moreover, admins or

SMEs who respond to the questions posted can reinforce their knowledge-based and improve knowledge transfer activities.

- Recognize awards/contributions/publication
    - ⇨ GDOT appreciates the contributions and publications of its employees by posting them on the application. Therefore, the employees feel proud of their work and are encouraged to perform better.

Weaknesses

- Not a knowledge-based system
    - ⇨ The system functions as an internal repository of applications that provide users with guidance to their desired destinations. However, there is currently a notable absence of a comprehensive framework for knowledge storage within the system. In contrast, the Question and Answer (Q&A) functionality serves as a mechanism for storing knowledge. It is important to note that certain knowledge is accessed and utilized more frequently than others, which may result in a knowledge gap when relying solely on the Q&A system.

      A robust knowledge system has the potential to generate predictions, streamline processes, and assist humans in their day-to-day activities. However, Experience U primarily operates as a support center rather than a knowledge-based system. It serves as a valuable resource for employees seeking assistance, but there is room for improvement in terms of incorporating a more structured knowledge management approach within the system.
- Forum is Obsolete
    - ⇨ The forum feature allows users to interact in a central location to ask questions directly to SMEs. However, the discussion forum has lost popularity over the years due to the lack of valuable information. If anyone can post questions, and anyone can post answers, it is not ideal because the answers lack credibility. Those who ask questions can face information overload because there is no standard of right versus wrong questions.
- Costly to Maintain

⇨ Another point to keep in mind is that the organization spent money on maintaining the system but did consider the ROI (return on investment).

- Draw people out of their day-to-day activities to answer questions.
  ⇨ While subject matter experts can provide valuable insights and assistance on forums, it is essential to consider the impact of their shifted focus on their regular duties. Their expertise and contributions in their designated roles contribute to the overall functioning of the organization. Therefore, striking a balance between their core responsibilities and their involvement in forum activities is crucial to ensure efficient workflow and optimal utilization of their skills and knowledge.

- Poor user experience and poor user adoption
  ⇨ Although the software has been in operation for almost two years, GDOT staff are unaware of this software because it offers a poor user experience and there is a lack of user adoption.
- The language used in the discussion is not formal and may lead to misunderstanding.
  ⇨ One notable limitation of discussion posts is the absence of physical cues, which can hinder effective communication and comprehension. Presently, there is a lack of mechanisms in place to monitor or regulate the language being employed within the discussion forum. Consequently, this can result in poorly constructed questions and responses that are difficult to understand or open to misinterpretation.

Importance of Tacit Knowledge:

Tacit knowledge is knowledge that cannot be communicated orally, whereas explicit knowledge is knowledge that can be easily transferred via physical or electronic means, or shared [40]. Knowledge capture and learning strategies are classified into two types within DOTs: (1) information recordings, such as consultant reports, written teachings, or recorded films; and (2) individual person-to-person interaction, such as group presentations, post-project debriefs, mentorship meetings, or staff training sessions [41]. DOT described KM as "an umbrella term for a variety of techniques for building, leveraging and sustaining the know-how and experience

of an organization's employees" [42] DOT considers Knowledge Management as the process of maintaining the organization's knowledge during its operation and record its employee and partners' experience to support the company's strategic operation. [42]. The state DOT Knowledge Management program aims to improve organizational efficiency and effectiveness, strengthen organizational resilience/workforce capabilities, leverage external expertise, and foster learning and innovation. [42]

SUMMARY AND CONCLUSION

Experience U is a useful product and practical to use for all GDOT staff. However, its functionality is too broad to be considered as Knowledge Management Software. GDOT needs another tool/software whose main function is storing and disseminating tacit knowledge, which is the focus of this research.

STRENGTHS AND WEAKNESSES

Strengths

- Community of practice (CoPs) is a common practice being used across DOTs. Community of Practice both focus on promoting tacit knowledge and explicit knowledge sharing among the organization and they serve the same goal, which is sustaining and maintaining organizational tacit knowledge.
- Some organizations already implement tools for capturing and transferring knowledge, for example, wiki pages, SharePoint, MS Teams, and MS Streams.
- Knowledge Management programs within DOTs have been around for a long time. These methods will be investigated and integrated into the final KMS developed in this research paper.
- Inside DOTs and outside DOTs already have a baseline for tacit knowledge sharing, tacit knowledge modeling, and designing frameworks. Therefore, there is no need to ‘reinvent the wheel’.

Weaknesses

- Tacit and explicit knowledge are being used interchangeably within DOTs; however, there is a lack of dedicated software to manage knowledge.

- Some knowledge management programs are short-lived.
- Some knowledge management programs focus only on theoretical and without implementation.
- There is a lack of a formal team to carry out knowledge management responsibility.
- References that the research team has been outdated. Some practices/software/programs are no longer available. Moreover, people who were in charge of the KM program are no longer with the organization.

Recommendation

- Identify a CoP: there is a need to define a community of practice within GDOT to experiment on Tacit Knowledge Management.
- Knowledge Identification: there should be a structural/standardized method to recognize knowledge. More importantly, this way should be employed across the organization. The team, as well as GDOT, should identify if the knowledge is Tacit or Explicit/ WHO is responsible for identifying the knowledge/ HOW to identify the knowledge/ WHICH tools are being used to identify the knowledge.
- Knowledge Capture: similar to knowledge identification. WHO is responsible for knowledge capture/ WHICH system is being used to capture the knowledge/ HOW to know if there is knowledge loss during the process?
- Knowledge Transfer: the distribution of knowledge from person to person, from person to a group, and from group to group. There is a need to guarantee that the knowledge is not lost during the transferring process.
- Knowledge Maintenance: this is equally as important as other steps and complements the Knowledge Life Cycle. Knowledge should be continuously re-evaluated to retain integrity and value.
- Knowledge Management Software: MS SharePoint, Lotus Note, VDOT Lesson Learn, Meridian KSI. The team must figure out what qualifies as tacit knowledge management software and adopt it for the in-house software.

9.2 TASK 2: KM IMPLEMENTATION IN GDOT

Timeline: *January 26th, 2021, to July 26th, 2021*

9.2.1 Task 2 Description:

Understand how different GDOT departments are connected and how information and knowledge are shared with each other.

9.2.2 Deliverables Task 2:

Technical report showing understanding of current Tacit Knowledge Life (TKL) cycles in GDOT implemented by key decision-makers.

9.2.3 Milestone Task 2:

Obtain a comprehensive understanding of how GDOT departments are connected, how information is communicated, the type of knowledge being shared, and the key decision-makers (Month 12).

9.2.4 Task 2 Report:

Executive Summary

Task 1 of the project researched the elements of Knowledge Management (KM) initiatives and the methods currently employed by DOT by studying and analyzing previous DOT KM project results and outside DOTs. The current method employed by GDOT is Experience U. The focus of Task 2 is to understand how different GDOT departments are connected as well as the mechanisms through which information and knowledge are disseminated. This report will detail the eight activities to achieve Task 2 deliverables. The overarching objective is to gain an in-depth understanding of the intricate network of relationships between GDOT departments, the channels employed for effective communication, the nature of knowledge shared among these entities, and the pivotal decision-makers involved in the process.

Task 3 will build further on this research by studying the I-85 Highway Bridge Collapse case study and the communication flow during the incident with outsourced agencies that were involved. The traffic operation office has been identified as an ideal expert group to explore how departments are connected and how information and knowledge are shared in GDOT.

Overview

The KSU research team's primary concerns for Task 2 are the Tacit Knowledge Life Cycle and how tacit knowledge is shared among various GDOT offices. Most of the data used for this task came from the survey, which was widely spread throughout GDOT to identify the key information and knowledge shared between GDOT departments and offices, as well as the communication flow between those entities. Specifically, the verbal and electronic channels of communication used by GDOT departments and divisions, including face-to-face meetings, phone calls, emails, and Community of Practice (CoP) are studied. The traffic operation office was identified as an ideal expert group to explore how departments are connected and how information and knowledge are shared in a GDOT. The information shared during this process is recorded for future research and aids in the development of the experimental software at the project's conclusion. Below are detailed findings on the eight activities determined to measure the tasks.

Identify Communication Methods

Identifying the communication methods between GDOT departments is an important aspect of GDOT Tacit Knowledge Life Cycle creation. The goal is to visualize the knowledge transfer method within the cycle, analyze it, and apply the knowledge gained to what is used within the Traffic Operation Office. According to the survey distributed, all GDOT employees communicate via Outlook emails, Microsoft Teams, and face-to-face interactions. Communities of Practice (CoP) is a group of people who have common interests and share their experiences, skills, and intuitions, which is commonly used not only in GDOT but also in DOTs across the country. Some CoPs are categorized into specific tasks, for example, Bridge Construction, Project Management, or Appraisal while GDOT has a dedicated Microsoft Teams Community Learning site. Namely,

- GIS
- Business Intelligence
- ACEC/GPTQ and AASHTO conferences; Appraisal Organization
- Bridge PMC matters
- Project Delivery Methods and Managed Lanes
- GDOT MS Teams Community Learning

Communication and Knowledge Shared Between GDOT Departments

GDOT employees engage in knowledge sharing pertaining to various domains such as projects, processes, appraisal, permits, roadway, environment, structural design, utilities, and more. These areas of knowledge are directly connected to the Plan Development Process (PDP) within GDOT. To gain a comprehensive understanding of communication and knowledge sharing practices within different GDOT departments and areas, the team has actively participated in training sessions and thoroughly examined the PDP Flowchart and related documents. These efforts have facilitated a deeper comprehension of how information and knowledge flow among different departments and areas within GDOT, specifically within the context of the Plan Development Process.

The research team identified the communication flow within the Traffic Operation Office by studying the process to create a Project Justification Statement, a task that is overseen by the Office of Traffic for safety and operational projects. The statement requires a designated program (Governor's Road Improvement Program, Strategic Highway Network, Oversized Truck Network, etc.), a summary of the problem that needs to be resolved, the limits of the proposed project, and the desired outcomes. All information needed for the Project Justification Statement comes from different sources and the team studied the information flow within that process.

Understanding Current Tacit Knowledge Life Cycle in GDOT Implemented by Key Decision Makers

In the ASME-IMECE 2021 paper case study, tacit knowledge in human-robot interaction is captured using storytelling, patterns, sketches, and photo reports. The result is tacit knowledge successfully captured and the expert can replicate the process. The research team would like to apply similar methods to capture tacit knowledge in GDOT with an emphasis on Traffic Operation Office.

GDOT is aware that tacit knowledge/institutional knowledge is lost whenever a skilled employee retires or a project is being carried out by an external consultant. They have used the following ways to implement Tacit Knowledge Life Cycle. The most widely used ones are formal or informal group interaction and training. The rest are, namely:

- Interview: whether it is within a Community of Practices (CoPs), interviewing upcoming retirees, exit interview, etc.
- Storytelling, video clips, sketches
- Documentations

Identify the Key Departments Outsourced Project

According to the information gathered and the PDP, these following departments and offices are directly related to the outsourced project. The Traffic Operation Office plays an important part with outsourcing agencies in conjunction with the following offices:

- Office of Design Policy and Support
- Office of Material and Support
- Office of Engineering Services
- Office of Environmental Services
- Office of Planning
- District Engineer Office
- Office of Bridge Design
- Office of Traffic Operation
- Right of Way Office

Identify the Communication Flow Between GDOT Departments

Following consultations with GDOT, the Traffic Operation Office was established as a significant role in conducting crucial traffic studies, including those related to GDOT processes. Recognizing the importance of understanding the communication flow from the Traffic Operation Office to other departments and offices, the research team has prioritized this area of investigation.

Contact information from key individuals within the Traffic Operation Office, specifically Sam Harris and Matthew Glasser, were secured and the team proceeded with arranging a meeting to initiate knowledge extraction processes. These discussions provided an invaluable opportunity to engage with the subject matter experts, gather insights, and gain a comprehensive understanding of the communication dynamics and knowledge sharing practices between the Traffic Operation Office and other relevant entities within GDOT.

By establishing direct lines of communication with Sam Harris and Matthew Glasser, the research team facilitated an effective knowledge exchange and gathered valuable information to further enrich the study's findings.

Identify Key Information Shared Between GDOT Departments Offices

According to the PDP and the survey conducted, here is the key information and knowledge being shared between GDOT departments/offices. After the meeting with Sam Harris and Matthew Glasser, the team would learn the "big picture" and how the traffic operation office connects with other GDOT offices.

- Project/Process Design
- Structural Design
- Roadway Design
- Mitigation
- Utilities
- Environment Permits/ Reevaluation
- Certifications
- Roadway Acquisition

Identify Knowledge weaknesses/strengths within each GDOT department/offices

Strengths

According to the survey distributed to GDOT staff during Task 1, almost half of GDOT employees surveyed believe that knowledge management services/tools are beneficial to performance management. Most GDOT employees mentioned that they are a part of one and/or many CoPs. Moreover, the knowledge within their department is easily accessible. Therefore, when the team proposes a knowledge management model/experimental software as the result of this research, the level of adoption/enthusiasm is expected to be high.

The research team validated this information with Sam Harris and Matthew Glasser to confirm the level of knowledge management proficiency that is currently implemented within GDOT.

Weaknesses

The knowledge management weaknesses within GDOT primarily stem from external factors. Specifically, departments and offices store essential knowledge in various formats, lacking automated transfer mechanisms between them. This situation is understandable due to the organization's size and the reliance on subject matter experts' skills and experiences. However, formal knowledge management practices are lacking, resulting in undocumented knowledge and its loss upon retirement. Additionally, there is limited information available regarding software implementation for knowledge management within GDOT. Addressing these weaknesses requires proactive measures to capture and retain critical knowledge, establish formalized knowledge management strategies, and explore software solutions tailored to GDOT's needs. By doing so, GDOT can better preserve and leverage institutional knowledge for organizational success.

These are the following ways GDOT employees store Tacit Knowledge:

- Soft copy notes, papers
- Repository
- Shared drive

A greater picture of the knowledge weakness within the Traffic Operation Office was gained after the research team had the chance to consult/interview Sam Harris.

Create Surveys

After implementing the survey for DOT departments for Task 1, a specific survey was created for Task 2. As a result, the research team met with GDOT May through June to come up with questions to extract tacit knowledge from employees involved in the I-85 bridge collapse and near-retirees. The research team interviewed Sam Harris and the following section provides the questions that were asked.

Questions for Sam Harris - Traffic Engineer

A. Are you familiar with the I-85 bridge collapse and reconstruction?

B. If not, do you have any related experience which is similar to the I-85 bridge collapse and reconstruction?

C. How was the traffic office involved in this situation before/during/after the I-85 bridge collapsed?

D. Would you mind mentioning a successful example where the traffic office was involved either before, during, and/or after the I-85 bridge collapsed?

E. According to your participation identified (previous questions), please identify the main departments/areas/key decision-makers from the traffic officers who helped in implementing these actions items.

F. What documentation was required during the I-85 bridge collapse and reconstruction?

G. Mentioning the communication methods and flows between the traffic office and other departments/areas/key decision-makers in this process.

H. What was your first response/immediate action after the I-85 collapse?

I. Please identify the knowledge shared with traffic operations departments/areas in this process.

J. Please identify some of the key departments/offices from outsourced areas participating in this process. How did you interact?

L. Did you inform and provide the alerts to people as soon as the accident happened? Can you list out the names of people to whom you informed?

L. What was the key information and knowledge (experiences) that you think made the difference in avoiding accidents and how it was shared between traffic operations groups?

M. Did you find any weaknesses among the traffic office/areas/key decision-makers during the I-85 collapse?

N. What are the things/actions you wished you had done differently?

O. Do you know any near retired people from your team who could help the Research Team (in addition to your participation)- who have good experience on traffic operations and I-85 bridge collapse?

Questions For Near Retirees

The research team identified employees who are directly related to the GDOT "core processes" and modify questions specifically to extract valuable Tacit Knowledge from the individual. According to the conversation with GDOT, GDOT assisted the team to produce a list of near retirees who are neither related to I-85 incident nor the Traffic Operation Office.

Moreover, the goal was to get more contacts of near retirees from Traffic Operation Office after the meeting with Sam Harris and Matthew Glasser.

9.3. TASK 3: GDOT CASE STUDY: I-85 BRIDGE COLLAPSED

Timeline: May 26th, 2021, to February 26th, 2022

9.3.1 Task 3 Description:

Analyze the I-85 Highway Bridge Collapse case study and the communication flow with the outsourced agencies involved.

9.3.2 Deliverables Task 3:

Technical report including the GDOT TKL implemented on the I-85 Case Study.

9.3.3. Milestone Task 3:

Obtain a comprehensive understanding of the I-85 Bridge collapse, how it was repaired (along with the key GDOT departments involved), and how they communicated with the key decision-makers during the collapse and repair period in addition to the processes and methods that were utilized.

9.3.4. Task 3 Report:

Overview:

The research team chose the I-85 Highway Bridge Collapse as the case study due to its recognition as a highly esteemed initiative within GDOT. This selection aimed to extract valuable insights by examining the lessons learned from the event. The team focused on identifying crucial information that had been successfully implemented by various project phases and teams involved in the bridge collapse and subsequent reconstruction efforts. Through meticulous research, the team discovered a collection of noteworthy best practices that had been embraced by influential decision-makers within the specific context of this case study. These findings highlight effective strategies and approaches employed by the decision-makers, contributing to the overall success of the project and providing valuable lessons for future endeavors. Furthermore, conducting research on GDOT procedures played a pivotal role in equipping the team with the necessary preparedness to respond swiftly and effectively to similar

situations. In order to prevent further risks to public health and safety, economic loss, deaths, and/or other tragedies, it was crucial that important individuals work together quickly after the bridge collapsed. The team's internal and external stakeholder collaboration as well as the processes that were utilized for this study must be well understood. For instance, identifying novel concepts that were crucial and implemented in the bridge rebuild was a significant lesson learned. A GDOT Tacit Knowledge Life Cycle (TKL) must first be established in order to identify the creative solutions used in the bridge reconstruction and to understand how tacit knowledge was recorded.

Task 1 compares inside GDOT knowledge management efforts vs outside GDOT (outside of federal agencies scope) while Task 2 is about studying the communication among GDOT departments. The primary objectives of Task 4 encompass the development of a Tacit Knowledge Model and Tacit Knowledge Life Cycle based on the data and insights acquired from the I-85 Bridge Incident. This information is obtained through the comprehensive case study conducted in Task 3. Grateful for the valuable contributions made by Sam Harris and Matthew Glasser from the Office of Traffic Operation, as well as Bill DuVall from the Office of Bridge Maintenance, the research team successfully constructed a case study that effectively captures the tacit knowledge embedded within the I-85 Bridge incident experience. This case study serves as a vital foundation for the subsequent creation of the Tacit Knowledge Model and Tacit Knowledge Life Cycle, enabling the team to further understand, document, and leverage tacit knowledge within the context of the incident.

Below are detailed findings on seven (7) activities that the research team has discovered. Each activity is meant to support Task 3 deliverables.

Timeline of the I-85 Incident

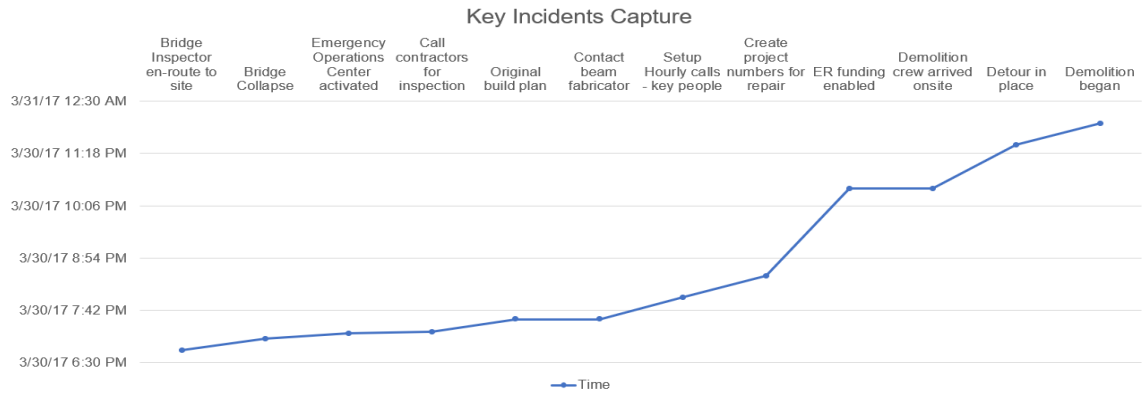

Figure 32. Graph. Key Incidents Captured within the I-85 incidents and timeline associated with the events.

Figure 32 illustrates the reaction power of GDOT in response to the bridge collapse incident. Notably, the reaction time between the bridge collapse and the activation of the emergency operation center is recorded at 7 minutes. Subsequently, the time between the bridge collapse and the creation of the project is approximately 1 hour and 30 minutes. Additionally, it takes approximately 3 hours and 30 minutes for the demolition crew to arrive on-site following the bridge collapse. The overall time from the incident to the demolition process is approximately 12 hours.

The research team aims to investigate the factors contributing to GDOT's quick reaction power, which potentially include standard operating procedures (SOPs), expert knowledge, collaboration among contractors, and collaboration among different GDOT offices. This study seeks to delve deeper into the reasons behind GDOT's ability to complete such a complex project within a remarkable 6-week timeframe, surpassing initial expectations. Conducting a case study on the I-85 bridge collapse will enable a comprehensive exploration of the strategies and practices employed by GDOT, shedding light on the successful execution of this project.

Identify Key Knowledge Between Project Phases and Teams

Office of Traffic Operation

Below are a few key knowledge points extracted from different project phases and teams.

Detour: The Office of Traffic Operation used their expert knowledge to produce the detour. First, they identified the affected areas and figured out the alternative routes for traffic. Moreover, they

incorporate traffic data from the sensors, and devices in the affected area to measure the effectiveness of the Detour Plan implemented.

Notifying travelers/civilians traveling in the roadway: It was important to let the travelers be aware of the incidents and take immediate actions to avoid being stuck in traffic. Therefore, GDOT has collaborated with HERO and CHAMP fleet to be prepared for the number of calls from the travelers, and be ready to explain to them how to use the detour.

In conjunction with the call center, GDOT also updated its social media platform (Facebook, Twitter, etc.). GDOT used its Traffic Management System to push out the overhead billboard notification to notify travelers on the roadway.

Contractor: The knowledge in collaboration between HERO and CHAMPS result in resolving congestions and quickly reacting to travelers' concerns.

TMC's Role

Initially:

- TMC (Traffic Management Center) initially uses cameras to detect abnormal activities, generate traffic reports, control signs, signal, and overhead billboards. They can also dispatch HEROs to assist pedestrians, and posting messages on social media.

Long term

- TMC's long-term goal is to keep motorists notified using social media and traffic signs. Moreover, they would like to report traffic data regularly and make sure to engage in process improvement discussions more regularly.

Quick response project

During the I-85 incident, TMC has made upgrades to Traffic Signal, RTOP Expansion, and CCTVs to better accommodate the reconstruction of the bridge.

Support from Atlanta

- APD Traffic Enforcement
- Renew Atlanta Signal

This has shown GDOT has proactively reacted to the incident, and this has contributed to the early completion of the project. The information provided is lesson-learned for future implementation for a similar incident.

Office of Bridge Maintenance and their plans

The office is responsible for designing and detailing the bridge.

Key tasks identified:

- The Bridge Maintenance engineers assessed the damage and created a plan to repair and replace necessary components.
- They coordinate with the Construction Office throughout the reconstruction project.

Office of Traffic Operation

- The office was able to identify who were the people to reach out to in this case, Sam Harris, Matthew Glasser, and Dee Taylor (RTOP)
- They can prioritize the tasks, from the most important to the least important.
- The office relies heavily on SOP (Standard Operating Procedure) to operate during the incident.

These were three of the detour plans in the Office of Traffic Operations implemented.

- Piedmont Circle Reconfiguration:
    - The idea was developed to meter vehicles into (eastbound) the "Epicenter" and flush vehicles out (westbound) of the "Epicenter".
    - Before this reconfiguration, during the detour westbound vehicles would typically queue back through Piedmont Road.
- Due to the detour, many Cheshire Bridge and Piedmont vehicles were turning onto Piedmont Circle to access Buford-Spring heading NB and SB. To accommodate this new pattern, the Piedmont Circle 3-lane cross-section was converted from two lanes eastbound, and one westbound TO one lane east and two lanes westbound.
- Piedmont Rd @ Cheshire Bridge
- Optimized flow of traffic towards Buford-Spring by lagging the Piedmont NBL at Cheshire Bridge. This permitted a more uniform and easier coordinate platoon away from Piedmont and the Epicenter.
- Cheshire Bridge @ Lindberg
- By Leading the LT Phase on the shorter turn bay approach or dominant volume approach, progression could be optimized AND create gaps in opposing traffic downstream.

- These detour routes provide learning opportunities for GDOT for future reuse and were successful in reducing the queue of traffic.

Office of Bridge Maintenance

Identify Key-decision makers:

- Leon Kim: Structural Engineer
- Steve Gaston: Assistant State Bridge Engineer
- Lyn Clements: Assistant State Bridge Engineer
- Donn Digamon: State Bridge Engineer
- Others Involved in collaboration: Clayton Bennett (State Bridge Maintenance Engineer), Mike Garner (Construction Liaison Engineer who managed the project)

Best Practices

- The road closure is the best step for the rebuild. In case the bridge department needs to develop shoring and tries to stage traffic it would have likely delayed the overall construction.
- As with all emergency projects, the environmental permitting was streamlined but due to being a grade separation, the bridge office did not have to be concerned with any of the species.
- The process of shop drawing review was not skipped, but the bridge office was able to coordinate with both the Contractor and the Fabricators to go directly from plans into shop drawings, which saved time and contributed to early completion.

Lessons learned:

- One important consideration in putting out the fire and cooling the concrete rapidly is the fire hoses should point directly to the fire and not directly to the concrete structure. Also, even a day after the fire, the structure continued to cool and concrete would spall. There is a need to allow sufficient cooling before sounding concrete with hammers.
- Getting Roadway Design involved from the start is important because there was a lot of work in putting together the plans and all of the roadway quantities.
- Contractors' experience and input proved valuable for this study. The experience from contractors is valuable to be captured.

- The value-added of understanding the I-85 incident from the Bridge Maintenance Office standpoint is the knowledge captured can be analyzed and reused in similar incidents.

IDENTIFY NEW PROCESSES

Office of Traffic Operation

Work with RTOP - Epicenter: Emergency center to oversee emergency activities regarding I-85 incidents. The below number represents the effort of Traffic Ops in diverting the traffic flow by implementing a detour plan. Moreover, these numbers represent the effectiveness of the detour plan.

- # of intersections in RTOP Zone 1: 196
- Total # of Flush Plans (4 Plans per intersection) Developed and Implemented: 784
- # of Detour Plans (6 Plans per intersection) Developed and Implemented: 180
- # of manual changes to Zone intersections daily on an average day: eight
- # of manual changes to Zone intersections daily during the Bridge Event: 120.
- Highest Flush Plan Cycle: 250 sec.
- Highest Detour Plan Cycle: 200 sec.
- Epicenter Cycle Lengths:
- Typical Weekday AM-Noon Cycle = 140 sec
- Detour Weekday AM-Noon Cycle = 200 sec
- Typical Weekday PM Cycle = 160 sec
- Detour Weekday PM Cycle = 200 sec
- Approx. 20-30% increase in cycle length
- Epicenter AM Peak Hours Comparison
- Typical AM Peak = 7:30-9:30
- Detour AM Peak (the first week) = 6:30 – 10:30
- Detour AM Peak (thereafter) = 5:45-10:30
- Epicenter PM Peak Hours Comparison
- Typical PM Peak = 4:15- 6:45
- Detour PM Peak (the first week) = 3:00- 9:30
- Detour PM Peak (thereafter) = 3:00-8:45

- Traffic Operations office perform analysis on average traffic in the affected area before, during, and after the incident
- They performed Data communication to Travelers Impact analysis using data from app download, 511 calls, and website usage.
- The office was able to perform a field study from historic data to analyze the traffic condition using Probe Data Analytics Suite

Office of Bridge Maintenance

- In the incident, the bridge office allowed beams to be shipped with shortened time in the yard and allowed beams to be delivered inside I-285 outside of normal permitting practice.
- Initially, the bridge office was going to replace the Type V PSC girders in kind, but the forms were in Florida and the plans/notes indicated that the beams had been modified. Donn Digamon proposed to change the beams to Bulb Tee's which the bridge office proceeded to utilize
- Analyzing the keys which result in the change from the original plan is a way to capture Tacit Knowledge. The instances which were captured from this process were useful for producing Tacit Knowledge Model in Task 4

Future Work

Due to the complex nature of the project, GDOT suggested that the KSU research team switch gears into Bridge Maintenance instead of continuing to pursue the Traffic Operation Office angle. However, the knowledge gathered previously will not go to waste. A process will be defined to capture the experience and come up with instances for the Tacit Knowledge Model and Tacit Knowledge Life Cycle. A few processes of interest are listed below.

- Bridge demolition and reconstruction
- How to handle the debris and material on site
- How the Bridge Office collaborates with OMAT (Office of Material and Testing) and Traffic Operations.

The plan is to schedule a meeting with the Bridge Office to continue working on the information given by the Bridge Office in conjunction with the creation of instances of the Tacit Knowledge Model and Life Cycle.

The research group is exploring a new research venue with GDOT. For example, Industry 4.0 is considering the next industrial revolution and the research team is exploring some ideas on bridge maintenance and construction implementing Industry 4.0 trends. The KSU team started to explore some Industry 4.0 trends [2]. The next step is to explore how these technologies could be applied in GDOT and particularly for bridge maintenance and construction.

9.4. TASK 4: A FIRST TKM DRAFT BASED ON A GDOT CASE STUDY

Timeline: January 2022 to May 26th, 2022

9.4.1. Task 4 Description:

Define and create a model that captures the valuable tacit knowledge implemented at I-85 highway bridge collapse.

9.4.2. Deliverables Task 4:

Technical report including the first draft of the GDOT TKM based on the I-85 case study.

9.4.3. Milestone Task 4:

Successfully create a Tacit Knowledge Model that captures the experiences of the I-85 Highway Bridge Collapse.

9.4.4. Task 4 Report

Overview:

In contrast to Tasks 1, 2, and 3, Task 4 will involve a first draft of the GDOT Tacit Knowledge Model (TKM), which will be based on the case study of the I-85 Bridge Collapse. The research team will classify the various forms of knowledge representation in this task in order to develop the basic knowledge structure that has been suggested, but specifically for the I-85 Highway Bridge. The goal of this task is to connect the GDOT Tacit Knowledge Life Cycle with the GDOT Tacit Knowledge Model with a basic framework.

The information provided by GDOT people who were met/questioned, allowed the creation of a case study that captured the I-85 Bridge incident experiences. The KSU Research Team created instances for the tacit knowledge model to showcase the I-85 bridge collapse project in some key areas.

ReCORD Software Analysis

Upon the recommendation of GDOT, the research team explored implementing ReCORD software, a lesson-learned database specifically designed and utilized by the Construction office. The objective was to assess the potential for reusing any aspects of the ReCORD system or leveraging the data contained within the database for the current research project. After careful analysis of the ReCORD documents shared by the GDOT team, several key insights were gleaned by the research team concerning the functionality and operation of the ReCORD system:

- ReCORD system scope is for construction-related projects within GDOT, especially the Construction office.
- The system users are DOT engineers, inspectors, construction managers, and maintenance personnel.
- Main components/features of the ReCORD system:
    - Push notification
        - Mobile compatibility: Compatible with mobile devices which makes it easier for field engineers to engage in capturing lessons learned.
        - GIS capability
        - Miscellaneous Option allows users to include links to relevant codes or specifications from internal and external sources.
        - Lesson tags enable users to easily search the lessons learned Database and there is also a text search option for users.
        - Project-based lessons learned are stored in the database.
        - Connected to GDOT's GeoPI Dashboard.
- Case Studies considered for ReCORD implementation:
    - Colorado Department of Transportation's T-REX Mega-Project
    - Virginia Department of Transportation's Program

    - Pennsylvania Department of Transportation
- System Flow: The field engineer creates a lesson in the database, then the lesson is subject to be reviewed by SMEs (Subject Matter Experts) and Lessons Learned curators (edit if necessary), and the Lessons Learned curator publishes the lesson learned, if the lesson is approved, the system notifies the lesson creator.
- ReCORD system maintenance: GDOT IT decided to discontinue the use of systems that require JavaScript. Therefore, a solution is to redevelop the ReCORD system with GDOT IT.

Thanks to the data received from the GDOT team regarding ReCORD, the research team discussed implementing the Tacit Knowledge Management tool (Experimental software) in one of the following ways:

- Use the database (data) available in ReCORD in the application directly for applicable bridge department instances.
- Directly use ReCORD to input in the model with additional efforts from users.
- Integrate and further develop the ReCORD software.
- Develop a completely new application that can not only capture bridge lessons learned but also captures all departments' tacit knowledge within GDOT.

Note: Before proceeding with any of the above ideas, approval/suggestions will be needed from both GDOT IT and GDOT.

9.5 TASK 5: A TKM BASIC STRUCTURE VERSION TO SUPPORT GDOT AREAS

Timeline: March 1st 2022 to September 30th, 2022

9.5.1 Task 5 Description:

Evaluating the findings and utilizing them for one department or area.

9.5.2 Deliverables Task 5:

Technical report including the improved version of the basic structure of the GDOT TKM supporting a specific department or area.

9.5.3 Milestone Task 5:

Created a Tacit Knowledge Model that shares knowledge within the identified department or office (Month 26).

9.5.4 Task 5 Report

Overview:

The objective for Task 5 is to create a basic knowledge structure specifically for the I-85 Highway Bridge. The team has finished categorizing the various types of knowledge representation. They have also chosen one GDOT department and area to evaluate the basic structure of how well the model TKM can support important decisions. A preliminary Tacit Knowledge Model (TKM) is being created in collaboration with the Traffic Operations Office and the Bridge Maintenance office. The new updated version of TKM was acquired by working with subject matter specialists from the office of materials and testing. In order to develop a "Tacit Knowledge Model" that exchanges information inside the designated department or office, the KSU Research Team generated a set of questions for subject matter experts from one department, such as the material and testing office. In order to improve the tacit knowledge instances and fill the tacit knowledge model, the KSU Research Team completed the tacit knowledge representation using different categories, such as know-hows, lessons learned, and best practices, with various instances, such as storytelling, graphs, sketches, and video clips for the I-85 incident.

Tacit Knowledge Instances from Office Of Construction (Jeremy Information)

Here are some instances created on “How to Maintain a Bridge?” that have been learned from subject-matter experts like Jeremy for instance such as:

- Storytelling: Hi! My name is Jeremy, and I am the Co-Construction Project Manager during the I-85 Bridge Collapse in 2017. One of the first items that needed to be done was the inspection. The engineers need to assess the damage caused by the fire, specifically the beams, the footings, and the column. The result was that 61 support beams over 5 spans needed replacement. Although the column and footings were damaged it was not severe enough to need replacing.
- Videos

- National Bridge Inspection Standard- Federal Highway Administration **https://youtu.be/uwa4y5dRBro**

- Sketches

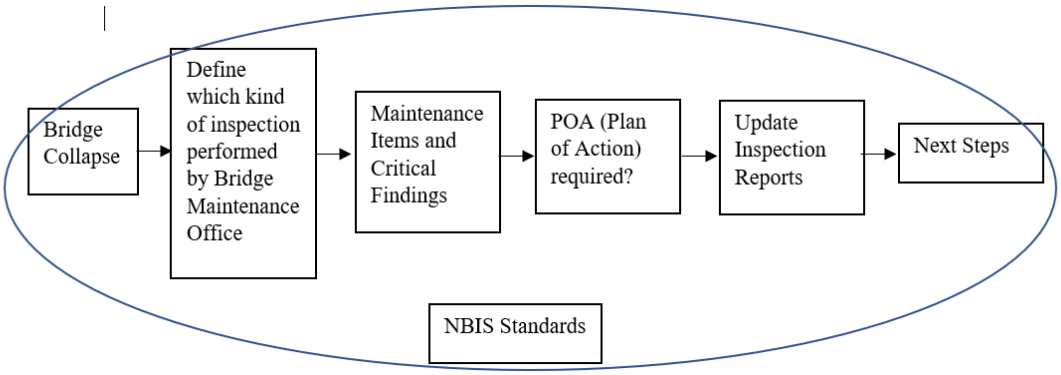

Figure 33. Flowchart. Tacit Knowledge Instances Sketches

Figure 33 Depicts primarily the detailed sketches showcasing the collapse of the bridge, these instances represent tacit knowledge.

- Patterns

Table 8. Tacit Knowledge Instances Patterns

Element	Description	Details
Pattern Name	The name of the pattern	Perform bridge inspection on the I-85 bridge collapse
Problem	An existing problem that needs to be solved	The I-85 incident was unique because it needed immediate inspection to define the damages. From the damage inspections, bridge offices could brainstorm the plan for reconstruction.
Context	Description of the situation and things or people involved	The people involved were Marc Mastronardi, Mike Garner, Jeremy Daniel, and Bill DuVall. The inspectors identified the beams which need replacement and assess the damage to the bridge footings and the columns
Forces	Interests of key characters	Making sure all components of the bridge are inspected. Produce damage reports Identify critical findings
Solution	Solution found	There is not necessarily a solution found here in this case. An alternative to this "solution" is the bridge was thoroughly inspected
Rationale	A statement that explains why the solution is used and how it works	This step is important because the team identified that the beams are one of the critical items that need replacement. Assessing the level/severity, and the impact radius of the incident assisted the Traffic Operations to define the detour.

Table 8 shows the patterns instances clearly with pattern name, problem and context in detail and the solution that is found.

9.6 TASK 6: A TKM DRAFT TO SUPPORT GDOT AREAS

Timeline: April 1st 2022 to February 28, 2023

9.6.1 Task 6 Description:

Finalizing Tacit Knowledge Model structure for outsourced areas.

9.6.2 Deliverables Task 6:

Technical report including the improved version of the GDOT TKM supporting more than one specific department or area.

9.6.3 Milestone Task 6:

Successfully developed a Tacit Knowledge Model that fits for more than one GDOT department or office (Month 31).

9.6.4 Task 6 Report:

Overview:

Task 1 contrasts knowledge management initiatives within GDOT with those outside GDOT (outside the scope of the federal agency), while Task 2 examines departmental communication within GDOT. Within the I-85 bridge collapse case study, task 3 concentrated on identifying a number of effective practices, lessons learned, and important individuals. The primary objectives of Task 4 are to construct a tacit knowledge model and a tacit knowledge life cycle using the data from the I-85 Bridge Incident, which was acquired in Task 3 and used as a case study [46]. In Task 5, the KSU Research Team was able to create a case study that encapsulated the experiences with the I-85 Bridge event as a result of the information provided by GDOT personnel that the teaminterviewed thus far [47]. In Task 6, the team was able to develop a case study that included experiences from more than one specific department and office involving the I-85 Bridge. In order to illustrate the I-85 bridge collapse project in some important areas and enhance the "DRAFT 13-6 Tacit Knowledge Model," instances for the tacit knowledge model were generated [48].

The team has accomplished Task 6 by organizing the different forms of information related to the I-85 Highway Bridge. They evaluated the effectiveness of the Tacit Knowledge Model (TKM) in supporting crucial decisions by choosing one GDOT department and location. The TKM was developed in partnership with experts from several departments and offices, including Bridge Maintenance and Office of Construction, to produce updated versions [49]. A list of questions was created for subject matter experts from various departments, including Bridge Maintenance and Office of Construction, to build a Tacit Knowledge Model that facilitates the transfer of knowledge within the designated department or office. The tacit knowledge representation was completed using categories such as know-hows, lessons learned, and best practices, and enhanced using storytelling, graphs, sketches, and video clips from the I-85 incident.

With guidance from Teague Buchanan's references, the KSU Research Team initiated an examination of power apps to develop an application akin to Tacit Knowledge Management

software. This involved utilizing data sources like Microsoft SharePoint or Microsoft Excel, along with Figma UI kit for designing the user interface.

9.7 TASK 7:EXPERIMENTAL SOFTWARE APPLICATION TO SHOW THE TKM AND TKL IN GDOT

Timeline: September 1st 2022 to April 30th 2023

9.7.1 Task 7 Description:

Develop the experimental KM tool that can be implemented for outsourced areas (construction, maintenance, design, and operations).

9.7.2 Deliverables Task 7:

Technical report including the KM tool showing the implementation of the GDOT TKM supporting more than one specific department or area.

9.7.3 Milestone Task 7:

KM tool developed for outsourced areas (Month 32).

9.7.4 Task 7 Report:

Overview:

The task at hand is to develop a TKM tool that can be implemented within the Georgia Department of Transportation (GDOT). The proposed timeline for completing Task 7 is between September 1st 2022 and April 30, 2023. The primary focus of this task is to address the fundamental structural issues of the existing Tacit Knowledge Model (TKM) and create a new one that caters to the specific GDOT departments that have been outsourced [52].

To achieve this, the KSU team collaborated with experts from various GDOT offices, including the traffic operations office, bridge maintenance office, and Office of Construction . Through this collaboration, they were able to acquire the most recent version of the TKM and incorporate recommendations from State Bridge Engineer, Donn Digamon, to create a new and improved version of the TKM.

To facilitate knowledge sharing within the designated departments, a list of questions was prepared for SMEs like Jeremy Daniel from the Construction Office. Their responses were recorded, and storytelling, graphs, sketches, and video clips were used to create a Tacit

Knowledge Model that captured their experiences. This representation was then used to populate the new TKM [53].

The team completed Task 7 within the set timeline, improving the TKM's fundamental structure, gathering information from experts across several departments and offices, and developing better Tacit Knowledge Model instances. Additionally, 75% of Task 8 Documentation was completed, which focused on documenting the project [54].

To ensure that the implemented tool or system is well-received by GDOT, the team opted to focus on a single GDOT office rather than trying to cater to all the departments. The Bridge Maintenance office was chosen based on the case study of the I-85 Bridge Collapse (TKM) and will be the office where the GDOT Tacit Knowledge Model and TKM will be implemented [55].

In conclusion, the KSU team's efforts in improving the fundamental structure of the Tacit Knowledge Model and creating a new and polished version that meets the specific needs of GDOT departments are commendable. The use of various knowledge representation techniques to capture the experiences of subject-matter experts and populate the new TKM is an excellent example of knowledge management in action.

PROGRESS ON TASK 7:

Task 7 has been completed by implementing the Tacit Knowledge Management software to organize various forms of information representation related to the I-85 Highway Bridge. The evaluation of the Tacit Knowledge Model's (TKM) efficacy in facilitating critical decision-making involved the careful selection of a specific GDOT department and location [56]. Collaborative efforts from experts representing various departments and offices, such as Bridge Maintenance and materials and testing, were employed to develop and refine updated iterations of the TKM. A list of questions was created for subject matter experts from various departments, and the tacit knowledge representation was completed using categories such as know-how, lessons learned, and best practices, along with storytelling, graphs, sketches, and video clips from the I-85 incident [57].

Initially, software was initially created using PowerApps but ultimately Oracle was used to create it.

Using Oracle Database for the TKM has several advantages. Firstly, it can handle a large amount of data, which is necessary as the TKM expands and more knowledge is added. Secondly, the security features of the Oracle Database are beneficial for storing sensitive and confidential tacit knowledge related to the I-85 Highway Bridge incident. The security features include encryption, access controls, and auditing, which help in protecting the data from unauthorized access [58].

As this Task is completely based on the implementation part, the screenshots and diagrams of the tacit knowledge model have been placed in the Implementation Module which is Section 10.

10. IMPLEMENTATION

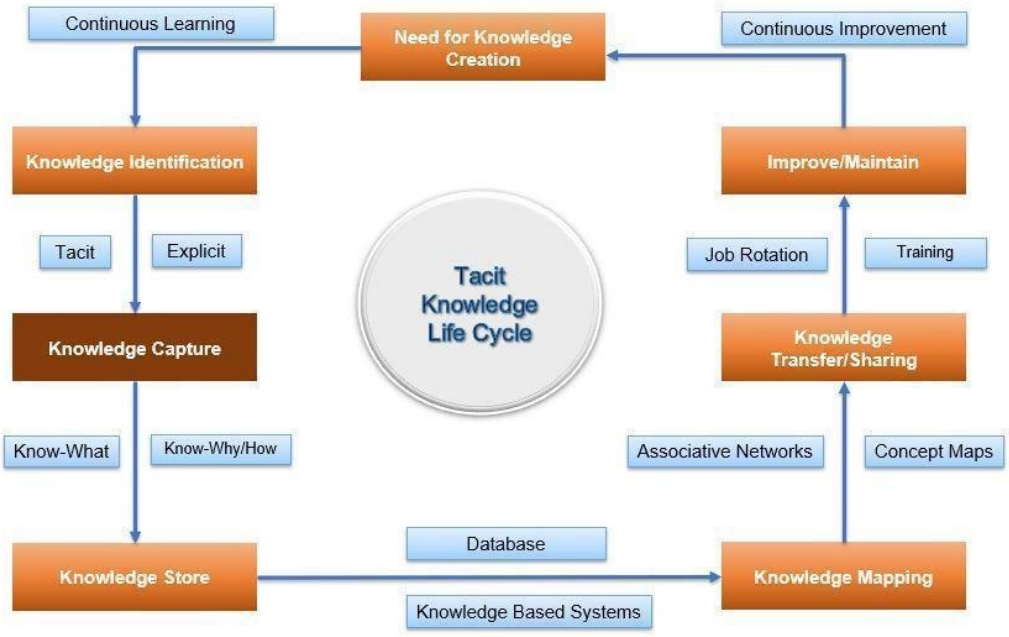

Figure 34. Chart. Tacit Knowledge Life Cycle

Figure 34 shows the **Need for knowledge creation** is the basic need of all organizations due to the fact that the organization is well-diverse and no single individual can memorize every process on their mind. The next step is **(2) Knowledge Identification.** This step involves separating the knowledge into its respective type, for example: explicit, implicit, or tacit

knowledge. Once the knowledge be identified, it needs to be **(3) captured** and **(4) stored** in a knowledge-based system. **(5) Knowledge mapping** is a way for making sense of the knowledge captured. Knowledge mapping is useful for retrieving the knowledge for later reuse. Knowledge will later be **(6) transferred and shared** across the organization for assisting subject matter experts performing complex tasks. However, knowledge management is not successful without proper (7) maintenance and improvement by the organization. This is for making sure the knowledge that became outdated is no longer useful (Guerra-Zubiaga et al., 2021) [59].

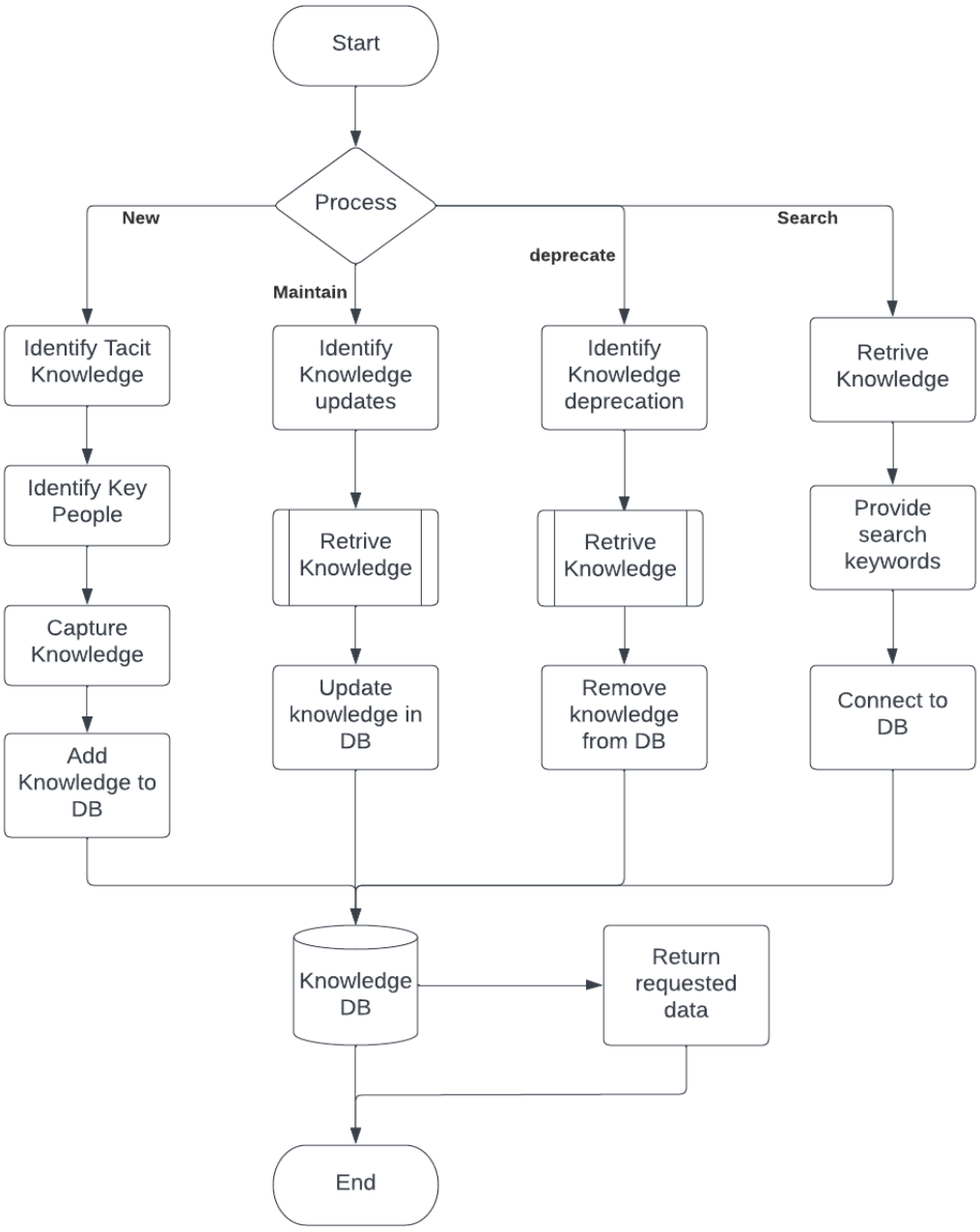

Figure 35. Flowchart. Tacit knowledge flow chart

Figure 35 shows Tacit Knowledge flowchart diagram illustrates the process that takes place within the experimental software which is obtained from Tacit Knowledge Life cycle.

This flowchart is designed to identify, capture, maintain, deprecate, and search for tacit knowledge in the organization. The start of the process is divided into four categories: New, Maintain, Deprecate, and Search. Each of these categories represents a different stage in the knowledge management process.

In the New category, the flow continues with the identification of tacit knowledge. The key people who possess this knowledge are identified, and their knowledge is captured and added to the knowledge database.

In the Maintain category, the flow continues with the identification of knowledge updates. The knowledge is retrieved from the database, updated, and then added back to the database.

In the Deprecate category, the flow goes through the identification of knowledge deprecation. Once identified, the knowledge is retrieved from the database and deleted from it.

In the Search category, the flow starts with retrieving knowledge from the knowledge database. Users can then search keywords to find the knowledge they need.

All these categories connect to the knowledge database, which flows into two different ways. The first way is to end the flow, and the second way is to return the requested data. The requested data flows through the end of the flow. Overall, this flowchart represents the process of managing tacit knowledge within an organization. By following these steps, organizations can capture, maintain, and use their tacit knowledge to improve their performance and achieve their goals.

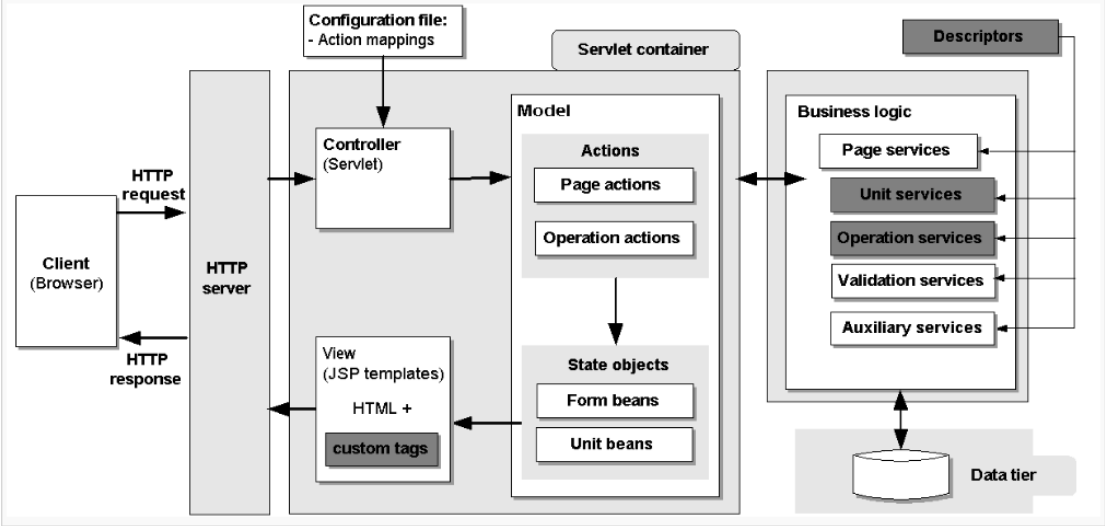

Figure 36. Flowchart. Logical Diagram of Experimental Software

Figure 36 represents the Logical diagram of the experimental software where the web application flow typically starts with the client sending an HTTP request to the server. The request is received by the HTTP server, which passes it on to the Controller. The Controller is responsible for determining the appropriate action to take based on the request. If the request is for a page, the Controller invokes the corresponding page action. If the request is for an operation, the Controller invokes the corresponding operation action [60].

The page action and operation action are responsible for interacting with the business tier to retrieve data and perform any necessary operations. The business tier consists of a set of services, including unit services, operation services, validation services, and auxiliary services. The unit services are responsible for computing the content of individual units, while the operation services encapsulate the business logic for performing operations. The validation services are responsible for validating user input, and the auxiliary services provide additional functionality as needed.

As the page action and operation action interact with the business tier, they may retrieve state objects such as form beans and unit beans. These objects contain the data needed to generate the HTML page that will be sent back to the client.

The HTML page is generated using a JSP template, which contains the necessary HTML code to define the layout of the page and custom tags to render the content of the units. Once the page is generated, it is sent back to the client as an HTTP response. Throughout the web

application flow, data may be stored and retrieved from a database. This allows the web application to maintain state and persist data across sessions.

Overall, the web application flow involves the client sending HTTP requests to the server, the server invoking the appropriate page action or operation action, the action interacting with the business tier to retrieve data and perform operations, and the resulting HTML page being generated and sent back to the client as an HTTP response.

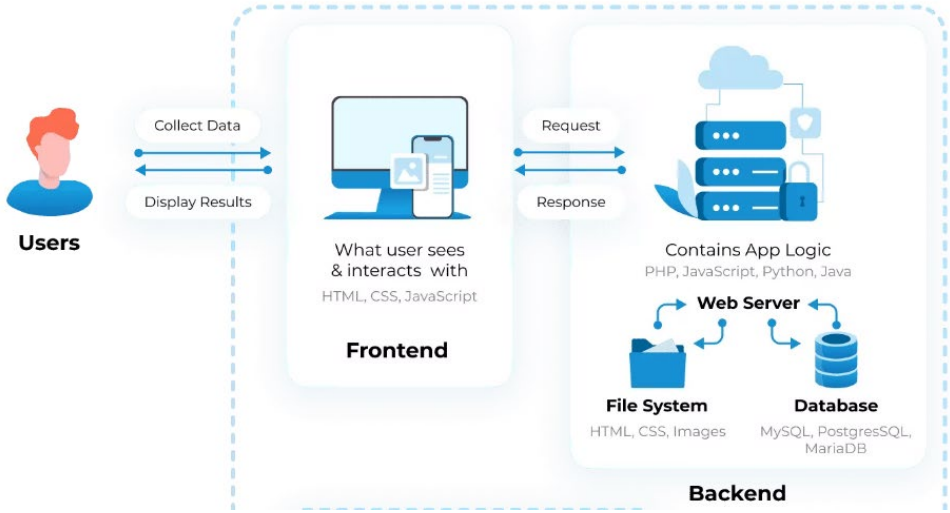

Figure 37. Flowchart. High-level architecture and low-level components

Figure 37 shows the high-level architecture and low-level components of tacit knowledge software and how they interact with each other. In. In the next section, more details are included.

Front-End Component (Browser)

Tacit Knowledge Software client-side component allows users to communicate with the server and backend service via a browser. The code runs in the browser, accepts requests, and displays the necessary information to the user. This is where user interface/user experience design, dashboards, notifications, configurational settings, layout, and interactive components come into play. The whole front-end component of the Tacit Knowledge Software is developed using HTML, CSS, jQuery, AngularJS.

- **HTML**: HTML or Hypertext Markup Language is a popular standard markup language that enables developers to structure web page contents using a series of page elements.

- **CSS**: CSS or Cascading Style Sheets is a popular style sheet language that enables developers to separate website content and layout for sites developed using markup languages.
- **JavaScript**: JavaScript or JS is the most popular client-side programming language which is used by more than 90% of websites in recent times.
- **Angular.js**: Angular is an open-source web app framework developed by Google in 2016. It is a complete rewrite of the Angular.js framework. As of now, it is one of the most popular front-end development frameworks available in the market.

Presentation Component

Presentation Component contains Web App servers. In Tacit Knowledge Model Software, Nodejs Servers are being used to perform CRUD (Create, Read, Update, and Delete) operations by processing a user's request and sending documents (JSON, XMK, etc.) back to a browser.

Back-End Component

Back-end Component of Tacit Knowledge Software Contains Business Layer and Data Layer.

- Business Layer is a virtual server instance that is built, delivered, and hosted on the Internet utilizing a public or private cloud. It functions as a physical server that can move between devices effortlessly or deploy numerous instances on a single server.
- Data Layer a critical component of a web application that stores and organizes information. In the case of tacit Knowledge Model, Oracle is being used as the Database.

A database is an organized collection of structured information, or data, typically stored electronically in a computer system. A database is usually controlled by a database management system (DBMS). Together, the data and the DBMS, along with the applications that are associated with them, are referred to as a database system, often shortened to just database. Oracle Database, also known as Oracle RDBMS (Relational Database Management System), is often used as a backend database for ERP systems like Oracle E-Business Suite,

which is used for managing financials, supply chains, human resources, and other business operations.

Data within the most common types of databases in operation today is typically modeled in rows and columns in a series of tables to make processing and data querying efficient. The data can then be easily accessed, managed, modified, updated, controlled, and organized. Most databases use structured query language (SQL) for writing and querying data.

I-85 Case study- Tacit Knowledge Modelling

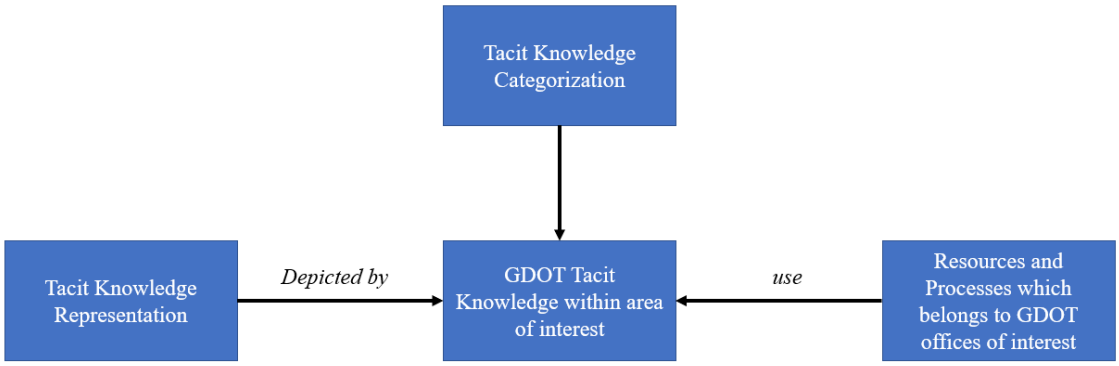

Figure 38. Chart. Preliminary Tacit Knowledge Model

Figure 38 shows the preliminary model which would be completed in Task 4. This model represents how Tacit Knowledge can be captured and categorized based on GDOT's organizational structure. Specifically, the knowledge structure includes the processes and resources within GDOT. In the current task, the Traffic Operation office has been focused and it slowly transitioned to the Bridge Maintenance department. As per the research idea, the team will use storytelling, video clips, sketches, and patterns to represent the knowledge that was captured and categorize the knowledge into experiences, core competence, incident, and analysis. The research team used this model as a foundation for the preliminary experimental software.

- **Resources and Processes which belong to GDOT offices of interest:** this is the information gathered from different offices (can be either Bridge Maintenance or Traffic Operations) in many forms such as processes, resources, camera data, sensors, or third-party applications.

- **GDOT Tacit Knowledge within the area of interest***:* originally Traffic Operations were selected but due to the complexity of the project, the Bridge Maintenance direction will be continued.
- **Tacit Knowledge Categorization**: Depends on the type of tacit knowledge already captured. The SME (Subject Matter Expert) can divide the tacit knowledge into Know-how, Lesson Learned, and Best Practices.
- **Tacit Knowledge Representation**: this is the step where the experimental software comes in. Based on the information the SME provided to the team, four tacit knowledge representations were used to capture the knowledge: Storytelling, Sketches, Video Clips, and Pattern. Further detail on the software UI (user interface) is available in Section 7.

Implementation of Tacit Knowledge Life Cycle and Tacit Knowledge Model within GDOT.

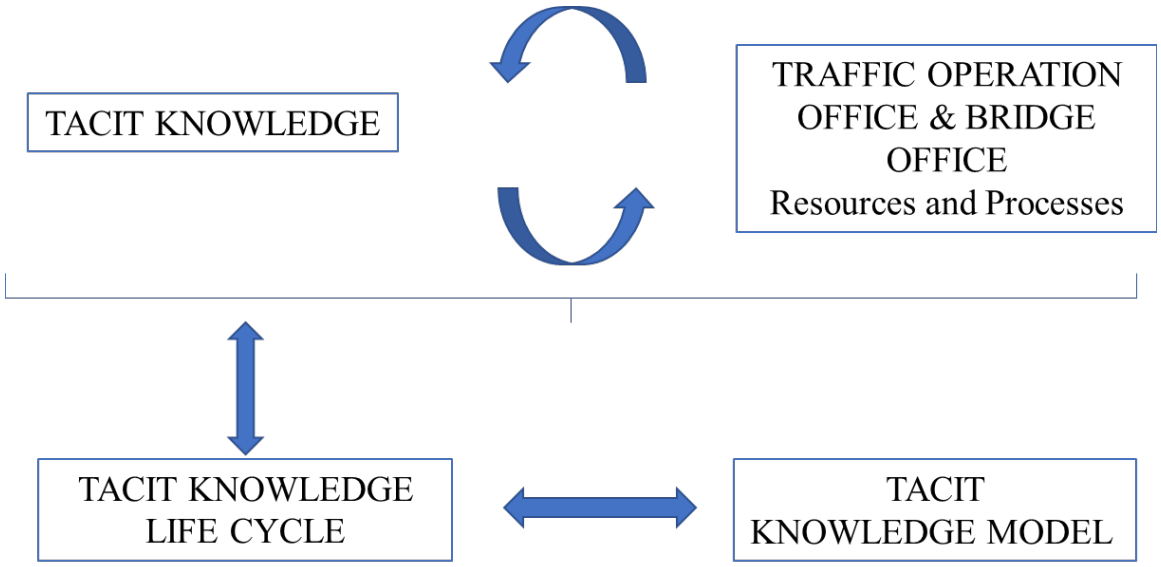

Figure 39. Chart. Implementation of Tacit Knowledge Life Cycle and Tacit Knowledge Model on GDOT

Figure 39 shows the big picture of how Tacit Knowledge Management is being used in GDOT for traffic operation offices. It starts with tacit knowledge being categorized as either process knowledge or resource knowledge. In the project, the resources and processes of the Traffic Operation and Bridge Maintenance office have been focused. The next step is feeding the tacit knowledge to the tacit knowledge model for further analysis. The model's preliminary

version was discussed in section 5. Lastly, keeping track of the creation and maintaining the validity of the knowledge via the proposed Tacit Knowledge Life Cycle, which was discussed in Section 4. Here is a detailed explanation of each component.

1. Traffic Operation Office and Bridge Office: Processes and Resources: All knowledge including processes and resources (SOPs, manual, etc.) related to Bridge Maintenance and Traffic Operations Office are valuable for capturing and reusing.

***2. Tacit Knowledge*:** knowledge resides within the expert's mind and is unlikely to be written down or verbally expressed. In GDOT, an example of tacit knowledge is the unique experiences gathered from the I-85 incident. For traffic operation, tacit knowledge is the thought processes and procedures which contribute to a successful detour. On the other hand, for the Bridge Maintenance office, the tacit knowledge is how to use the right girders, or how to cool down the concrete effectively.

3. Tacit Knowledge Life Cycle: how Tacit Knowledge starts because there is a need for knowledge creation involved, knowledge identifying, knowledge capturing, knowledge storing, knowledge mapping, knowledge sharing, and knowledge improvement.

4. Tacit Knowledge Model: the plan demonstrates the knowledge capturing process using the class diagram. This model plays the role of foundation to develop the experimental software.

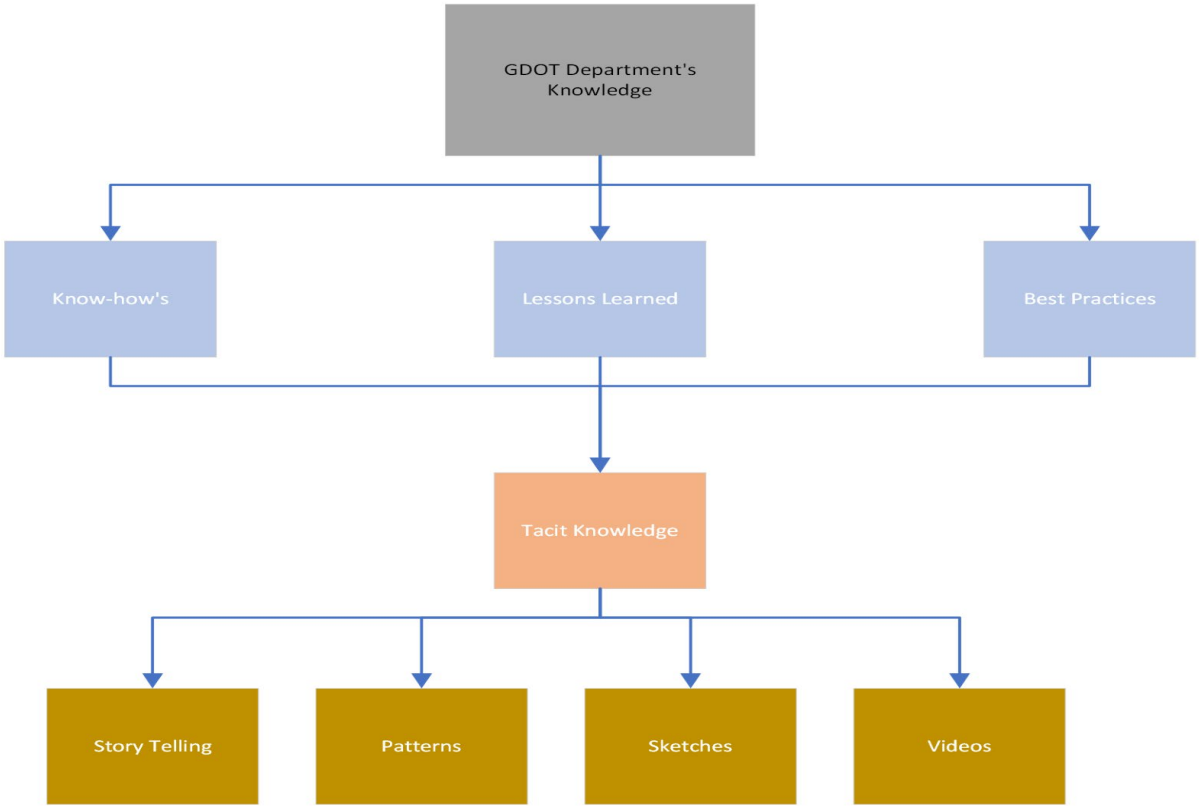

Figure 40. Flowchart. Tacit Knowledge Model

Figure 40 is the initial draft of the Tacit Knowledge Model used to represent the system using the Unified Modelling Language (UML) class diagram for the GDOT organizational structure. This technique can be used in any department to record tacit knowledge utilizing several formats, including storytelling, video clips, patterns, and sketches. The source of knowledge that has been recorded and how it might be presented are the main topics of Tacit Knowledge Model, which is an expansion of Implementation of Tacit Knowledge Life Cycle and Tacit Knowledge Model on GDOT. The KSU team discussed the Tacit Knowledge Life Cycle in Preliminary Tacit Knowledge Model, and the model complements that cycle.

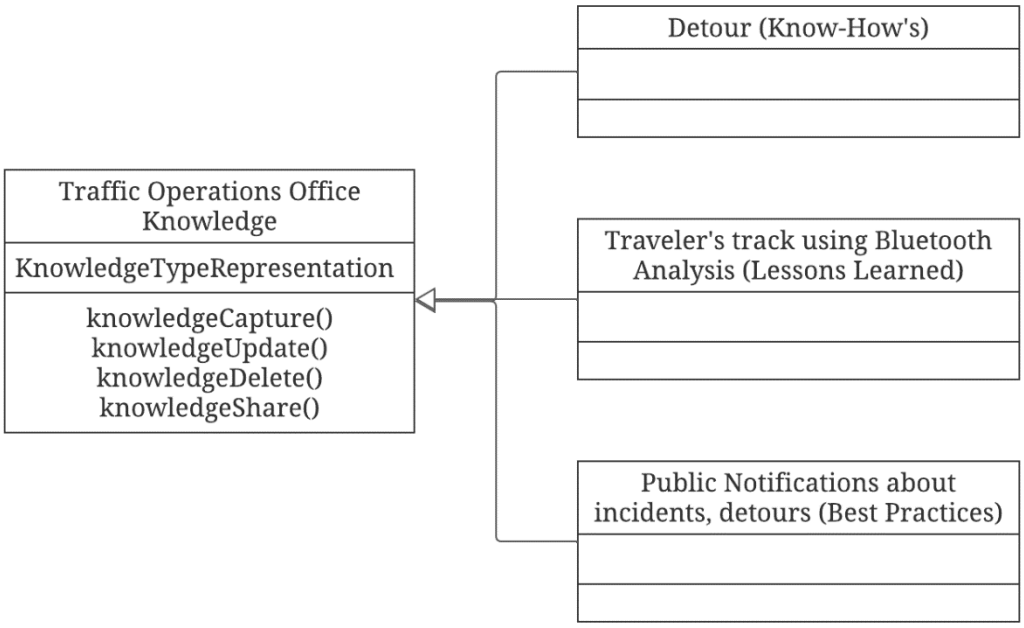

Figure 41. Chart. Example of Traffic Operations Office for the case study

Figure 41 represents the example of traffic operations which is a case study having a detail description of the detour and analysis.

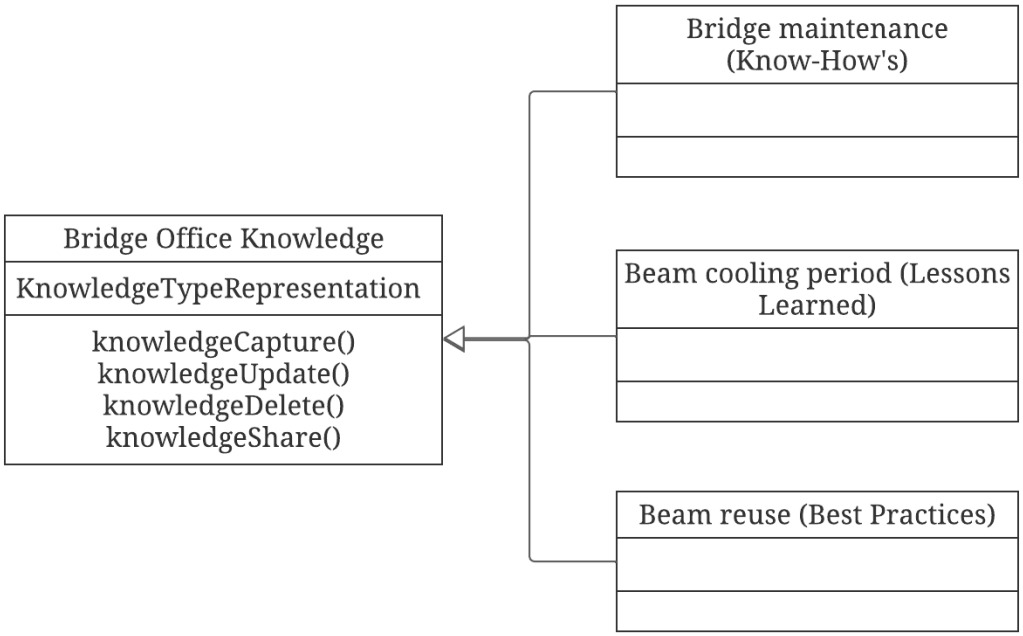

Figure 42. Chart. Example of Knowledge capture in Bridge office for case study

In Figure 42, both the Office of Traffic Operations and Bridge Maintenance are depicted. Figures 43 and 44 showcase two distinct instances of collected data, presented through one of the variations identified for illustrating tacit knowledge, as discussed in section 1. These examples were formulated based on the collected materials, interviews, and surveys from the GDOT team. Each department can thus use various knowledge representations to capture, update, remove, and distribute knowledge here (video clips, storytelling, sketches, patterns). As shown in the example of Traffic Operations Office for the case study, knowledge of the traffic operations office is the best practice is to keep the public informed about diversions and traffic events. Detours and lessons learned are the problems with Bluetooth technologies for tracking the traveler's information.

First look at the preliminary experimental software

This section demonstrates how the web application (software) can be used to capture Tacit Knowledge using the Tacit knowledge model and Tacit knowledge life cycle. The preliminary software can capture the knowledge and store it in MongoDB. The KSU Research Team is continuing in further development of exploring the various ways to share the knowledge.

This software serves the purpose of demonstrating the ability of Tacit Knowledge Management can be done digitally.

The preliminary software implemented the following stages of tacit knowledge life cycle **(**Implementation of Tacit Knowledge Life Cycle and Tacit Knowledge Model on GDOT) in Knowledge Capture, Knowledge Store, Improve/Maintenance of knowledge; and Tacit Knowledge Model within Tacit knowledge representation.

This stage of the Tacit knowledge Life cycle represents the capture of new knowledge, as there are four different knowledge representations (Story Telling, Video clips, Sketches, and Patterns) as described in the defined Tacit knowledge Model, a form to capture the knowledge was created.

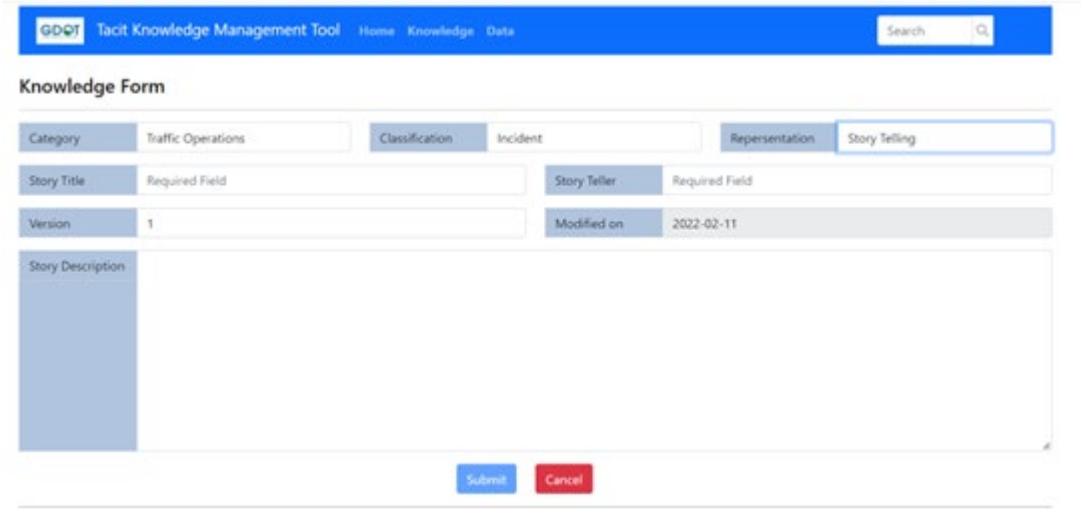

Figure 43. Screenshot. Storytelling Capture Form

Figure 43 shows the Storytelling form which captures the knowledge instance with attributes Story title, version, Storyteller, modified date, and Story description.

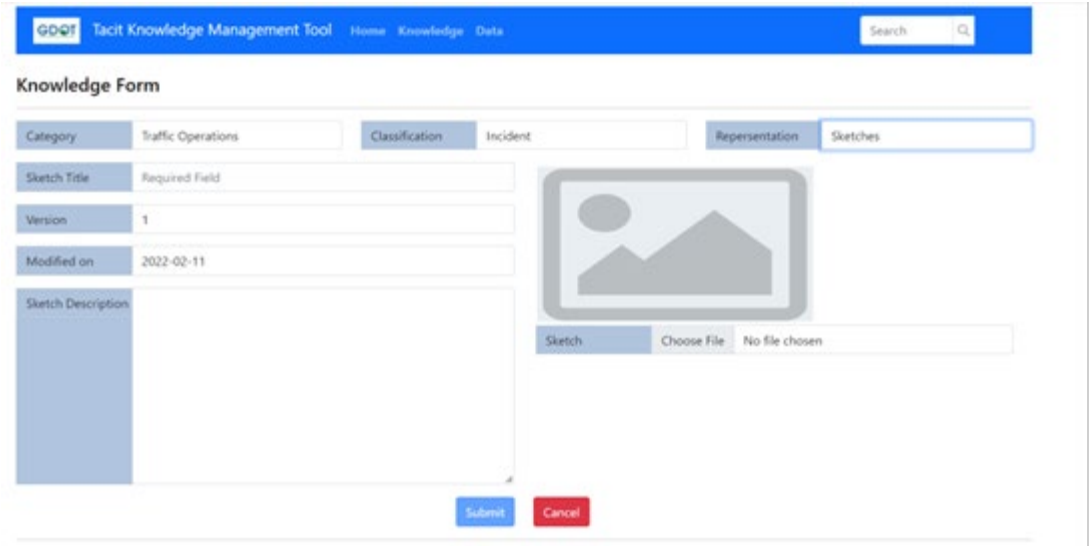

Figure 44. Screenshot. Sketch Capture form

Figure 44 shows the Sketch form which captures the Knowledge instance with attributes Sketch title, version, modified date, Sketch description, and Sketch image.

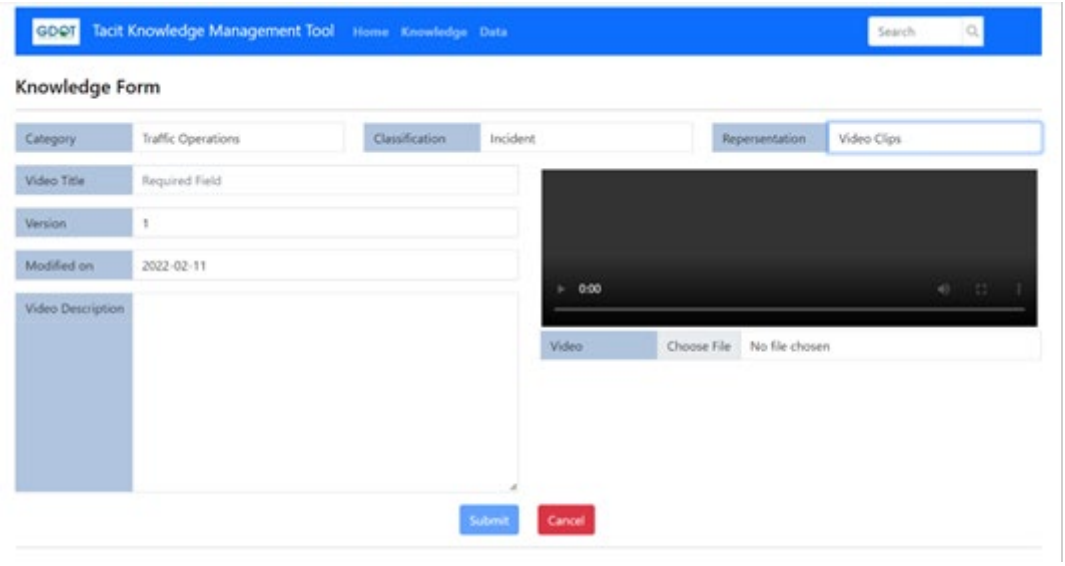

Figure 45. Screenshot. Video clip capture form

Figure 45 shows a video clip form that captures the Knowledge instance with defined attributes title, version, modified date, description, and video.

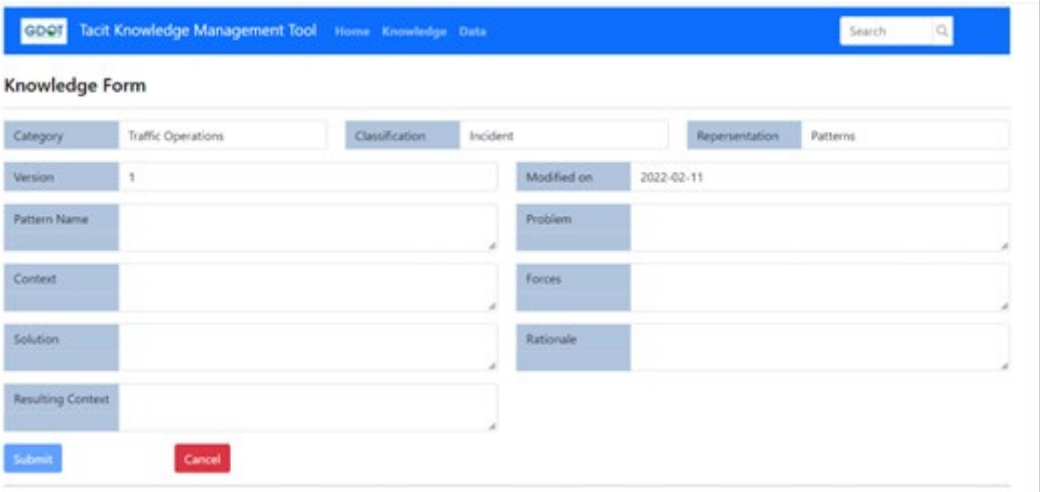

Figure 46. Screenshot. Pattern capture Form

Figure 46 shows the pattern form that captures the knowledge instance with defined attributes name, context, solution, problem, forces, rationale, and resulting context. With the click of the save button, the knowledge instance will be created and stored in MongoDB database as a document.

a. Knowledge Store

This stage of the Tacit knowledge life cycle stores knowledge, in the implemented software MongoDB, a cross-platform document-oriented database program. Classified as a NoSQL database program, MongoDB uses JSON-like documents with optional schemas.

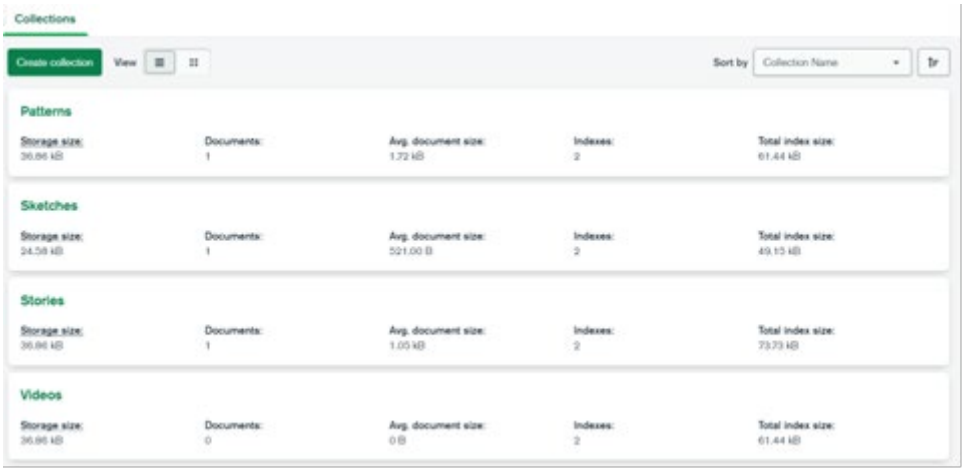

Figure 47. Screenshot. MongoDB storing the instances as documents

Figure 47 shows the stored knowledge in the database which is MongoDB used as previous database later moved for oracle database.

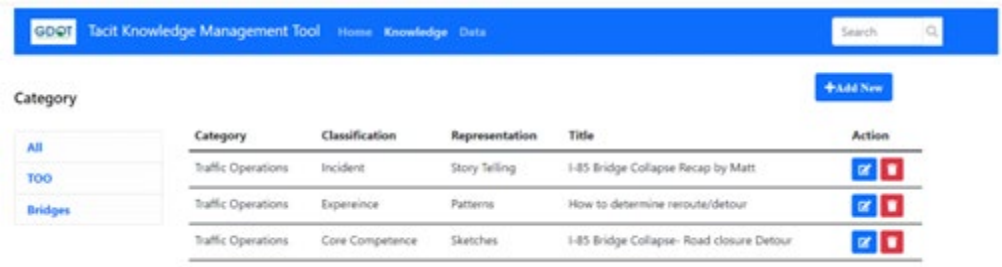

Figure 48. Screenshot. Display of knowledge stored

Figure 48 shows the User Interface screen developed to display knowledge based on the knowledge categories.

b. Knowledge Maintenance/Improvement

The preliminary software can edit/update the existing knowledge in the system and delete the depreciated knowledge which comes under the knowledge maintenance stage in Tacit Knowledge of the defined life cycle.

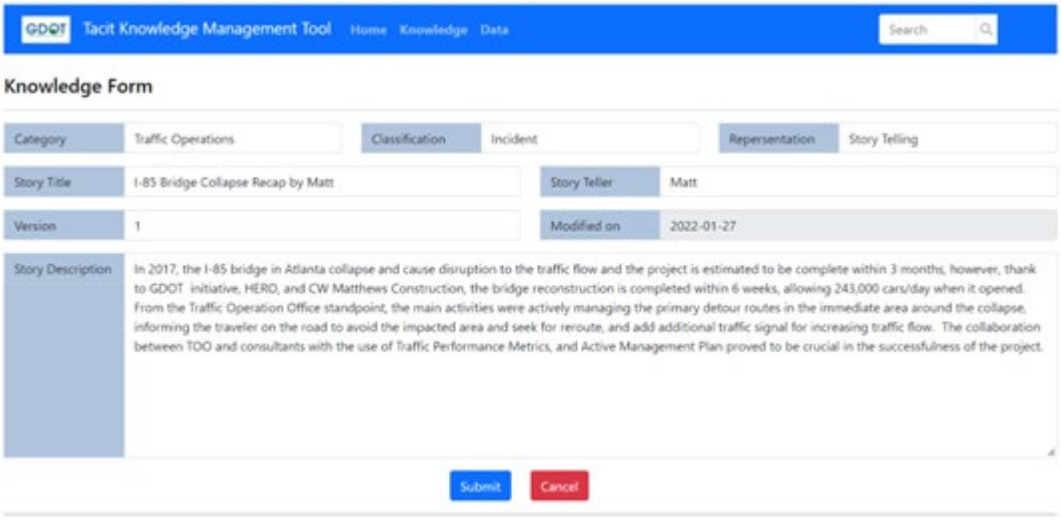

Figure 49. Screenshot. Knowledge Update

Figure 49 shows the edit page of the software developed to maintain the storytelling incident instance, on click of the save button the changes made to the form will be stored in MongoDB.

Note: For further work on the software, the compatibility of the software will be checked with the GDOT IT environment as defined in GDOT Project Proposal Task 7.

TKM Graphical User Interface:

Tacit Knowledge Model describes all the three categories (Know-hows, Lessons Learned, and Best Practices) with the common four instances (Story Telling, Sketches, Patterns, and Video Clips).

Going further the below figures describe the Tacit Knowledge Management Tool (TKM) with one of the categories (Know-hows) and representing all four instances Storytelling, Sketches, patterns and video clips.

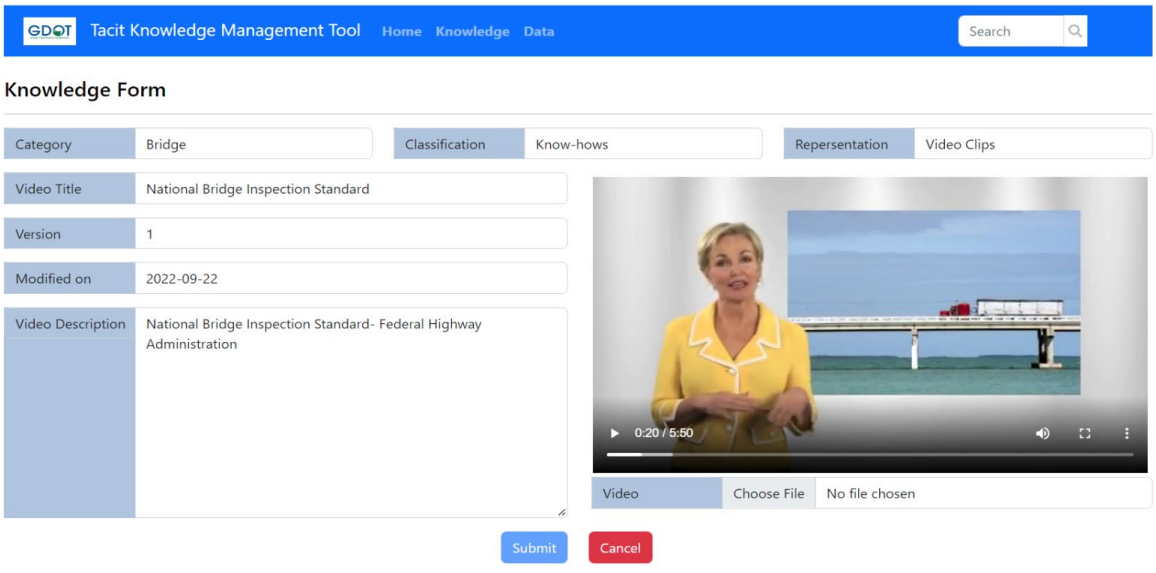

Figure 50. Screenshot. Know-hows video clips

Figure 50 illustrates the process of populating instances in the Tacit Knowledge Software for GDOT. Users can select categories (e.g., Bridge or Traffic) and classifications (Know-Hows, Lessons Learned, Best Practices) and represent information through storytelling, patterns,

sketches, or videos. In the example provided, MongoDB storing the instances as documents demonstrates a Know-How Videoclip instance, where users input data by choosing the category, classification, representation, and adding a video title and description. Users can then upload the corresponding video from their local system.

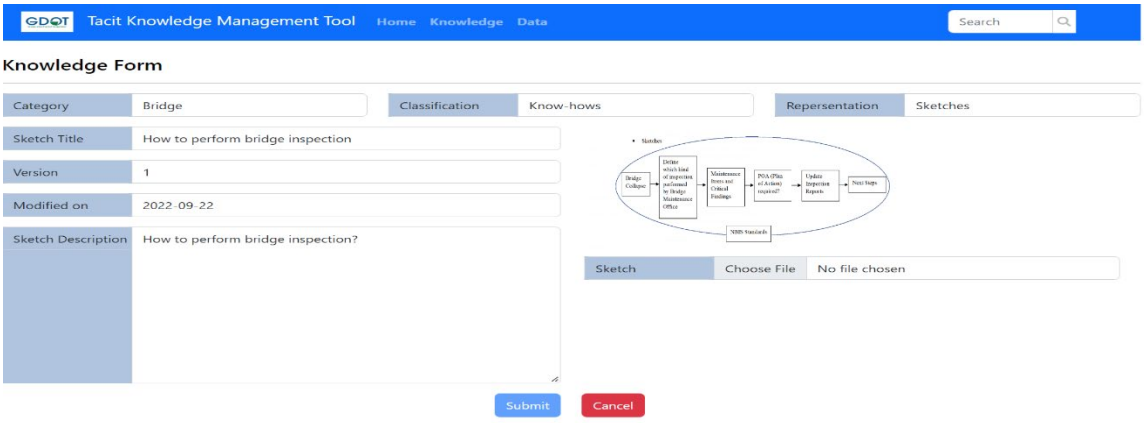

Figure 51. Screenshot. Know-hows sketches

The above Figure 51 explains how users can populate instances in the Tacit Knowledge Software for GDOT where users can choose categories (e.g., Bridge or Traffic) and classifications (Know-Hows, Lessons Learned, Best Practices), then represent the information through storytelling, patterns, sketches, or videos. Display of knowledge stored shows a Know-How Sketch instance where users can input data by selecting the category, classification, representation, and adding a Sketch title and Sketch description and can upload the Sketch (Blue-Print) image from the local system.

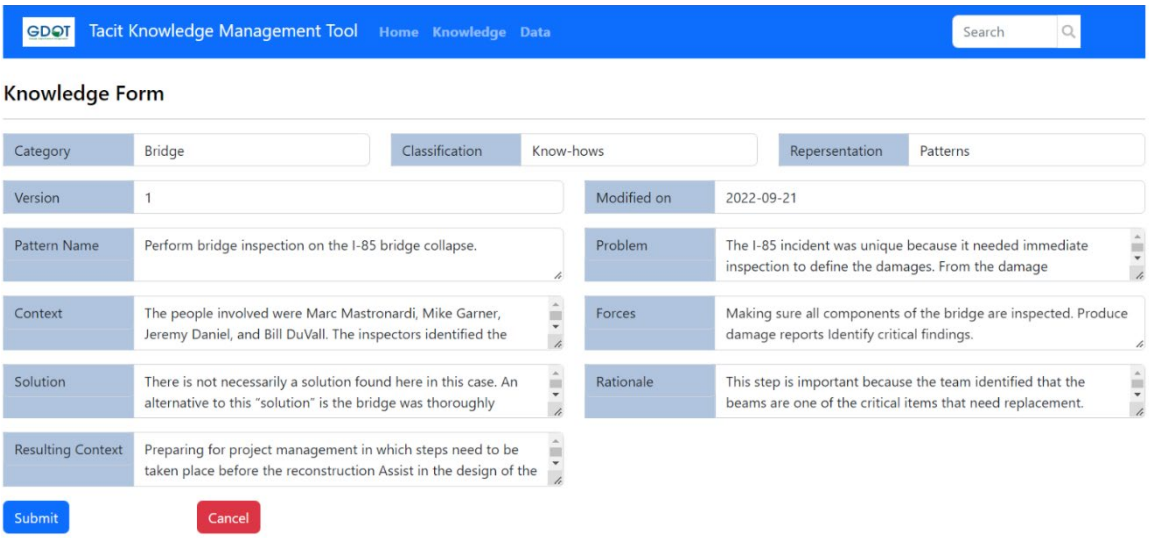

Figure 52. Screenshot. Know-hows Patterns

Figure 52 illustrates the process of populating instances in the Tacit Knowledge Software for GDOT. Users can select categories (e.g., Bridge or Traffic) and classifications (Know-Hows, Lessons Learned, Best Practices) and represent information through storytelling, patterns, sketches, or videos. In Figure 6 demonstrates a Know-How Patterns instance, where users input data by choosing the category, classification, representation, and pattern name and problem, context, Solution, Resulting Context, Forces and Rationale has context menu.

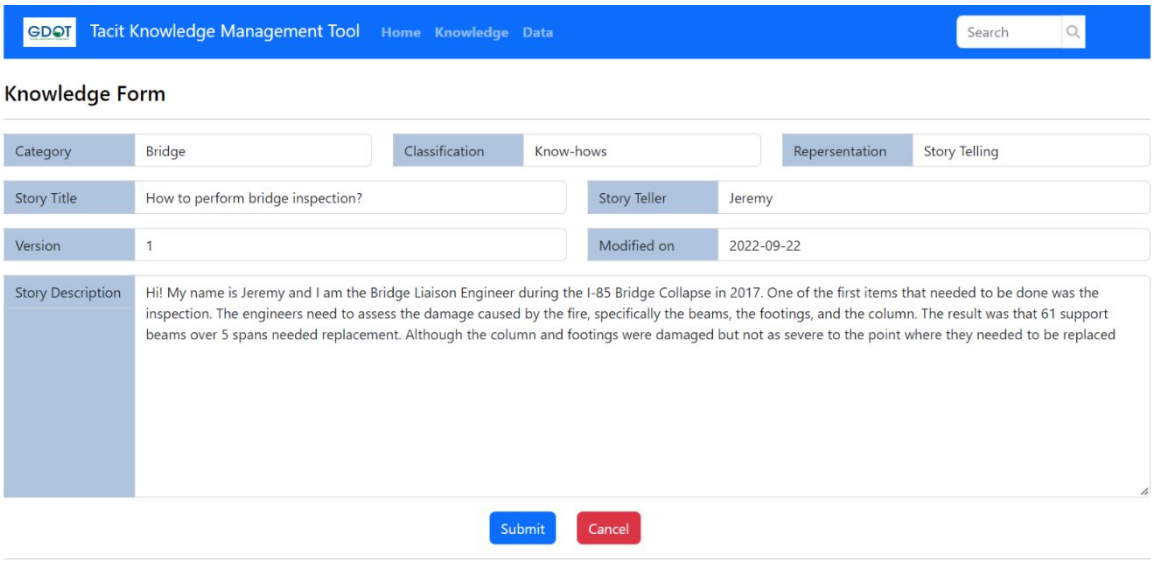

Figure 53. Screenshot. Know-hows Story Telling

Figure 53 explains how users can populate instances in the Tacit Knowledge Software for GDOT. Tacit Knowledge Repositories shows a Know-How storytelling instance where users can input data by selecting the category, classification, representation, and adding a story title, storyteller's name, and story description.

Tacit Knowledge Sharing

Figure 54. Screenshot. Tacit Knowledge Sharing

Figure 54 and tacit knowldge model depict the overall process of how the instances (video clips, stories, drawings, and patterns) are made and filled in the Tacit Knowledge model. The study project is focused on gathering people's experiences from a particular department and location and recording their expertise in the I-85 bridge collapse project. Using a tacit knowledge model (this model's first draft version was discussed in Experience U Software: section 2), the next step entails feeding and improving the instances of the tacit knowledge model for further

analysis. The proposed tacit knowledge life cycle, which was discussed in Experience U Software: section 1, is then used to track the creation and upkeep of the validity of the knowledge.

The term "Tacit Knowledge Sharing" denotes the process of sharing tacit knowledge within the GDOT tool. The TKM tool enables GDOT users to conveniently search for information within the software by utilizing the search bar functionality. For instance, users can enter queries such as "how to encapsulate the bridge column" and obtain refined outcomes relevant to the queried information, thereby optimizing their search experience.

Tacit Knowledge Store

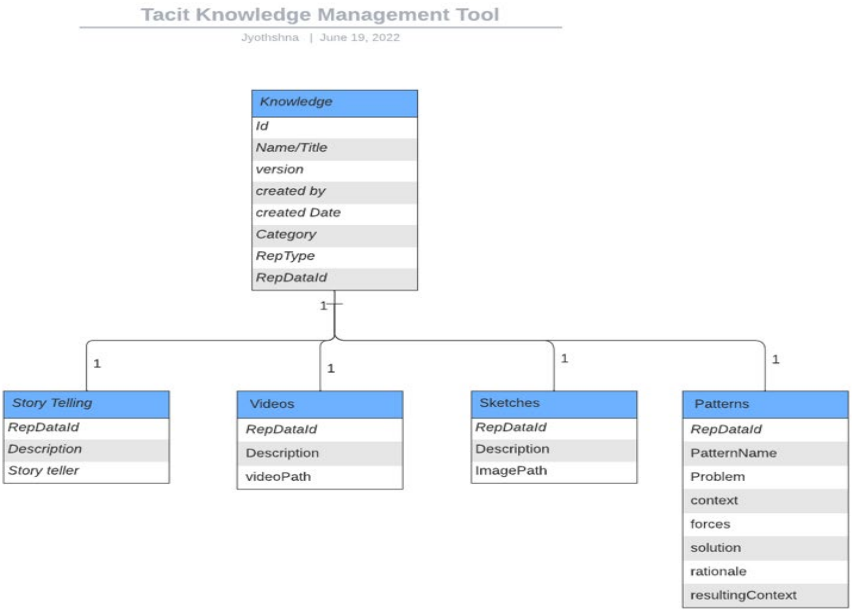

Figure 55. Screenshot. Tacit Knowledge Store

As depicted in Figure 55, in accordance with the Tacit Knowledge Model Life Cycle, the entirety of the identified and captured knowledge from various departments within GDOT is consolidated and stored within the Tacit Knowledge Store.

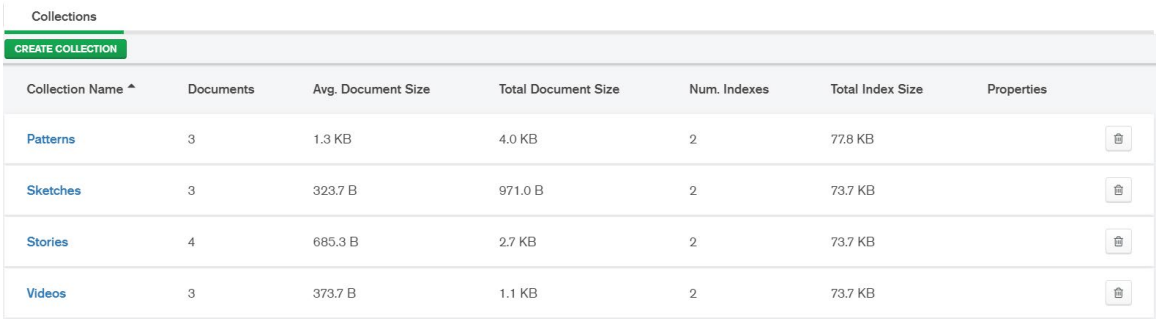

Figure 56. Screenshot. Mongo DB Screenshot

Figure 56 illustrates a stage within the Tacit Knowledge Life Cycle where captured knowledge is stored through the use of MongoDB database software. MongoDB is a versatile, cross-platform, document-oriented database system..

11. FUTURE RESEARCH:

11.1 Background & Continuation of Problem Statement:

In 2020, the KSU Research Team (KSURT) was honored to receive a grant from GDOT for the project called Tacit Knowledge Model (TKM) to support Knowledge Capture and Transfer in GDOT (RP 20-20/TO). During the project, the team analyzed tacit knowledge implementation inside and outside GDOT and interviewed near-retirees and GDOT engineers who were involved in the I-85 reconstruction in 2017. Based on the information the research team gathered, it proposed a Tacit Knowledge Model (TKM) and Tacit Knowledge Life Cycle (TKLC) to capture the experiences of experts in the organization. At the end of the project, multiple iterations of the TKM were presented to GDOT based on the information gathered [50]. The underlying drive was to present a tool that empowers knowledge experts to record their expertise using representations of tacit knowledge [51]. Moreover, this captured knowledge is useful for inexperienced engineers to gain new skills from their superiors.

In the previous project, the in-depth literature review was performed exploring the Knowledge Management advances inside and outside DOT. For example, within GDOT, there were ExperienceU and ReCORD systems available to capture knowledge. However, these systems were not used in the previous KSU project due to various reasons. One reason above all

is that both are not built to capture Tacit Knowledge. According to a survey conducted by the KSU Research team, most offices have Shared Drives or Microsoft Teams folders to store explicit knowledge - knowledge that can simply be learned by following instructions instead of critical thinking. Therefore, there is little room for an organization-wide system for storing tacit knowledge- knowledge that demands cognitive learning. The experimental software (demo) has proved that it has the capability to capture knowledge from experiences. KSURT finds it important to move forward with this research project to solve the GDOT Tacit Knowledge Management problems. The new research objectives are included in the following sections.

11.2 New Research Objectives:

Progressing with the acquired Tacit Knowledge Management (TKM) and Tacit Knowledge Lifecycle (TKLC), the next step involves enhancing the implementation process by developing a functional tool. This tool will be utilized by the HR department in GDOT to effectively gather tacit knowledge from GDOT employees nearing retirement.Using the current TKM and TKLC to create a new tool to be used by different DOTs and avoid tacit knowledge losses between DOTs organizations.

11.3 New Research Project Scope:

With the current project implementation, the complete tool functionality is proposed instead of a stand-alone application showing only a demo as an experimental software application. This new scope will need to be discussed based on objective A and objective B proposed above.

In addition to providing a more user-friendly application (new tool), the following aspects could be discussed later with the GDOT team:

- Prevent Security Issues (cyber threats/malware etc.)
- Adding New Features (as per the requirement of GDOT)
- Protect Classified Data / Precious Knowledge
- Bug Fixes (to enhance the performance of the software)

- Ensuring Compatibility (with the latest technology, multiple devices, and other software being used at GDOT). For example, connecting the new tool with the current Experience U and/or Record System at GDOT.

11.4 New Research Project Implementation Prospects:

This research delves into a fundamental knowledge framework within the Tacit Knowledge Lifecycle. It employs the notation of Unified Modeling Language class diagrams to devise a novel knowledge model aimed at effectively capturing and transmitting tacit expertise within GDOT. The figure provided below depicts the currently acquired TKM, designed for the ongoing implementation of either objective A or objective B, as previously outlined.

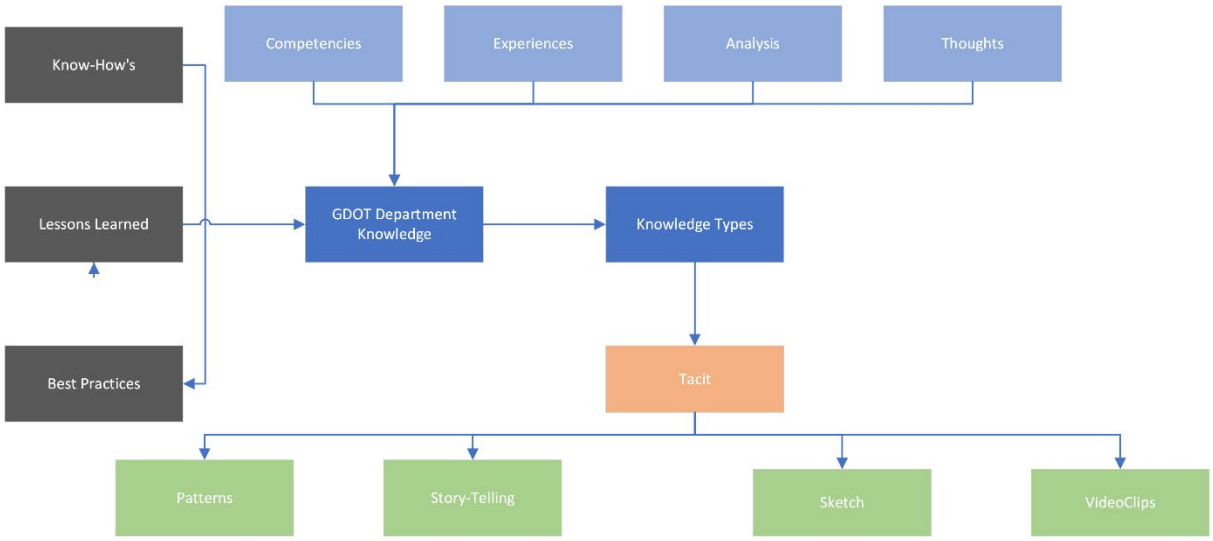

Figure 57. Chart. Capturing the Competencies, Experiences, Analysis and Thoughts

Figure 57 represents the capturing of competencies, experiences, analysis and thoughts with all the instances of the Tacit Knowledge. According to this structure, the software will be upgraded to demonstrate how GDOT tacit knowledge can not only be captured but also reused and transferred. The experimental software application could be proposed using current databases and graphical user interfaces used at GDOT or will be proposed as per latest technology advancements according to GDOT interests.

11.5 Fundamental Research about Tacit Knowledge Transfer:

This research objective is a bonus offer and dependent upon the direction GDOT chooses to advance. The KSURT is willing to develop a physical tool (e.g. a helmet) for converting Tacit Knowledge from the subconscious knowing that humans develop over time into Explicit Knowledge (which can be stated or stored). This tool will take Neurological Signals from the brain of the person (wearing it), and convert those into Electrical Signals, hence storing thoughts, experiences, ideas, etc. to be utilized for training purposes. The KSURT calls it 'Knowledge Helmet' and is willing to provide a detailed methodology for its creation.

The objective of this concept is to streamline knowledge capture and alleviate the challenge associated with extracting tacit knowledge from experts within GDOT. A noteworthy issue identified in this project pertains to the time constraints faced by experts in sharing their experiential insights.

12. CONCLUSION:

Knowledge is power, and in the case of managing critical situations such as emergencies, knowledge can be the difference between life and death. Tacit Knowledge Management (TKM) is a vital tool that can be used to manage critical knowledge that is not explicitly stated or documented. The Georgia Department of Transportation (GDOT) recognizes the importance of managing Tacit Knowledge and has undertaken a comprehensive study of TKM. The GDOT Tacit Knowledge Model (TKM) is a structured approach to managing and sharing critical tacit knowledge that has previously been withheld from traditional training methods. This research examined the importance of TKM in managing Tacit Knowledge, the development of the GDOT Tacit Knowledge Model, and its significance in promoting public health and safety.

Managing Tacit Knowledge is vital for any organization, especially for organizations that deal with emergency situations. Tacit Knowledge is knowledge that is not easily captured or documented and is usually acquired through experience and practice. This type of knowledge is critical in emergency situations as it can help decision-makers enact informed plans that save lives. Tacit knowledge gained from those with prior experience will prevent unnecessary mistakes from happening time and time again. However, managing tacit knowledge can be

challenging as it is not explicitly stated or documented. This is where TKM comes in as a vital tool for managing and sharing Tacit Knowledge.

The GDOT recognizes the importance of managing tacit knowledge and has undertaken a comprehensive study of TKM. The research team used various research methods, including document analysis, surveys, and a case study of the I-85 Highway Bridge Collapse, to develop the GDOT Tacit Knowledge Model. The model is a structured approach to managing and sharing critical Tacit Knowledge and includes best practices, lessons learned, and different forms of knowledge representation such as storytelling, graphs, sketches, and video clips. The model was evaluated by subject matter specialists in a chosen GDOT department or office and modified based on their feedback.

The deployment of the TKM will provide an invaluable resource for GDOT in managing Tacit Knowledge and ensuring quick and informed decision-making in emergency situations. The model's ongoing evaluation will identify areas for improvement and maximize its effectiveness, further strengthening GDOT's ability to manage Tacit Knowledge and promote public health and safety. The development of the TKM is a significant achievement that will positively impact public safety and underscores the importance of knowledge sharing in emergency situations. This task report identifies KM efforts in the given sectors:

a) Inside GDOT

b) Outside GDOT, but inside DOT

c) Outside DOT

The GDOT Tacit Knowledge Model is not only significant for GDOT but also serves as a model for other state DOTs. The development of the TKM is a testament to the importance of structured knowledge sharing in achieving better outcomes for the public. The research team's work provides a strong foundation for future research and innovation in the field of Tacit Knowledge Management. The model's success in managing Tacit Knowledge highlights the critical role of structured knowledge sharing in achieving better outcomes for the public.

Overall, Tacit Knowledge Management is a vital tool for managing critical knowledge that is not explicitly stated or documented. The GDOT Tacit Knowledge Model is a structured approach to managing and sharing critical Tacit Knowledge that has been developed by the research team. The deployment of the TKM will provide an invaluable resource for GDOT in managing Tacit Knowledge and ensuring quick and informed decision-making in emergency

situations. The model's ongoing evaluation will identify areas for improvement and maximize its effectiveness, further strengthening GDOT's ability to manage Tacit Knowledge and promote public health and safety. The development of the TKM is a significant achievement that will positively impact public safety and underscores the importance of knowledge sharing in emergency situations. The research team's work provides a strong foundation for future research and innovation in the field of Tacit Knowledge Management and highlights the critical role of structured knowledge sharing in achieving better outcomes for the public.

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APPENDIX 1: 13_6 Architecture Design Document (ADD):

This document is mainly about the implementation of the software whereas the Task 7 main deliverables is the implementation of software. This document extensively covers the step-by-step implementation of the software, starting from its foundational aspects. In relation to task 7, it specifically discusses the Tacit Knowledge Management tool (software). Therefore, this document has been included as a point of reference.Introduction

Tacit Knowledge management web application allows GDOT to capture the tacit knowledge across different departments. The application is not only to capture tacit knowledge but also to maintain and share the knowledge within GDOT. The knowledge capture is done using the created tacit knowledge model and following the Tacit Knowledge Life Cycle (TKLC) depicted in Figure 37. The tacit knowledge management tool is capable of the following operations:

- Capture knowledge.
- Store knowledge
- Maintain knowledge (update)
- Delete knowledge.
- Share/search for knowledge

The Figure 36 Tacit Knowledge management represents the need of knowledge creation.
Need of Knowledge Creation: It collects knowledge from Subject Matter Experts for Reuse, analysis and GDOT is no exception.

- Knowledge Identification: It categorizes the information from explicit and Tacit knowledge, where this research project mainly concentrates on Tacit Knowledge therefore, knowledge capture, knowledge store, knowledge mapping, knowledge transfer/sharing, and knowledge improving are regarding Tacit Knowledge.
- Knowledge Capture: Knowledge Capture that includes capturing experiences of things by asking basic questions such as "Know-How". Tacit knowledge is not fully understandable to the individual as this kind of knowledge comes with experience. Extracting conscious knowledge is situation-specific, writing down and documenting such knowledge is costly and difficult to use. Tacit knowledge capture cannot be done through specific rules and standards. The most useful technique that can be used to retrieve tacit knowledge is by using patterns. Behavioral interviews can be used to articulate knowledge. Another way is to simulate the artificial situation or made-up scenarios and ask the employees to apply tacit knowledge. This kind of knowledge can be retrieved and used for evaluation. This is done after the knowledge identification.
- Knowledge Store: Knowledge is stored within the database. The knowledge after being captured can be presented by storytelling, videoclips, patterns, and sketches.
- Knowledge Mapping: To properly store the knowledge, it needs to go through knowledge mapping for connecting to other knowledge within the organization.
- Knowledge Transfer/sharing: This is an important phase where the articulated knowledge will be available to utilize and create value. Knowledge can be shared and conveyed through several ways such as Storytelling, Video clips, Patterns and Sketches.
- Improve or Maintain: The organization needs to maintain and improve the knowledge continuously because outdated knowledge will no longer be useful.

1.1.System Overview

The application helps GDOT manage the project through its entire life cycle, from setting up a structure, to drawing up detailed plans, to executing and completing the project.

The tacit knowledge flowchart diagram illustrates the process that takes place within the experimental software which is obtained from Tacit Knowledge Life cycle which is shown in

Figure 61, the diagram of the Experimental Software Application. This flowchart is designed to identify, capture, maintain, deprecate, and search for tacit knowledge in the organization.

The flowchart starts with the process, which is divided into four categories: New, Maintain, Deprecate, and Search. Each of these categories represents a different stage in the knowledge management process.

In the New category, the flow continues with the identification of tacit knowledge. The key people who possess this knowledge are identified, and their knowledge is captured and added to the knowledge database.

In the Maintain category, the flow continues with the identification of knowledge updates. The knowledge is retrieved from the database, updated, and then added back to the database.

In the Deprecate category, the flow goes through the identification of knowledge decrease in the value. Once identified, the knowledge is retrieved from the database and deleted from it.

In the Search category, the flow starts with retrieving knowledge from the knowledge database. Users can then search with keywords to find the knowledge they need.

All these categories connect to the knowledge database which flows in two different ways. The first way is to end the flow, and the second way is to return the requested data. The requested data flows through the end of the flow.

Overall, this flowchart represents the process of managing tacit knowledge within an organization. By following these steps, organizations can capture, maintain, and use their tacit knowledge to improve their performance and achieve their goals.

1.2.Goals and Objectives

To create a tacit knowledge model and to identify, organize, store, reuse and maintain tacit knowledge in order to reuse complex experiences gained from previous projects in GDOT. The purpose of this model is to improve the agency's efficiency by providing a tacit knowledge model that transfers complex skills between GDOT departments, which the agency's current computer-based system cannot capture. This is an experimental software that intends to show case the working nature of Tacit knowledge model while implementing the Tacit Knowledge Life Cycle (TKL).

External Users:

- To be defined

Internal Users:

- GDOT

1.3.Design:

1.3.1. The web application does not have any user management module. It will be managed by GDOT internal authorization system for user management.

1.4.Logical Diagrams

Figure 38 represents the web application flow typically starts with the client sending an HTTP request to the server. The request is received by the HTTP server, which passes it on to the Controller. The Controller is responsible for determining the appropriate action to take based on the request. If the request is for a page, the Controller invokes the corresponding page action. If the request is for an operation, the Controller invokes the corresponding operation action.
The page action and operation action are responsible for interacting with the business tier to retrieve data and perform any necessary operations. The business tier consists of a set of services, including unit services, operation services, validation services, and auxiliary services. The unit services are responsible for computing the content of individual units, while the operation services encapsulate the business logic for performing operations. The validation services are responsible for validating user input, and the auxiliary services provide additional functionality as needed.

As the page action and operation action interact with the business tier, they may retrieve state objects such as form beans and unit beans. These objects contain the data needed to generate the HTML page that will be sent back to the client.

The HTML page is generated using a JSP template, which contains the necessary HTML code to define the layout of the page and custom tags to render the content of the units. Once the page is generated, it is sent back to the client as an HTTP response.

Throughout the web application flow, data may be stored and retrieved from a database. This allows the web application to maintain state and persist data across sessions.

Overall, the web application flow involves the client sending HTTP requests to the server, the server invoking the appropriate page action or operation action, the action interacting with the business tier to retrieve data and perform operations, and the resulting HTML page being generated and sent back to the client as an HTTP response.

1.5.Physical Diagrams

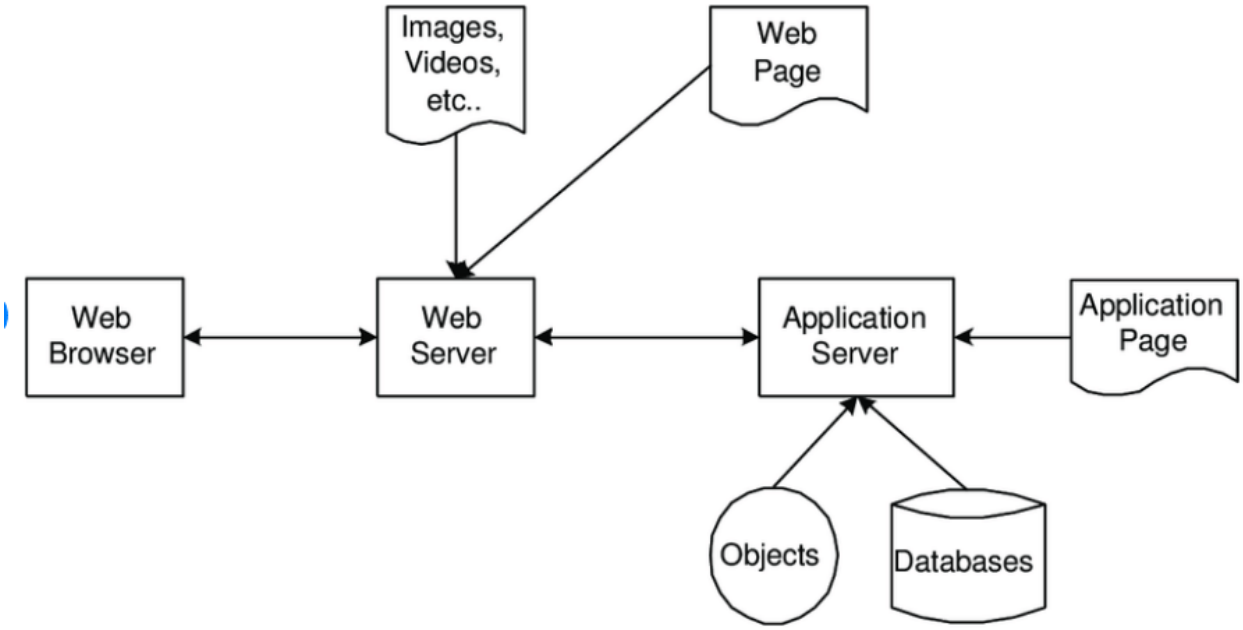

Figure 58. Diagram. Appendix1 - physical diagram of the Experimental Software Application

Figure 58 depicts web development involving various components, including web browsers that allow users to access web pages, images, and videos stored on web servers. Application servers are used to provide services to web applications, which can access and retrieve data from databases. Web pages typically contain various objects such as images and buttons, and application pages provide a user interface for web applications to interact with the server and access data. These components work together to enable users to access and interact with web-based content and applications over the internet.

RBAC (Roles Based Access Control)

Roles Based Access Control is an approach to restricting system access to authorized users. This mechanism can be used to protect users from accessing parts of the system that they do not need. It also can be used to restrict access to data which they do not need to see.

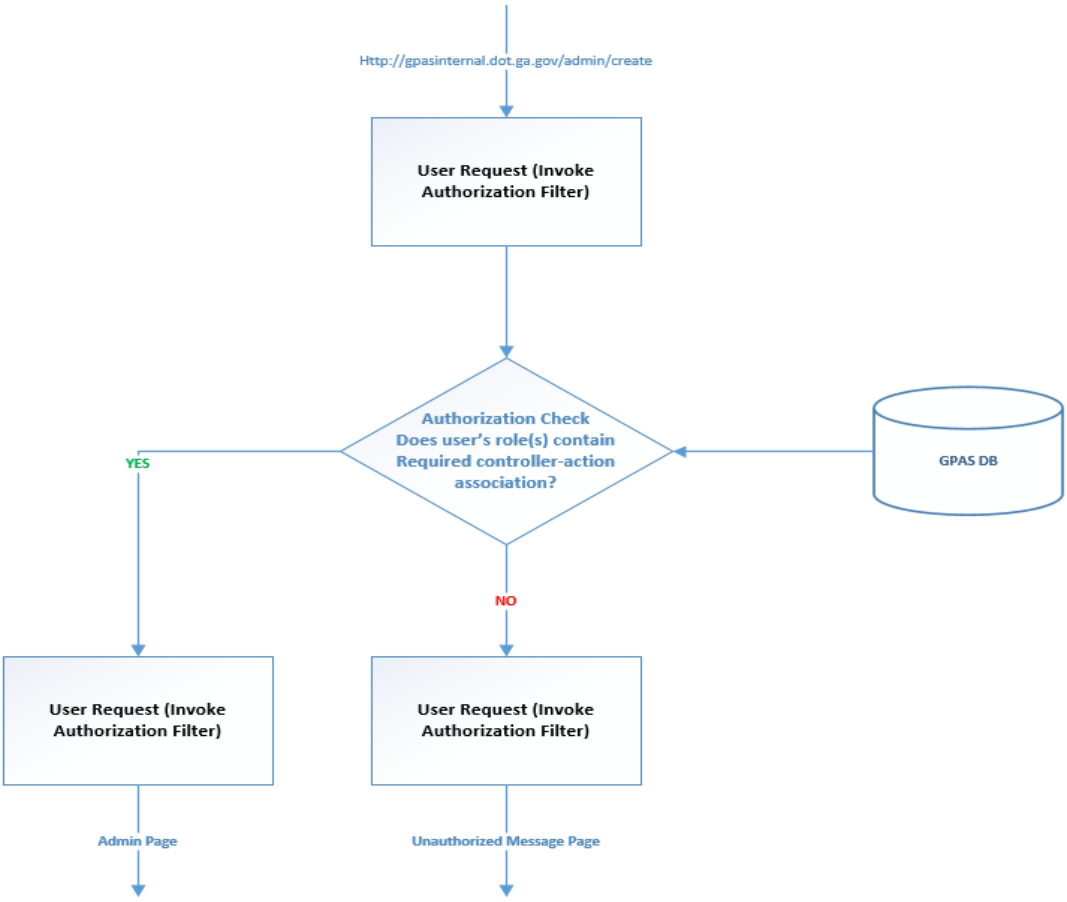

Figure 59. Diagram. Appendix1 - Role based Access Control.

Figure 59 shows the web application flow described after the first step after a user sends a request to the server is an authorization check. This is where the server checks whether the user's role contains the required controller-action association.

Role-Based Access Control (RBAC) is a method of restricting access to resources based on the roles assigned to users within an organization. In a web application, this means that certain actions or pages can only be accessed by users with specific roles. For example, a customer may be allowed to view their account information, but not to edit it, while an administrator may be allowed to edit customer accounts.

To implement RBAC, the web application needs to maintain a list of roles and the associated permissions. Each user is then assigned one or more roles, and their access to resources is determined by their assigned roles. When a user sends a request to the server, the server checks the user's role against the required role for the requested resource, and either grants or denies access accordingly.

If the user's role does not contain the required controller-action association, the server sends an unauthorized message page to the user, explaining that they do not have permission to access the requested resource. This helps to ensure the security of the web application and prevent unauthorized access to sensitive information or functionality.

1.6. System Pre-requisites

This solution will utilize the following software and languages which are explained in the Literature Review about knowledge Management from outside and inside GDOT.

- Oracle
- Angular CLI
- NodeJS
- Typescript
- Bootstrap
- Express
- Nodemon

2 Software Development

Introduction

This Software Development explains the development of the Tacit Knowledge software and how the software supports storage, maintenance, and sharing of GDOT's knowledge.

Four main sections are reported. The Tacit Knowledge Architecture and Design overview is explained in section 2.1.

The information and knowledge (Instances) population into the Tacit Knowledge Software is discussed in section 2.2.

New information and knowledge population into the Tacit Knowledge Software is presented in section 2.3

Search for an existing instance using Tacit Knowledge Search Engine is presented in section 2.4.

Software development environment is presented in section 2.5.

2.1 Tacit Knowledge Software Architecture and Design

High-level architecture and low-level components shows high-level architecture and low-level components of Tacit knowledge. Software and how they interact with each other. In the next section, more details are included.

Front-end Component (Browser)

Tacit Knowledge Software client-side component allows users to communicate with the server and backend service via a browser. The code runs in the browser, accepts requests, and displays the necessary information to the user. This is where user interface/user experience design, dashboards, notifications, configurational settings, layout, and interactive components come into play.

The whole front-end component of the Tacit Knowledge Software is developed using HTML, CSS, jQuery, Angularjs.

HTML

HTML or Hypertext Markup Language is a popular standard markup language that enables developers to structure web page contents using a series of page elements.

CSS

CSS or Cascading Style Sheets is a popular style sheet language that enables developers to separate website content and layout for sites developed using markup languages

JavaScript

JavaScript or JS is the most popular client-side programming language which is used by more than 90% of websites in recent times

Angular.js

Angular is an open-source web app framework developed by Google in 2016. It is a complete rewrite of the Angular.js framework. As of now, it is one of the most popular front-end development frameworks available in the market.

Presentation Component

Presentation Component contains Web App servers. In Tacit Knowledge Model Software, Nodejs Servers are being used to perform CRUD (Create, Read, Update, and Delete) operations by processing a user's request and sending documents (JSON, XMK, etc.) back to a browser.

➢ High Level Design

Back-end Component

Back-end Component of Tacit Knowledge Software Contains Business Layer and Data Layer

Business Layer

Business Layer is a virtual server instance that is built, delivered, and hosted on the Internet utilizing a public or private cloud. It functions as a physical server that can move between devices effortlessly or deploy numerous instances on a single server.

Data Layer

A database is a critical component of a web application that stores and organizes information. In the case of tacit Knowledge Model, Oracle is being used as the Database.

Oracle Database, also known as Oracle RDBMS (Relational Database Management System). Oracle Database is often used as a backend database for ERP systems like Oracle E-Business Suite, which is used for managing financials, supply chains, human resources, and other business operations.

A database is an organized collection of structured information, or data, typically stored electronically in a computer system. A database is usually controlled by a database management

system (DBMS). Together, the data and the DBMS, along with the applications that are associated with them, are referred to as a database system, often shortened to just database.
Data within the most common types of databases in operation today is typically modeled in rows and columns in a series of tables to make processing and data querying efficient. The data can then be easily accessed, managed, modified, updated, controlled, and organized. Most databases use structured query language (SQL) for writing and querying data.
To create tables in an Oracle database, the SQL CREATE TABLE statement can be used. The basic syntax for creating a table in Oracle is as follows:

```
CREATE TABLE Knowledge(
id NUMBER(5) PRIMARY KEY,
Name VARCHAR2(50) NOT NULL,
Version VARCHAR2(50),
createdBy NUMBER(10, 2),
createdDate NUMBER(10, 2),
Category VARCHAR2(50),
Rep Type VARCHAR,
RepDataId NUMBER
);
```

Data Access Layer
ERD (With data types and length)

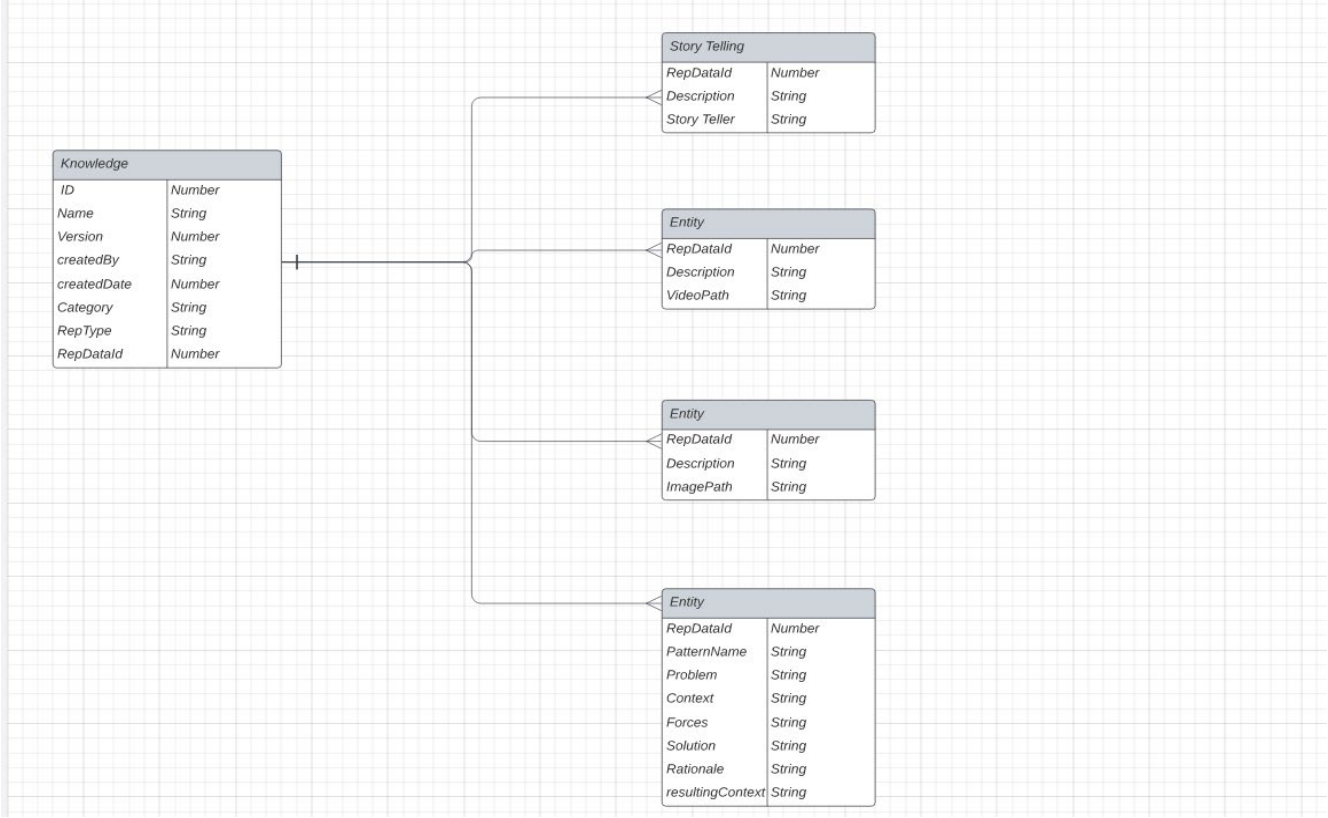

Figure 60. Diagram. Appendix1 - Entity Relationship Diagram

Figure 60 shows how the instances are stored in the Oracle database. This diagram extends the understanding of how the stages of the Tacit knowledge life cycle store knowledge in the implemented software used.

1.7 Dependencies and External Interfaces

As of today, the application uses the dependencies that are required for the MEAN stack application development, the high-level architecture is as below:

Required:

- Angular and its related dependencies
- Bootstrap
- Rxjs
- CSS

Other Dependencies:

- Multer - node.js middleware for handling multipart/form-data, which is primarily used for uploading files.
- Path module – to extract path from local system.

Note: As per current requirements, any external libraries have not been integrated, but any can be used based on the change of requirements.

The Information and knowledge (Instances) population into the Tacit Knowledge Software:

1.7.1 Low Level Design

1.7.1.1Solution Components (UI (User Interface), Business Layer)

1.7.1.1.1 UI

This section contains information regarding how the user can populate Instances in the Tacit Knowledge Software and seeks to validate the usage of model structures as a store for information and knowledge related to GDOT.

Any user from GDOT can populate information in Tacit Knowledge Software by selecting any one of the categories (for Example Bridge or Traffic) and classification (Know-Hows, Lessons learned, Best practices) and can represent in the form of Storytelling, Patterns, Sketches, and Videos.

1.7.1.1.1. Screen Mock Ups

Figures 8 – 11 show the instances stored in the tacit knowledge model using the graphical user interface designed using visual studio. The object-oriented design and analysis for the tacit knowledge model is presented in Approach to Retrieve Stored Knowledge and explained in the task 6 report. The Task 7 report includes how the tacit knowledge model was implemented.

1.7.2 Business Layer

1.7.2.2Entity Diagrams (Optional)

1.7.2.2.2 Class Diagrams, Interface Diagrams

The Tacit Knowledge Lifecycle depicts the basic structure of the tacit knowledge model represented using the Unified Modelling Language (UML) class diagram for the GDOT organizational structure. An extended explanation of this UML class diagram was presented in Task 6 report.

1.7.3 New information and knowledge population into the Tacit Knowledge Software

To populate new instances in the tacit knowledge model, the Tacit Knowledge Life Cycle (TKL) is used which is depicted in the next figure 13. This is a simplification of the TKL presented and explained in the task 6 report.

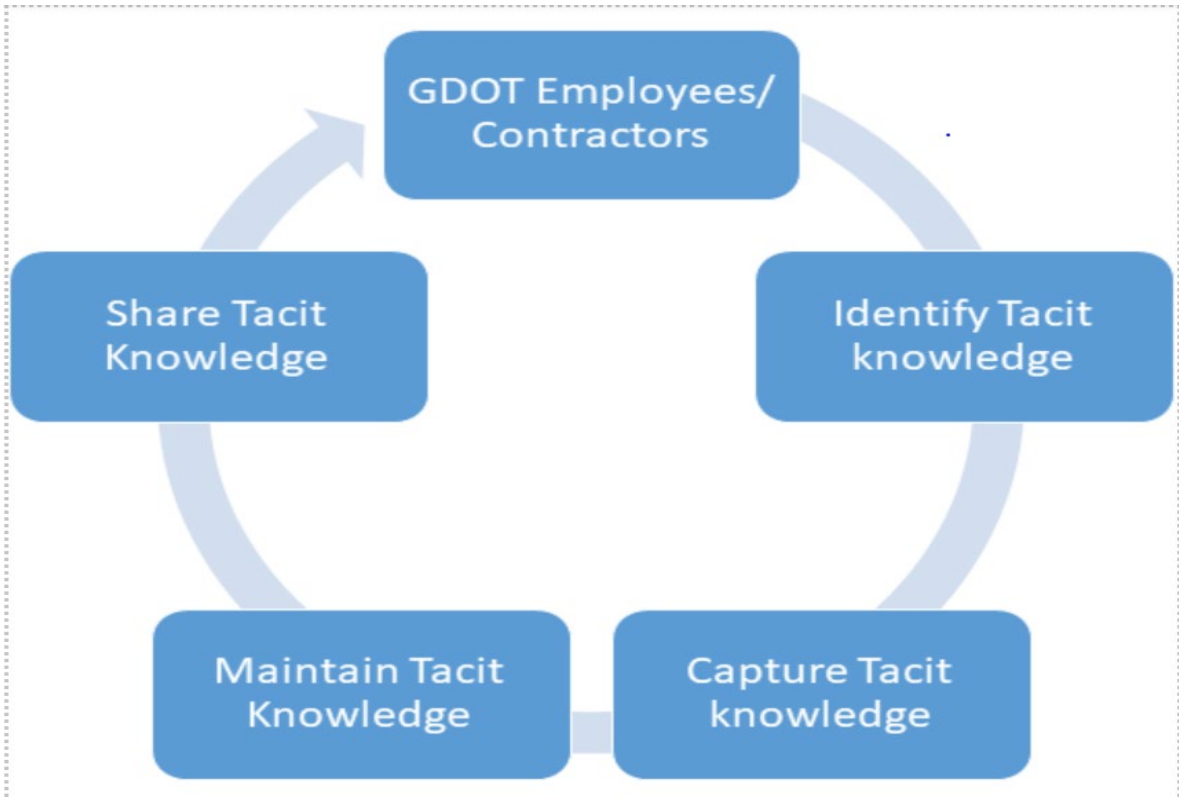

Figure 61. Flowchart. Appendix1 - Simplification of Tacit Knowledge Life Cycle

The Figure 61 describes the tacit knowledge life cycle of share tacit knowledge and the maintains of tacit knowledge.

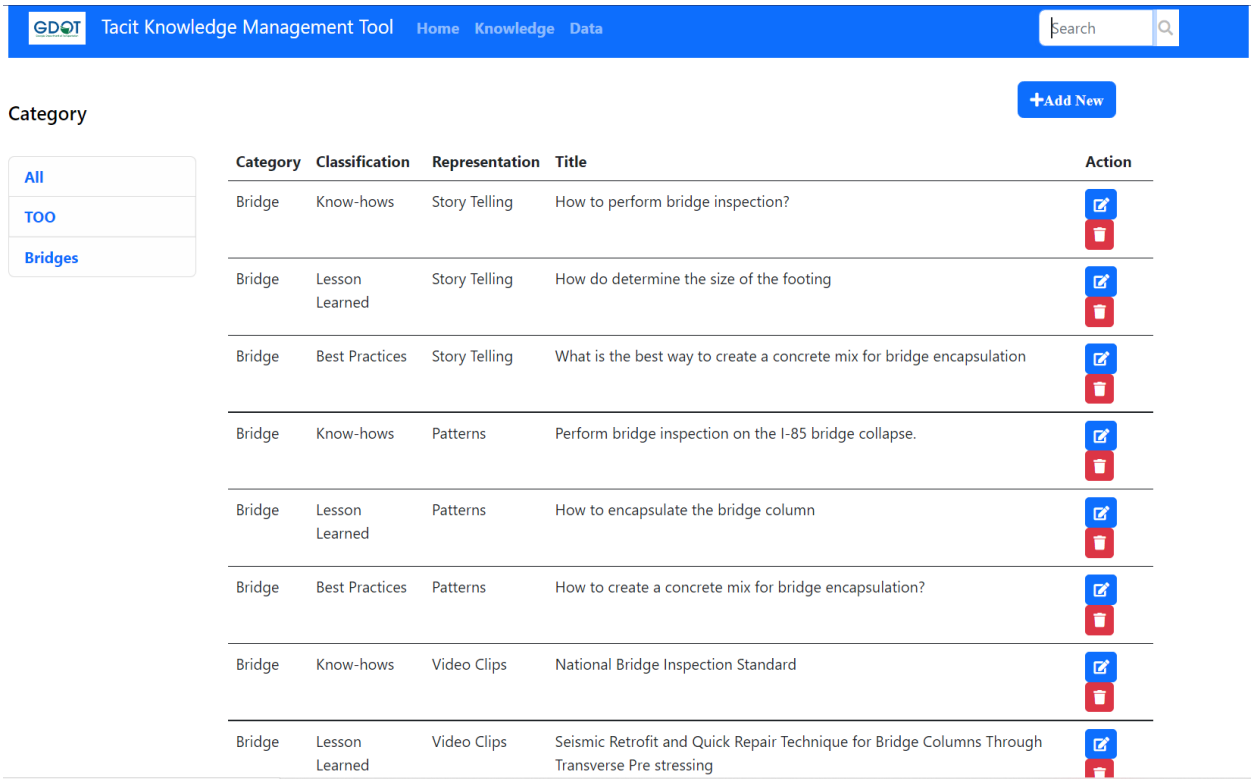

Figure 62. Screenshot. Appendix1 - New information and knowledge population into the Tacit Knowledge Software

Figure 62 shows existing instances stored into the Tacit knowledge Software. Updating the information can be done in three manners after simply clicking on edit and delete button: a) edit the instance from the database and update the attributes defined for an instance, b) add new resource instances, and c) delete the instance.

1.7.4 Search for an existing instance using Tacit Knowledge Search Engine

A search engine is integrated into Tacit Knowledge Software and its job is to find the instances the user is looking for by matching the user's keyword search with the existing instances in the software. It filters instances based on user queries.

1.7.5 Software development environment:

The Tacit Knowledge Software has three stages of environment: Development, Beta, and Production. Each environment has its own unique purpose.

Development Environment

The development environment is used to build Tacit Knowledge Software, and where developers from the KSU team will complete most of their work. Typically, the development environment is set up on local computers, and work is facilitated by a Git repository. Users and customers cannot access anything done in the development environment unless Developers show them.

Beta Environment

The beta environment is used to test the software. Before the team releases from development to beta, The KSU Research Team will usually copy what is currently on the production environment down to beta. This helps the team to test not only the new code, but allows them to assess how the next release will affect what is currently live.

This stage can be used not only for testing the new functionality, but also as an opportunity to demonstrate the newly completed work to the product owner or test it with users and get feedback.

Production environment

Production is the final environment in the software development process where the Tacit knowledge software should be ready to be available for the GDOT users, and only the most thoroughly tested code should end up here.

- **APPENDIX 2: Operation Manual:**

In order to run the Tacit Knowledge Software in a local system the following software needs to be installed.

Nodejs(Software1)

In order to Install Node.js and npm download and install Node.js from the official website:

Windows 64-bit Installer: https://nodejs.org/dist/v12.14.0/node-v12.14.0-x64.msi

After Downloading to ensure whether Nodejs is working open the command prompt by typing CMD in the Windows search bar.

In the following command prompt type node-v in order to show the current version of the software installed. This can be observed in the Screenshot of Starting Server.

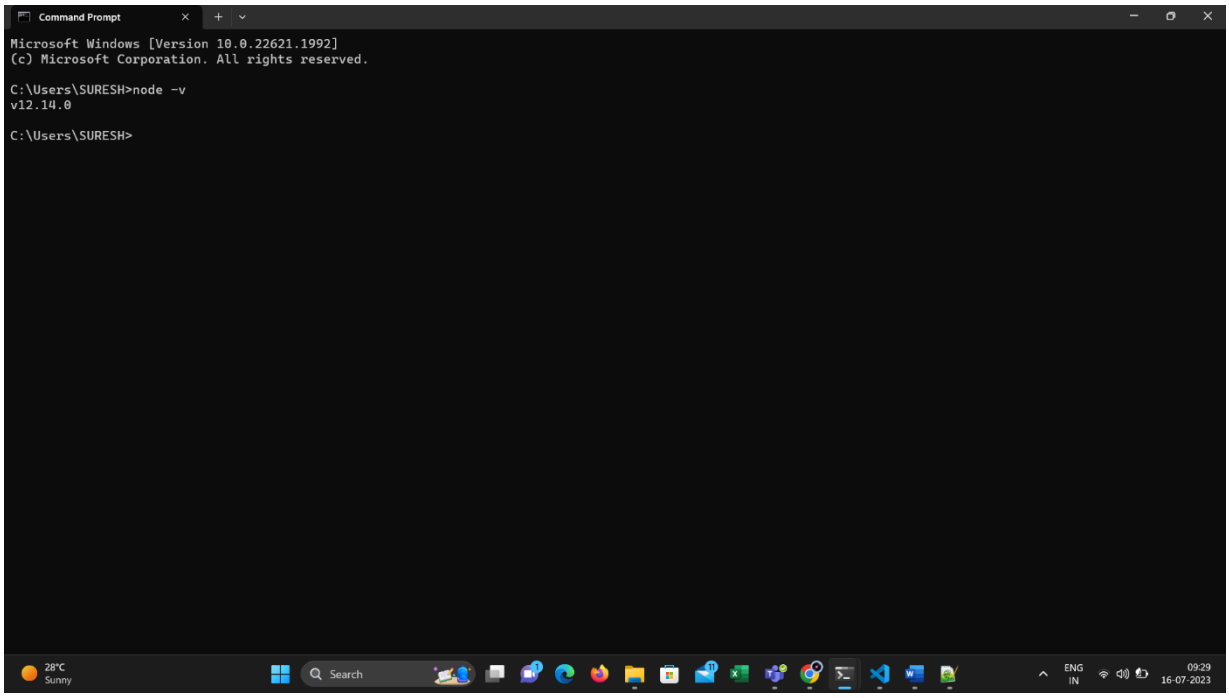

Figure 63. Screenshot. CMD in windows search bar

AngularJs (Software2)

For installing AngularJs, it is required to open CMD from Windows and type the command **npm install -g @angular/cli@12.2.5**

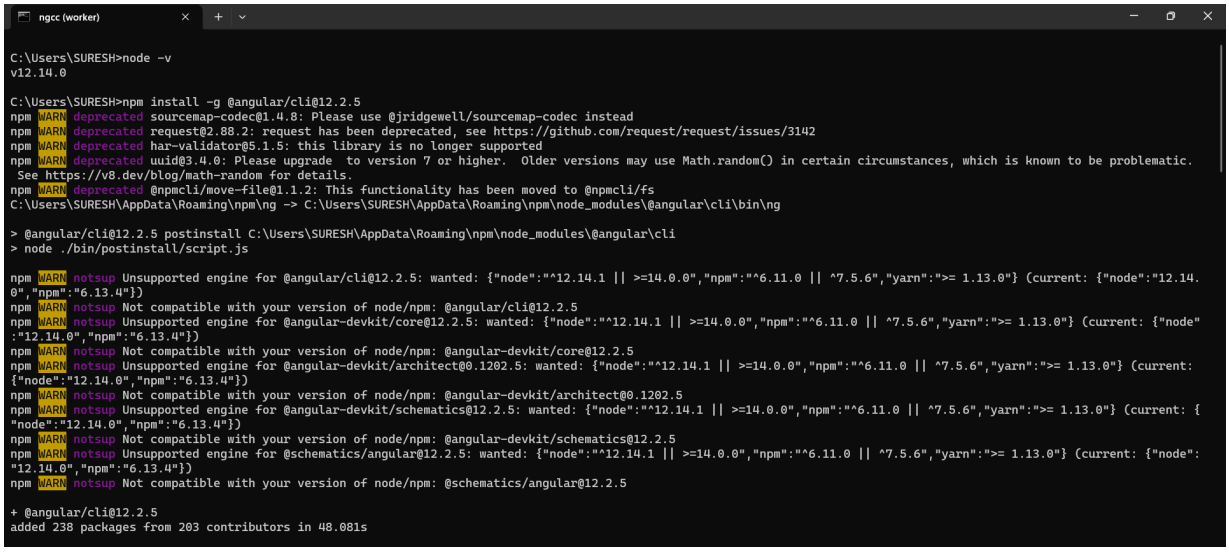

Figure 64. Screenshot. Installing AngularJs (Software2)

In order to ensure that AngularJs is installed type angular-v in CMD to show the current version installed in the user's local system

ng version

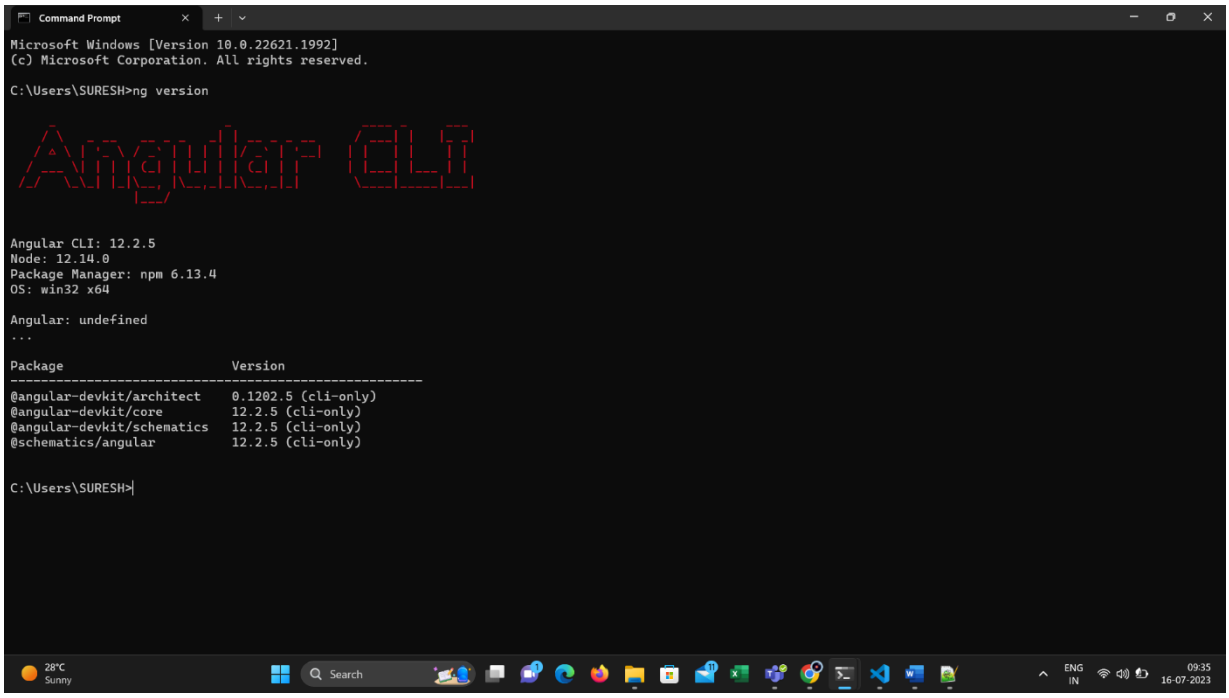

Figure 65. Screenshot. AngularJs Current Version

Install Oracle Database 19c on Windows step by step.

1. Download Oracle Database 19c software for Windows

The first step is to get the Oracle 19c software for Windows from the official Oracle download page. On this page, many packages can be found. In this guide, the *Oracle Database 19c (19.3) for Microsoft Windows x64 (64-bit)* package will be focused. If the user wants to access his/her future Oracle database remotely, he/she can also download the *Oracle Database 19c Client (19.3) for Microsoft Windows x64 (64-bit)* or *Oracle Database 19c Client (19.3) for Microsoft Windows (32-bit)* according to the architecture of the client computer.

Downloading Oracle 19c software is free, however, to use it in the production environment requires a license. Note also that downloading requires an Oracle account.

2. Launch the setup wizard

Once the download is complete

- unzip the package then copy it to the root of the disk;
- rename the folder, choose a shorter name (e.g. *db_home*);
- then launch the setup.

Note: the installation wizard may take several minutes to open. So be patient.

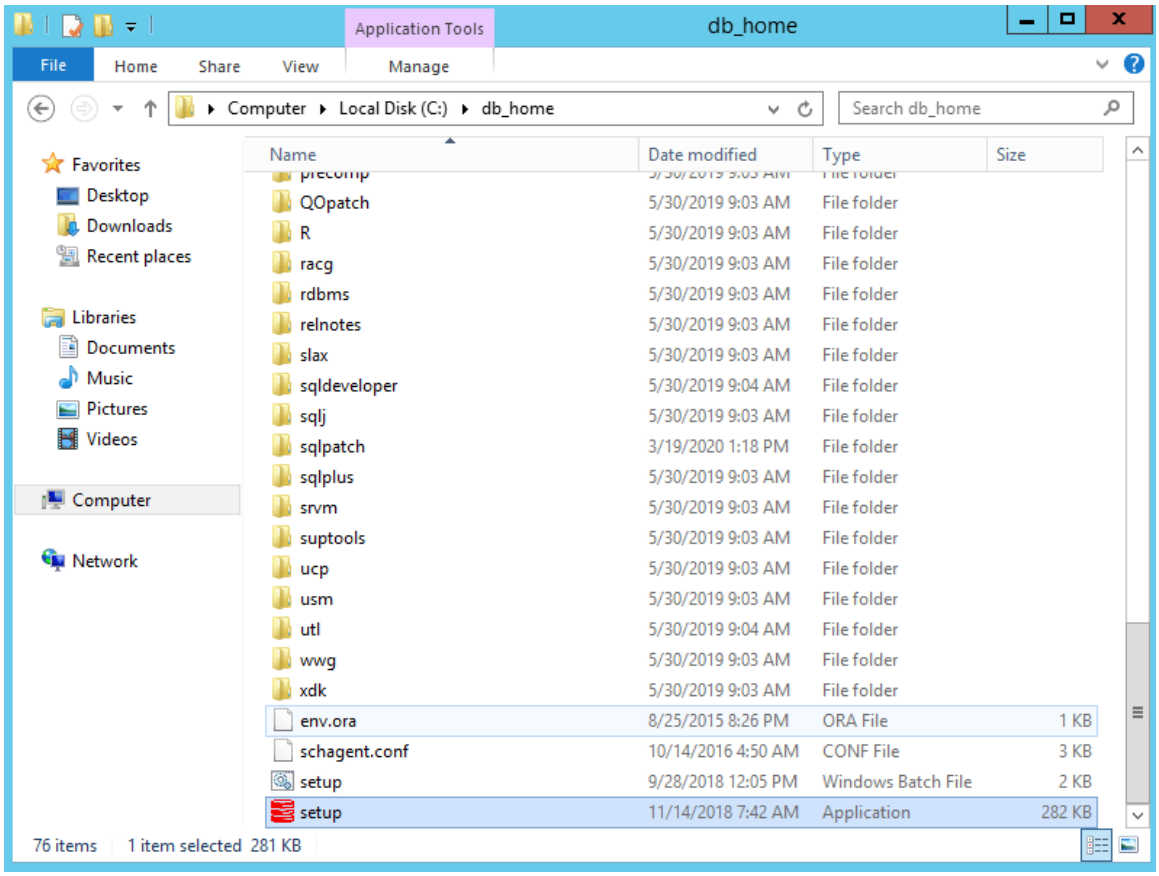

Figure 66. Screenshot. Installing Oracle Database

3. Choose database installation options

This step is very important. It allows the user to choose the database installation options. Oracle software can be installed and a database can be created at the same time (Create and

configure a single instance database). Since the team only wants to install the Oracle 19c software and its components, “Set up Software Only” will be opted. This option installs the essential components for creating and administering a database. The user can also use it to upgrade to an older version of Oracle (for example 12c or 18c) or install RAC.

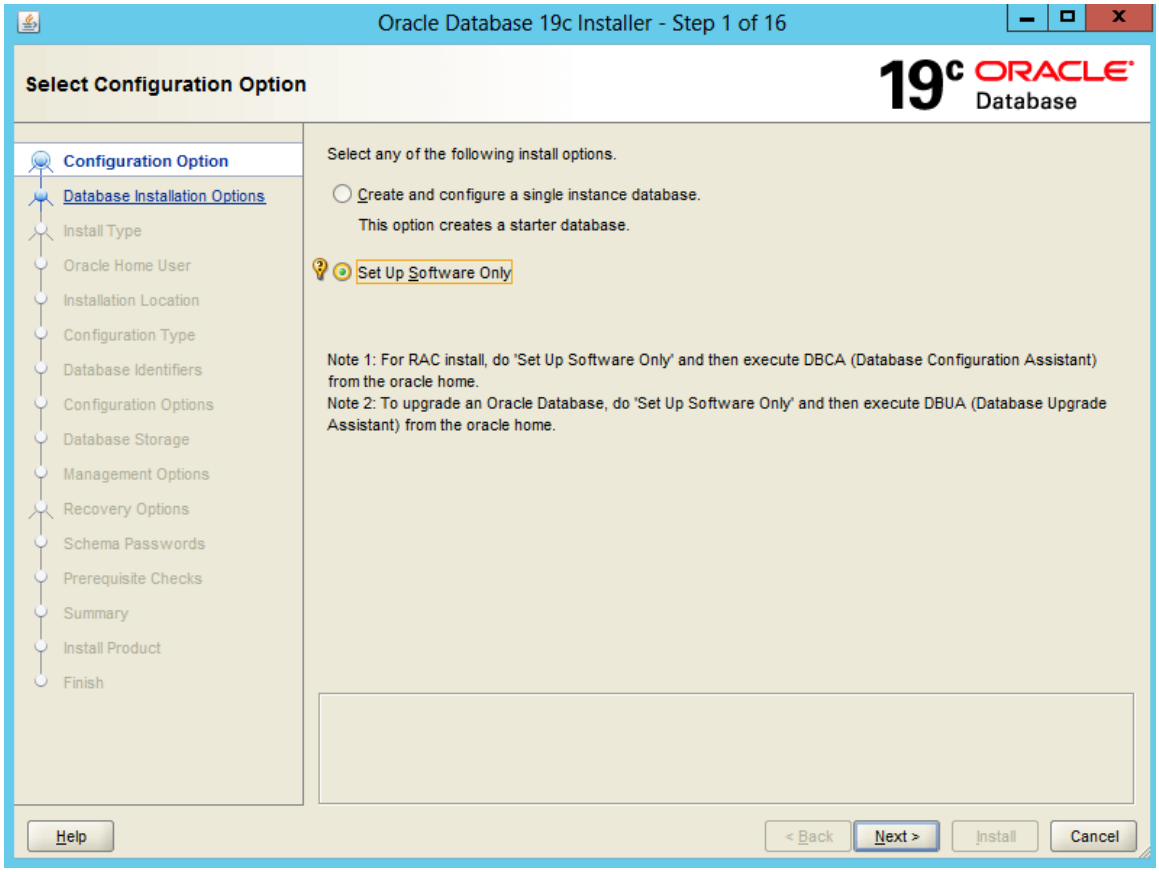

Figure 67. Screenshot. Database Installation Options

4. Select database installation type

The first option allows the user to install a single instance database on his/her server. Oracle Database with the Oracle Real Application Clusters (RAC) option allows multiple instances running on different servers to access the same physical database stored in shared storage. As the team wants to install Oracle 19c on a single server, option 1 is selected.

A database can be created after installation by using Oracle Database Configuration Assistant (Oracle DBCA).

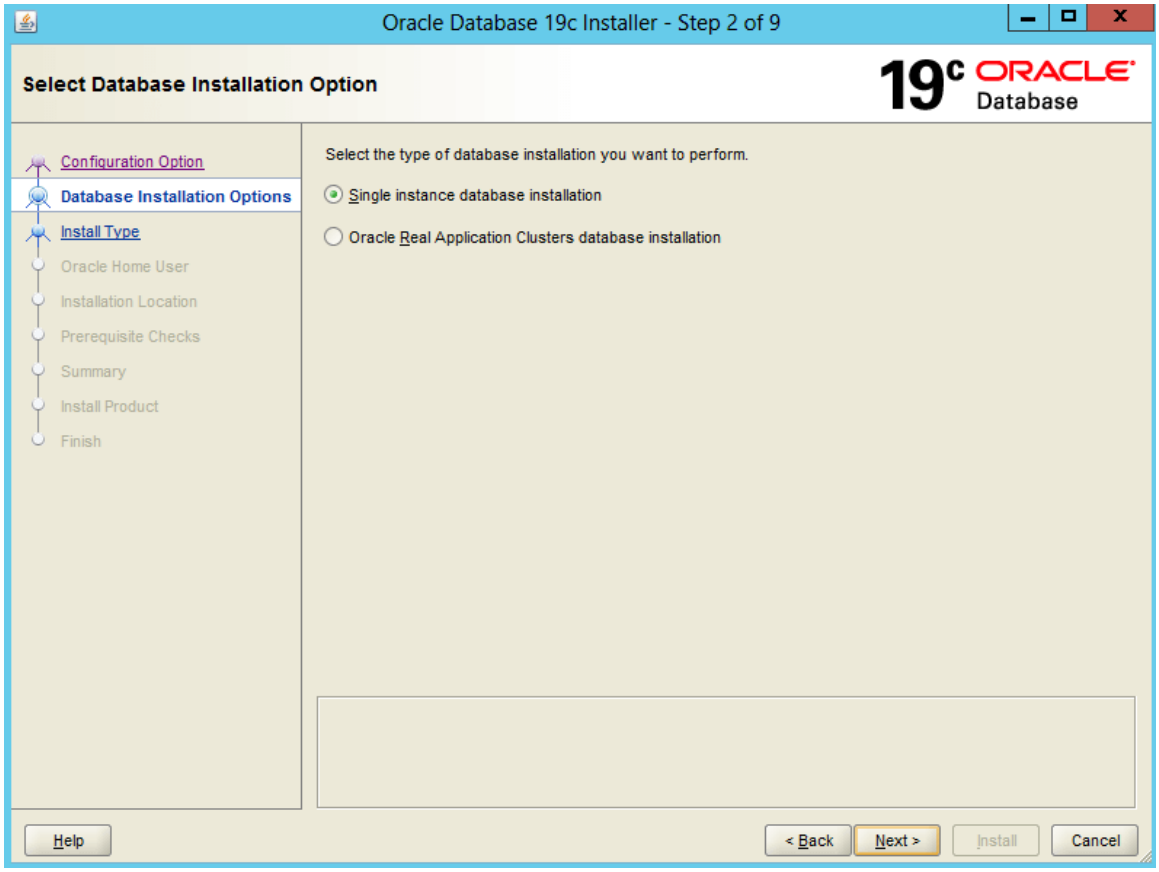

Figure 68. Screenshot. Database Installation Types

5. Choose database edition

The version of the database to install depends on the user's needs. For an application developer or and medium-size companies, the standard version covers practically all needs. To take full advantage of Oracle 19c, the Enterprise version can be installed. Obviously, the Enterprise version requires more resources (storage, RAM, CPU).

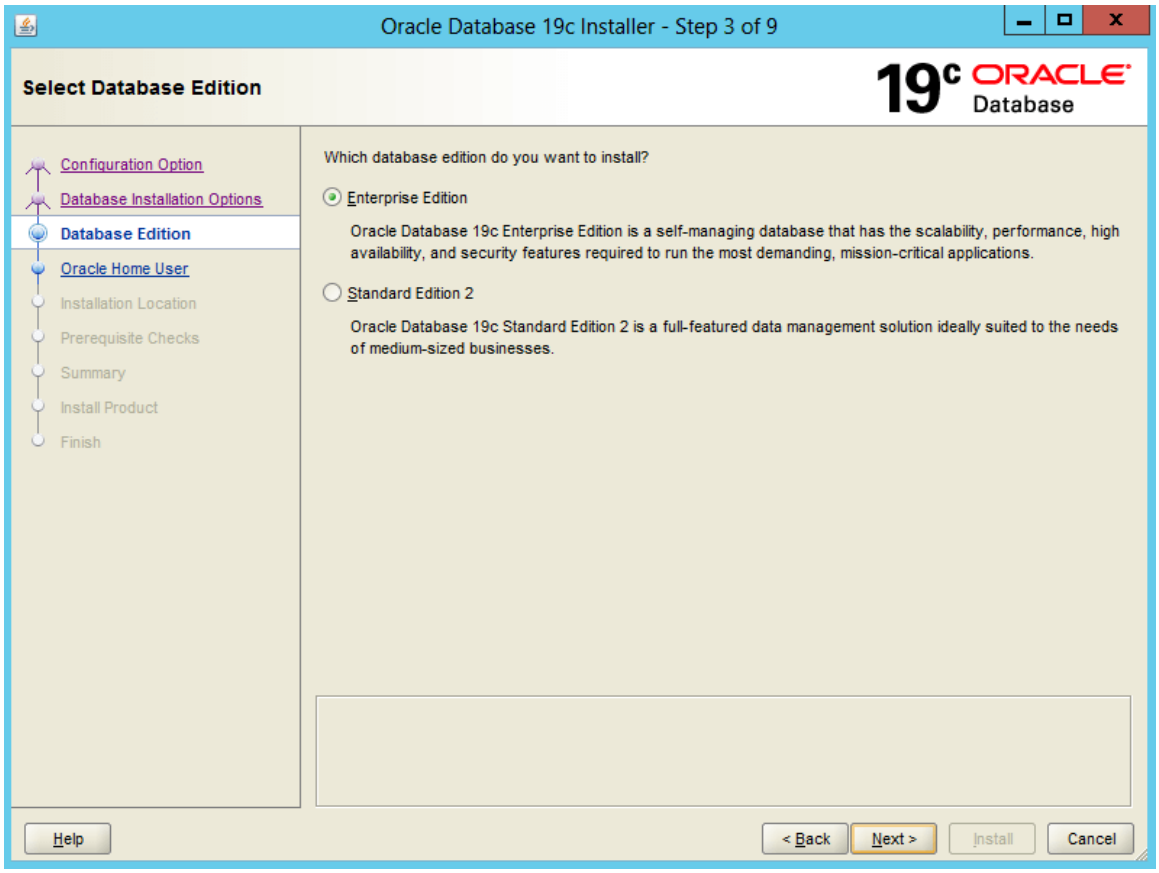

Figure 69. Screenshot. Database Editions

6. Specify Oracle home user

During Oracle Database installation, an optional Oracle home user can be specified associated with the Oracle home. Oracle home user can be a Windows built-in account (LocalSystem for Server and LocalService for Client), virtual account, or a regular (not an administrator) Windows account. If an existing user has been specified as the Oracle home user, then the Windows user account specified can either be a Windows domain user or a Windows local user.

A Windows user account need not be created by the administrator if a virtual account or a Windows built-in account is used during installation. If a non-existing user is specified as the Oracle home user, then the Windows user account specified must be a Windows local user. The installer creates this account automatically to run the Windows services for the Oracle home. Do not log in using this account to perform administrative tasks.

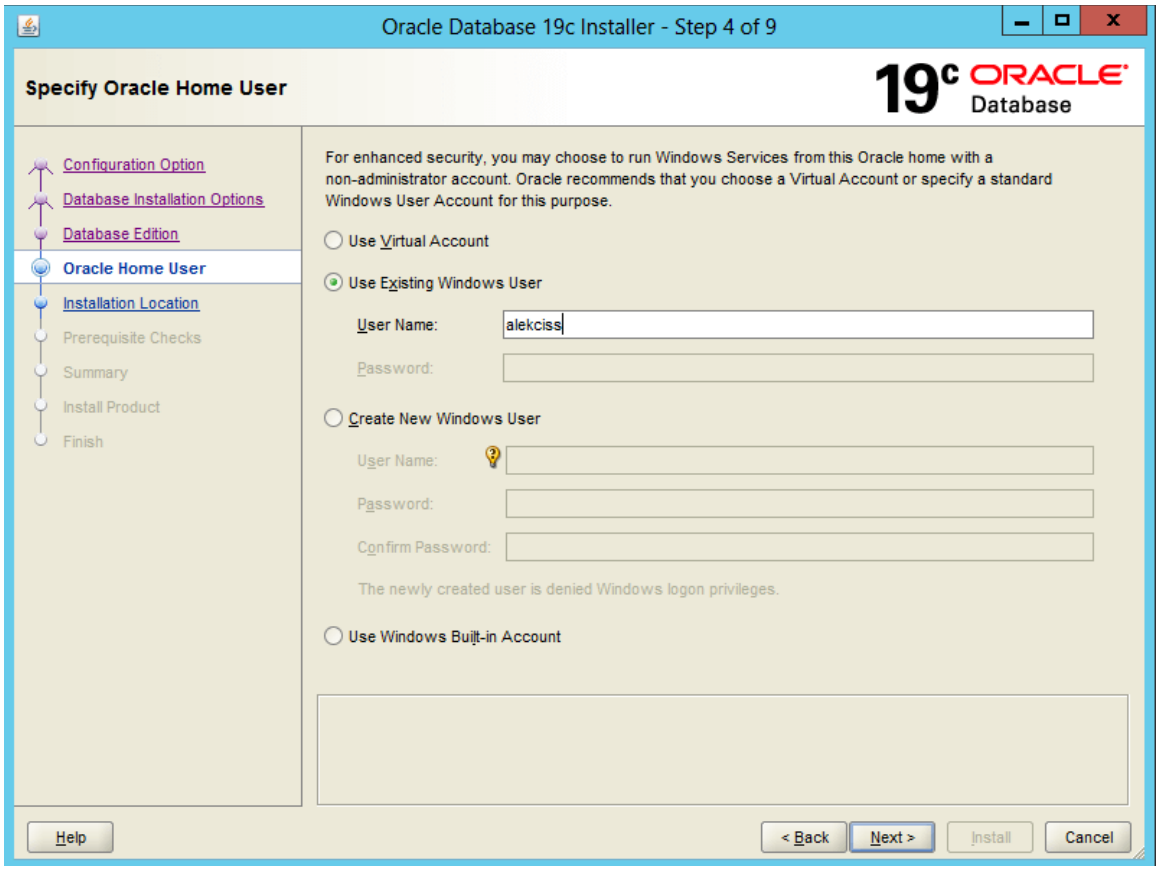

Figure 70. Screenshot. Database User

7. Specify the location of Oracle software

In a default Windows installation, the Oracle base directory appears as follows: *DRIVE_LETTER:\app\username* where *username* is the Oracle installation user if Windows built-in account is chosen, else it is the Oracle Home user (standard Windows user account). The user can change this directory at his/her convenience or leave it as default.

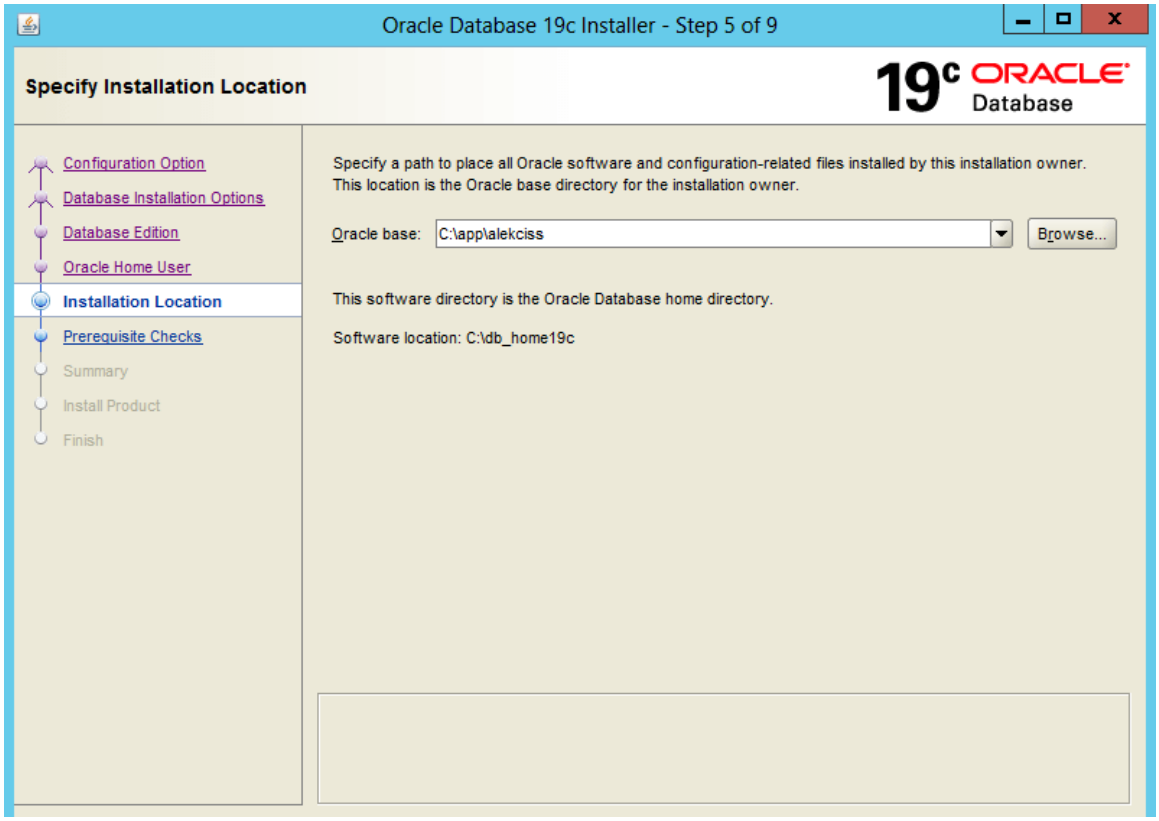

Figure 71. Screenshot. Database Location

8. Minimum requirements checks, summary and end of the installation

After these initial phases of configuration, let's check the installation prerequisites. If, however, there are errors, try to readjust the minimum installation requirements and start again.

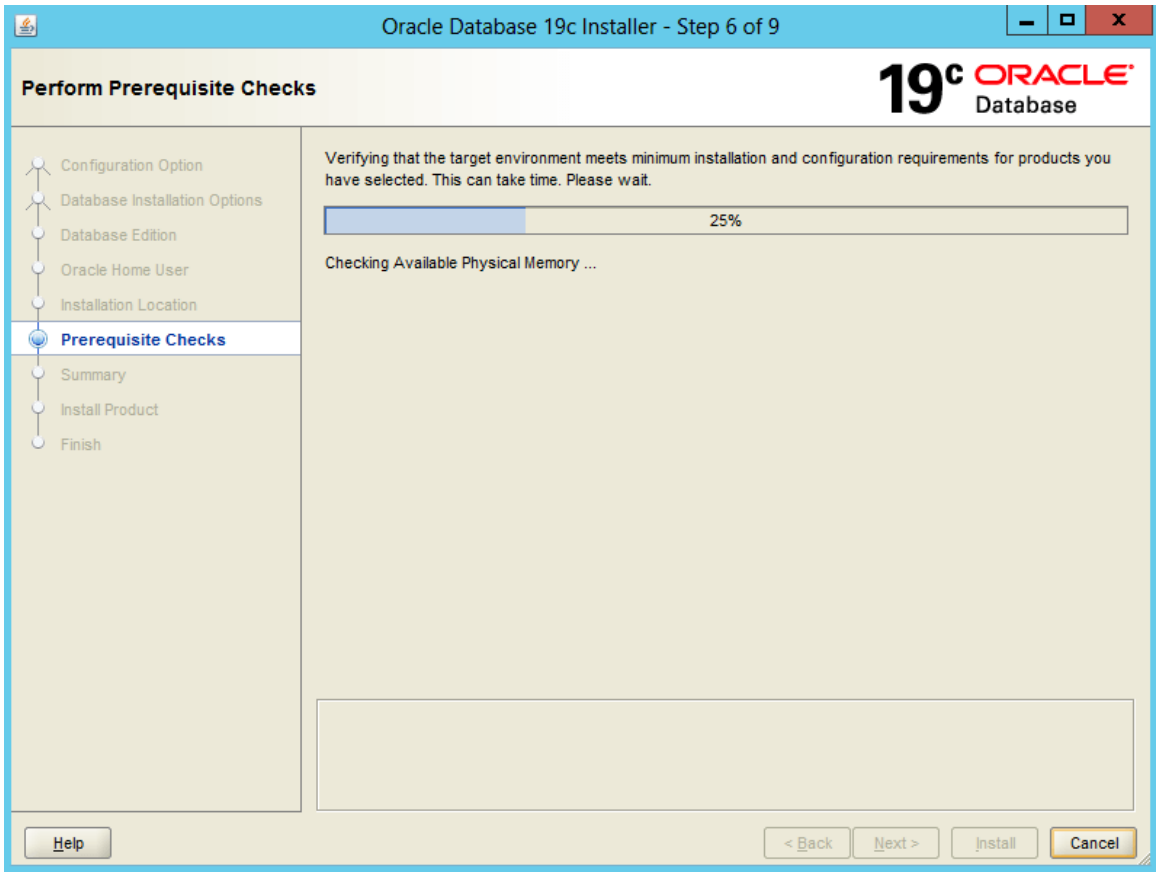

Figure 72. Screenshot. Database Requirements Check

Click install if no error occurs.

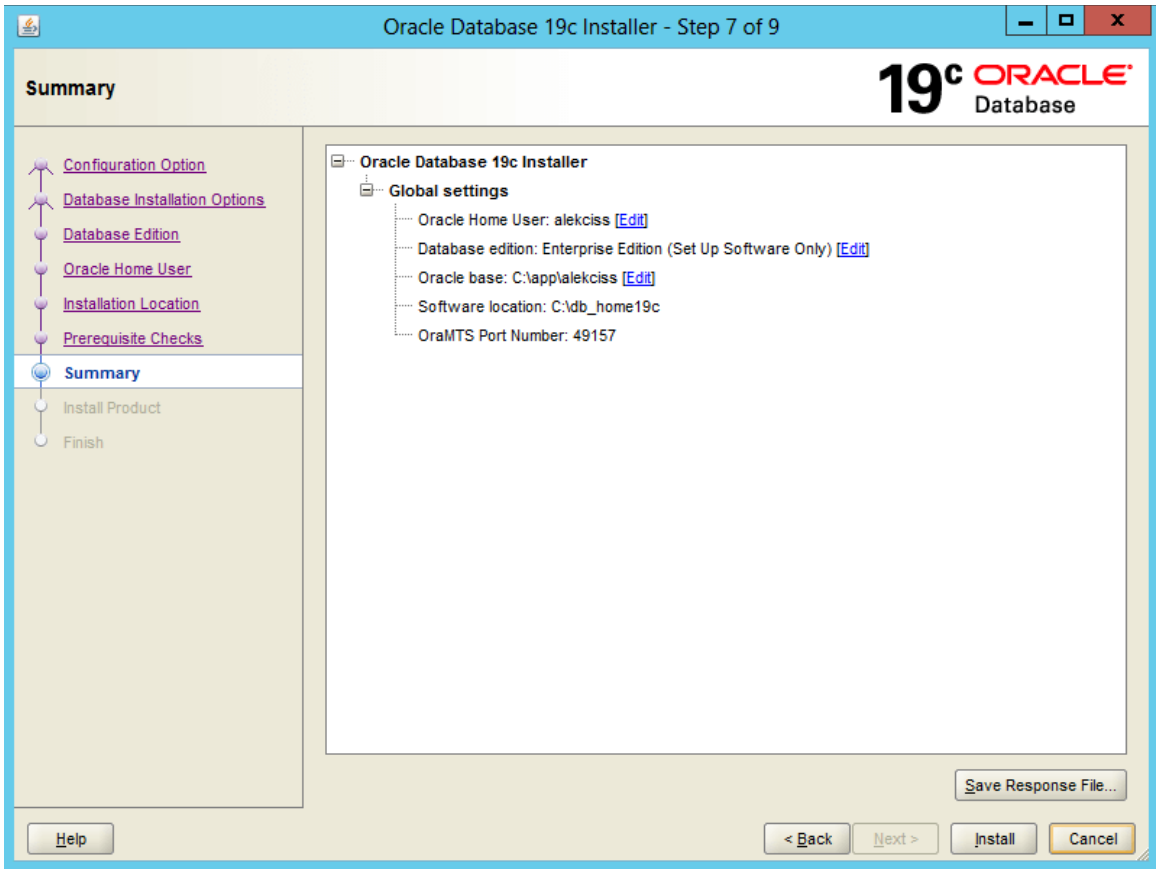

Figure 73. Screenshot. Database Installation Start

That's it. The installation wizard can be closed now.

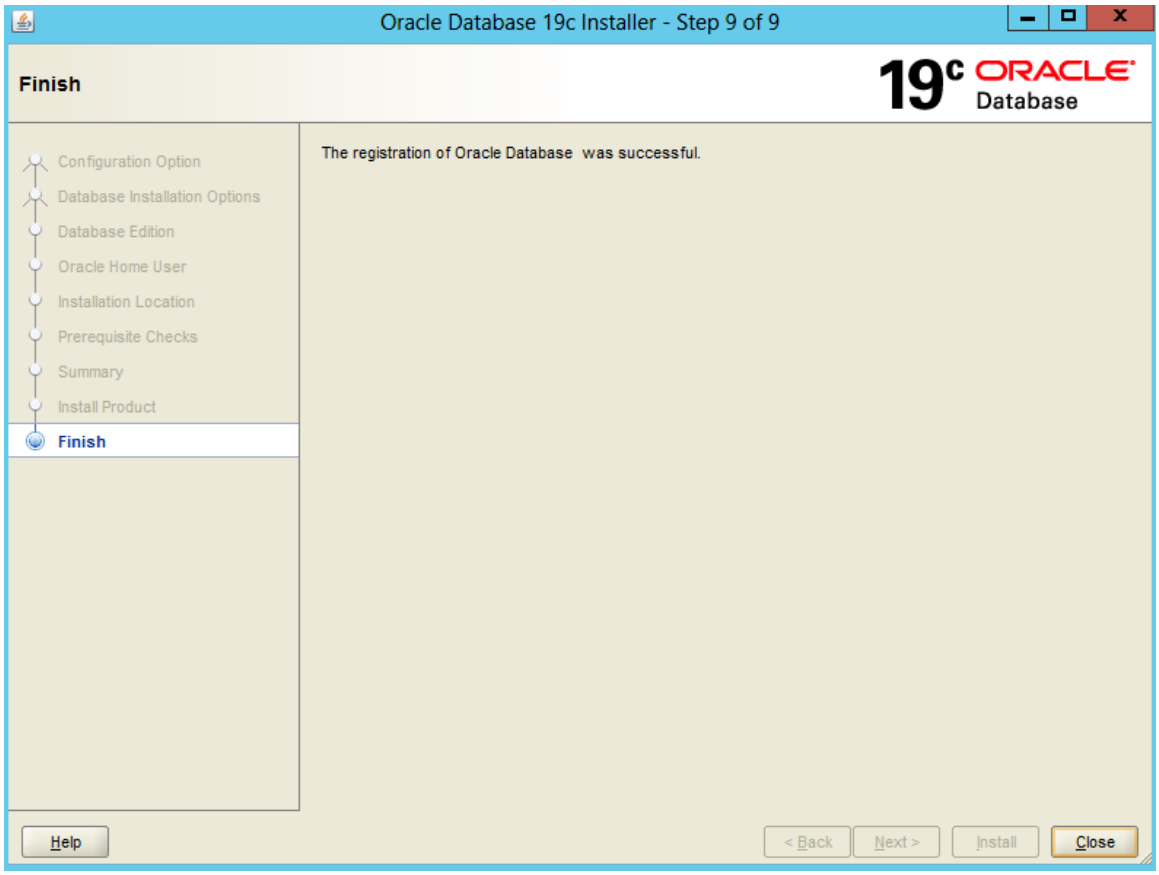

Figure 74. Screenshot. Database Installation Complete

The user can take a look at different components of the installation from the Windows start menu.

Step 1-Now the project files are required to be opened by clicking file->Open folder in Visual Studio code.

Step2- Right click on webserver.js file and click on open in the integrated terminal, after that type of command **npm i** the console and wait until the packages are installed.

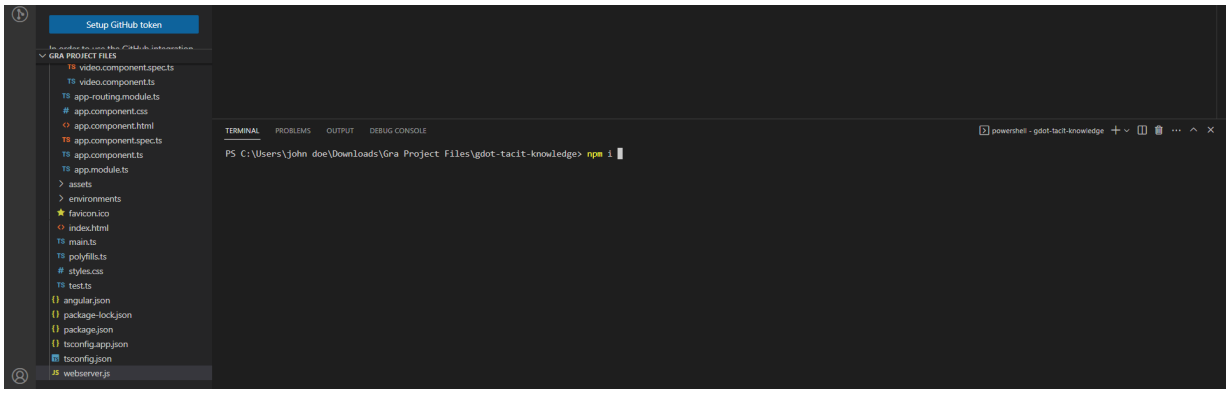

Figure 75. Screenshot. Opening Project Files

Step 3- In the console type command **node webserever.js** and wait until the server starts up and shows the message Server running on port 8000.

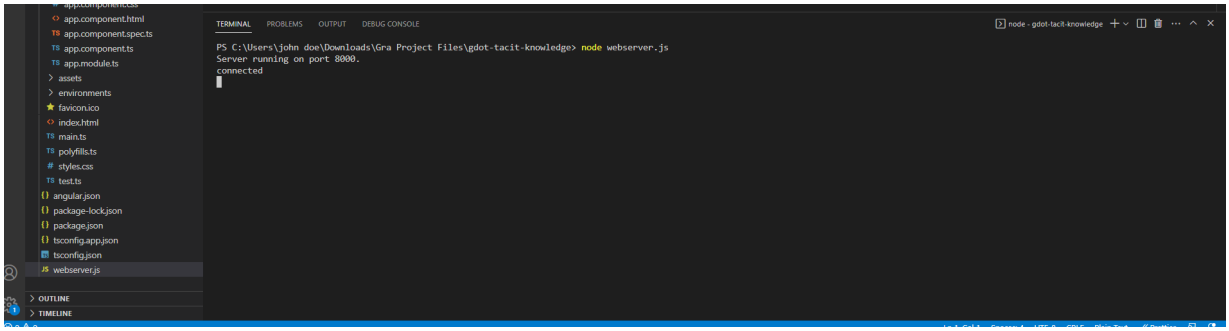

Figure 76. Screenshot. Starting Server

Step 4-> Right click on webserver.js file and click on open in integrated terminal, after that type command **ng serve** in the console and wait until compiled successfully message shows up. After that open this URL: http://localhost:4200/

Figure 77. Screenshot. Opening Server

Upon opening the URL, the tacit knowledge software running on the local system can viewed.

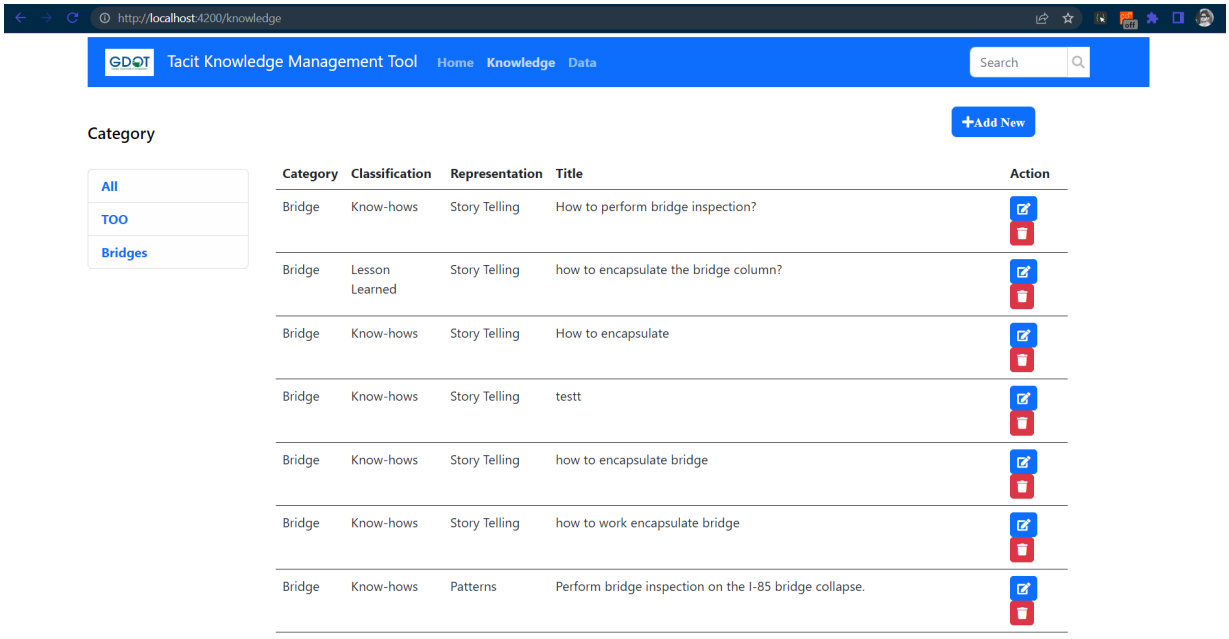

Figure 78. Screenshot. Running the Tacit Knowledge Software