DEVELOPMENT AND TESTING OF A PROCESS MATURITY MODEL IN THE DOMAIN OF INFRASTRUCTURE MANAGEMENT

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ABSTRACT

As information systems continue to expand their reach into the work process of the construction industry, communication and information exchange that traditionally occurs between humans is increasingly being replaced with automated or semi-automated information exchange between computer systems. These computer-based communications must be more formally defined and designed than the human-based communications that they replace. We are researching techniques to formally represent design information transactions within the construction industry. As part of this work, we are interested in assessing the degree to which information exchange processes are formalized and managed.

This paper focuses on the development and application of an Infrastructure Management-Process Maturity Model (IM-PMM) to benchmark the degree of formalization of work and communication processes in the infrastructure management field. The proposed IM-PMM evolved through reviewing a set of relevant maturity models. It uses a scale of five levels of process maturity and is based on three core dimensions (process, actor role, and information definition) to benchmark work processes, plus one dimension (message definition) to benchmark communication processes.

The proposed IM-PMM has been applied in the domain of infrastructure management and attempts to benchmark only the asset inventory and condition assessment reporting processes using researcher-administered structured interview approach. From the results of the survey, it is concluded that communication processes in the area of infrastructure management are typically accomplished in an *ad hoc* (undefined and unstructured) manner, emphasizing the need for improvement if advanced information systems are to be deployed to support efficient management of infrastructure systems.

Keywords: Process Maturity Model, Maturity Stage, Process Formalism, Infrastructure Management, Asset Inventory Reporting

1. INTRODUCTION

Efficient management of infrastructure system ensures high quality of services to the society. Management of these systems is a complex task due to its' interdependency on other systems, more stakeholder involvement, and longer time-horizons. We are interested in supporting better infrastructure management practices through improved information systems, focusing on communications and information exchange rather than specific computer applications.

As information systems advance, communications follow a general trend away from informal human-to-human communications towards computer-to-computer information exchange. In order to efficiently implement computer-to-computer information exchange, these transactions must be more formally described and agreed upon. Our current research goal is to develop a methodology of how to design and improve the processes of information exchange in infrastructure management. The questions are; what are the elements that are required to be defined while designing and improving communication processes for IT based solutions? What constitutes a properly defined and formalized process? How organizations can benchmark the formalism of their work processes? We propose a maturity model approach. According to OPM3 (2003), a maturity model is a structured collection of elements and terms describing attributes of process, product, and organization. Presently, many existing maturity models are assisting organizations to compare and benchmark their processes, products, and organizations, while none of these address the design level maturity of a work or communication process.

This paper describes the development and application of a technique for assessing and benchmarking work processes and communications in current municipal infrastructure management practice in terms of design elements including: process/transaction map definition, information definition, actor role definition, and message definition. The remainder of the paper is divided into five sections: i) review of the available benchmarking techniques; (ii) methodology for the IM-PMM development and application; (iii) development and application of IM-PMM for municipal infrastructure; and (iv) conclusion.

2. RELATED WORK IN THE DOMAIN

Maturity models are used to assess strength and weaknesses of organizations, quantify and benchmark management practices, and specify a continuum of best practices, (Harpham 2006). Maturity models have been in use since 1970 (Gibson and Nolan 1974) and hundreds of maturity models have been developed for information systems (Mettler and Rohner 2009) and other fields (Curtis and Alden 2007). This section reviews some of the relevant applications.

2.1 Maturity Models related to Project Management in Construction Industry

The Portfolio, Program, and Project Management Maturity Model - P3M3 is a five stage discrete maturity model developed by Software Engineering Institute (OGC-APM 2010). It is a framework that guides organizations to establish process improvement initiatives at portfolio, program, and project level.

The Organizational Project Management Maturity Model (OPM3), Version 2 was developed by the Project Management Institute – PMI to help organizations evaluate portfolio, program, and project level processes, (PMI 2003). Based on the project management body of knowledge, the OPM3 guides organizations to introduce best practices towards organizational project management through understanding their project management processes, measure strengths and weaknesses of the processes, and suggest improvements.

The Interactive Capability Maturity Model (ICMM) was developed by National Institute of Building Sciences, (McCuen and Suermann 2007); with the view to assist organizations evaluate their project management practices and processes in term of Building Information Model (BIM) implementation.

2.2 Maturity Models related to Software Industry

Capability Maturity Model Integrated (CMMI) Version 1.3 and Federal Aviation Administration - Integrated Capability Maturity Models (FAA-iCMM) are five stage discrete models developed by the Software Engineering Institute (SEI 2010), with a main focus on process improvements. It is a framework of best practices that helps organizations improves their processes through setting process improvement goals; provide guidance on how to achieve quality processes, and benchmark current processes.

2.3 Maturity Models related to Business Development

The Object Management Group developed the Business Process Maturity Model – BPMM, (OMG 2008). It is roads map that organization to follow to assess the maturity of processes, identify organizational strengths and weaknesses, and guide organizations to improve processes.

Standardized Process Improvement for Construction Enterprises (SPICE) is a five-stage discrete framework (Hutchinson and Finnemore 1999) that helps construction industry evaluate processes, identify strengths and weaknesses of organization, and suggest and prioritize process improvements programs.

All of these maturity models focus on the maturity of the way that work processes are managed. Our interest, however, is not in the operation and management of work processes themselves, but in the process-design aspects used to benchmark work processes and communications in terms of defining the work flow, specifying actors and roles, describing information content, etc. In order to focus on this aspect of process formalism, we developed a five-phased Infrastructure Management Process Maturity Model (IM-PMM) that we applied to benchmark the level of process formalism in terms of specific design elements in the infrastructure management domain.

3. METHODOLOGY FOR THE PROCESS MATURITY MODEL DEVELOPMENT AND APPLICATION

In order to better understand and to benchmark processes in terms of how formalized and structured these processes are; a five-phase approach was used to develop the IM-PMM as shown in Figure 1.

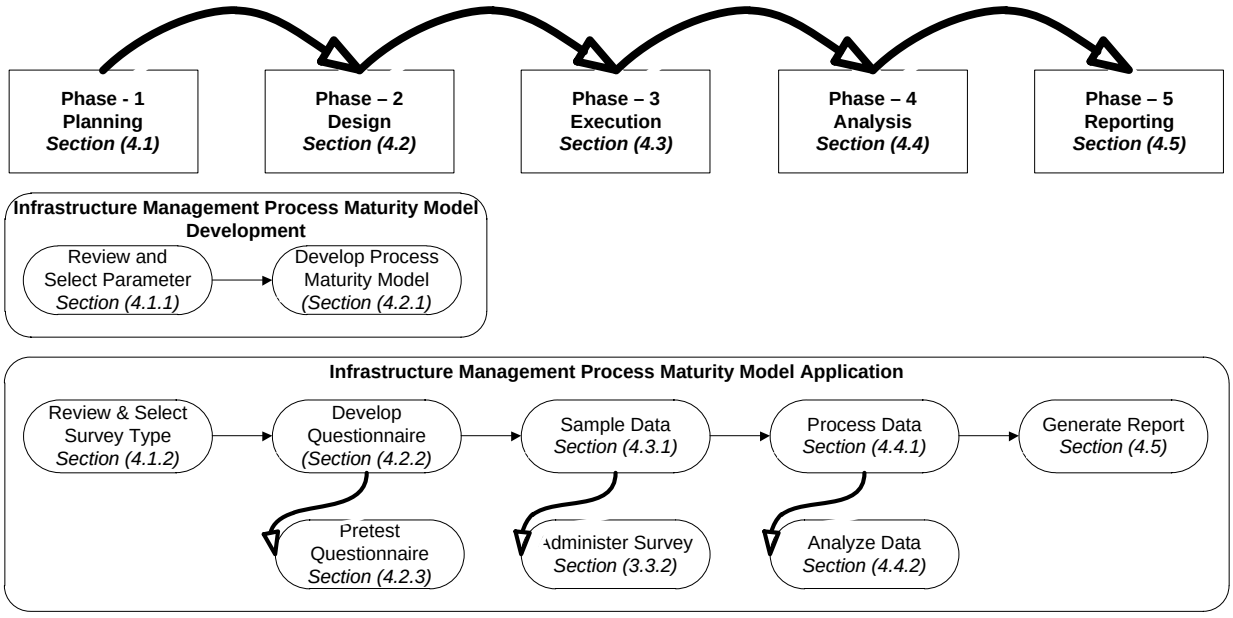

Figure 1: Process Maturity Model Development and Application Approach for IM-PMM.

The IM-PMM development and application approach used in this research consists of five phases including; planning, design, execution, analysis, and reporting, as explained below in accordance with the sections reflected in the Figure 1. This approach has been used to develop and apply the proposed process maturity model in the domain of infrastructure management.

First, the IM-PMM was developed in the planning and design phases, where diversified maturity models were reviewed, in order to develop a framework for the proposed process maturity model.

Second, the proposed IM-PMM was applied in the area of infrastructure management to benchmark work and communication processes using a five-phase approach. In order to test the proposed model in the field structured interview approach was used following the five phases shown in Figure 1. A group of experts from various municipalities were selected and interviewed, their responses were recorded, and analyzed and important conclusions were drawn.

4. INFRASTRUCTURE MANAGEMENT PROCESS MATURITY MODEL (IM-PMM), DEVELOPMENT AND APPLICATION

The development and application of the proposed process maturity model is described below.

4.1 Phase 1 – Planning

In this phase, a set of maturity models were reviewed to identify shortcomings in the existing MMs and to select suitable parameters (Becker and Knackstedt 2009) for the proposed maturity model.

Also, different types of surveys were reviewed from the maturity model application perspective and selected the one that best suit this research work.

4.1.1 Review and Select Parameters – (IM-PMM Development)

While maturity model approaches often assess the maturity level of a work process as a whole, they can alternatively separate out certain important factors of each process to assess individually. The IM-PMM follows this approach and assessed three different factors associated with the way that work processes have been defined—process and transaction map definition, information definition, and actor/role definition—along with a forth factor for communications—message definition. These factors are explained in the following sections.

i. **Process and Transaction Map Definition**

Process is defined as a function or sequence of functions that are necessary to transform a business object (Green and Rosemann 1999). Process includes a set of activities that are undertaken to accomplish an objective over a period of time. Process map definition refers to identifying and sequencing the set of activities (IDM 2007), and in case of the communication process, it is termed as the transaction map defined as a sequenced set of solo or atomic transactions in a bilateral or multilateral collaboration.

ii. **Actor role Definition**

Actors, either individual or organization, play certain roles in a given context, which is defined as “a set of connected behavior and attributes as conceptualized by actors in a given social position” (Zhang and El-Diraby 2009). These behaviours and attributes of role changes significantly with circumstance and the responsibility they accomplish in a specific context, (VISI 2007). Actor role definition refers to identification of respective role(s) actors play in a given context or process. Actors play two types of roles; the stakeholder roles which actor play by virtue of their position in a specific context or process; and transaction role which actors play in completing a transaction, (e.g., sender or receiver role).

iii. **Information Definition**

Information is defined as "data referenced and utilized during the process of creating and sustaining the built environment" (OCCS 2006). Information is data (refers to a series of atomic and disconnected facts, statement of event or observation) that is processed, analyzed and co-related to a context to make it useful for the user. Information definition focuses on identifying and defining the exchange requirements the actor roles need in a given process (IDM 2007). In simple words, it is the information that actor roles require to exchange to accomplish a work or communication process successfully.

iv. Message Definition

Message refers to the information formulated in tangible (written) and intangible (verbal and non-verbal) forms that is exchanged between collaborating partners. Non-verbal message is beyond the scope of this research work. Message definition focuses on defining the structure and format of the message in terms of information content and information context. Information content is the core information that needs to be exchanged in a communication process whereas information context represents the meta information about the message, (e.g. the name, actor and other contact information). Information in a message can be structured according to some degree of formality resulting in formulation of a fully-structured, semi-structured and un-structured message.

4.1.2 Review and Select Survey Type – (IM-PMM Application)

In this phase, different types of survey methods were reviewed and a researcher-administered face-to-face interview method was selected due to "the flexibility to react to the respondent's situation, probe for more details, seek more reflective replies and ask questions which are complex or personally intrusive" (Glastonbury and MacKean 1991). Moreover, according to Lindlof and Taylor (2002), structured interviews is the best suited for focus group studies.

4.2 Phase 2 – Design

From the development perspective, the design phase focused on the design and formulation of the proposed IM-PMM, whereas from application perspective, the design phase focused on the design and testing of the questionnaire used during the face-to-face interview survey.

4.2.1 Develop Process Maturity Model – (IM-PMM Development)

Based on the requirements and parameters identified in the planning phase, a process maturity model was developed, as shown in Figure 2 in a tabular format representing maturity stages along the horizontal axis and elements along the vertical. As noted earlier, the process maturity model developed consists of five stages (Infancy, Preliminary, Reactive, Proactive, and Integrated) and three core elements (Process/Transaction Map, Actor role, and Information Definition) to benchmark work processes. One additional element (Message Definition) was included to benchmark communication processes or transactions. Therefore, four elements have been identified and defined in the planning stage of the IM-PMM development. Definitions of the five stages in terms of elements are described below.

i. Infancy Stage – It is the very early stage of maturity where individuals in an organization don't know about the process/transaction map definition, actor role definition, information definition and message definition.

ii. Preliminary Stage – Awareness - Everyone in the organization is aware of the elements required for process formalism, but they don't practice design of work and communication processes based on process/transaction map, actor role, information, and message elements.

iii. Reactive Stage – Process Definition - Participants are aware of the basic elements required for the design of process formalism and they use these elements (process/transaction map, actor role,

information, and message definition), while designing their work and communication processes but on ad hoc basis. Process definitions are situation specific and dynamic as it changes frequently with time and context and no record of the defined elements are maintained that can be used in future.

iv. Proactive Stage – Process Standardization - All elements including; process/transaction map, actor role, information, and message are formally defined and documented and it is used repeatedly in future as standardized processes.

v. Integrated Stage – Process Management - Processes are actively managed against the standardized process definitions, including; process map, actor role, information, and message definition, and continuously monitored for improvements.

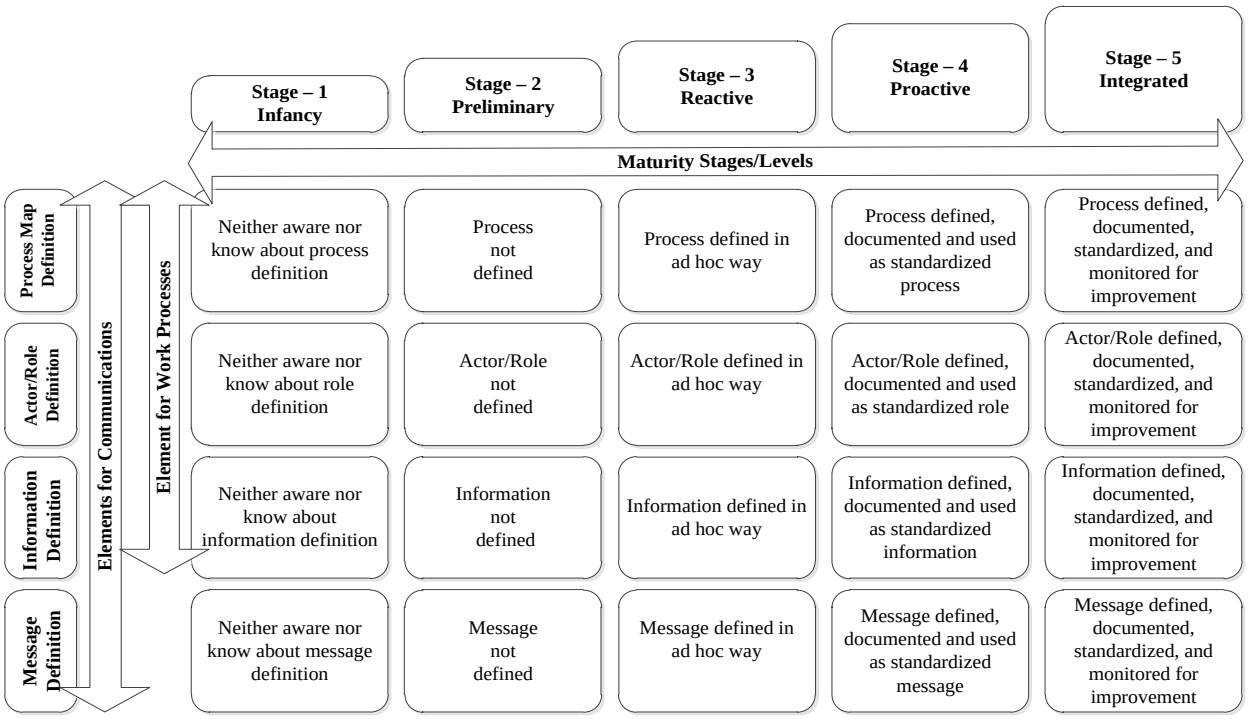

Figure 2: Process Maturity Model.

4.2.2 **Develop Questionnaire – (IM-PMM Application)**

For the survey, a structured questionnaire was developed incorporating only closed open-ended questions. It has 8 sections grouped into three parts:

Part A – covers questions relating to general profile information of respondent, municipality, engineering department, and asset infrastructure systems, (1 Section).

Part B – benchmark IT use and test the IM-PMM maturity model in the domain of Infrastructure Management (4 Sections). Out of the four sections, section 2 lists the infrastructure information systems; section 3 and 4 identify and benchmark asset information communication processes respectively using IM-PMM; and section 5 benchmarks interoperability of infrastructure information systems.

Part C – examines a methodology developed as part of this research work (3 Sections). Out of the three sections, section 6 identify requirements for the development of the methodology; section 7 identify and define communication process with experts; and section 8 evaluate the methodology.

The Part A of the questionnaire was web-based and participants were requested to respond electronically using web services, whereas responses of questions in Part B and Part C of the questionnaire were collected during face-to-face interviews with experts. The benchmarking of IT use and process formalism methodology examination is beyond the scope of this paper.

4.2.3 **Pre-test Questionnaire – (IM-PMM Application)**

To identify strengths and weaknesses of the questionnaire pretesting was performed in two stages; alpha testing was done in academic environment, shortcoming identified and incorporated before the start of the beta testing where questionnaire was tested again through industry experts. Their comments were incorporated as a second revision to the questionnaire.

4.3 **Phase 3 – Execution**

Actual survey in field was conducted in this phase. Core steps included; sample and administer survey.

4.3.1 **Sample Data - (IM-PMM Application)**

Samples were selected from each of the four different types of municipalities; city, district, town, and village using stratified random sampling approach and a sampling size of five was determined from each type at 95% confidence level and 40% confidence interval. Later, town and village municipalities were dropped due to non- response. Accordingly, survey was sent to 46 out of a total of 160 (29 percent) municipalities in the Province of British Columbia. Details of the survey data is shown in Table 1.

Table 1: Survey Data Profile.

Type of Municipality	Total No. of Municipalities	Sample Size	Percentage Sample	No. of Municipalities Contacted	No. of Municipalities Responded	No. of Personnel Contacted	Percentage Response
DM (Area > 800 Hectare and Pop Density < 5 pop/Hectare	50	5	10	18	4	45	22
CM (Population > 5000)	51	5	10	15	8	51	53
TM (Population ≥2500 ≤ 5000)	17	5	29	8	0	12	0
VM (Population < 2500)	42	5	12	5	0	6	0
Total	160	20		46	12	114	26

4.3.2 **Administer Survey - (IM-PMM Application)**

This step relates to the management, and administration of the survey. Considerable administration was required to select the appropriate municipality and individual(s) working in the water/wastewater and transportation departments of the municipality.

4.4 **Phase 4 – Analysis**

In this phase the raw survey data was processed and analyzed, discussions on the results of the processed data were made amongst the team members, and conclusions are drawn.

4.4.1 **Process Data – (IM-PMM Application)**

This step included sorting, organizing, storing, merging and computing the data. In the step, the raw survey data was transformed into useful information, as represented through tables and graphics/charts.

4.4.2 **Analyze Data – (IM-PMM Application)**

The proposed IM-PMM was applied to various communication processes in the domain of infrastructure management. During the survey, specific communications carried out between various infrastructure organizations were identified using the IM-PMM, which were grouped into two general categories; *Asset Inventory Reporting* – provision of reports reflecting the type, quantity, cost, and location of infrastructure asset; and *Asset Condition Reporting* – provision of reports detailing the current condition and remaining

life of the infrastructure assets. Typical roles like asset managers, works managers, project managers, infrastructure technologist manage this information using various infrastructure information systems and also responsible for the efficient exchange and reporting of this data. Based on the parameters of the proposed IM-PMM model, data was collected, processed, and analyzed as described below.

4.4.2.1 Benchmarking of Asset Inventory and Asset Condition Assessment Reporting Processes

Results of the data collected is shown in Figure 3, with x-axis represents the four elements including; (a) Process, (b) Actor role, (c) Information, and (d) Message Definition; each of which is further divided into five maturity stages, y-axis identifies the responses in terms of the number of reporting processes, and z-axis represents Asset Inventory and Asset Condition Assessment reporting process. To compare the relative maturity of processes and Elements, average maturity levels were calculated as described below.

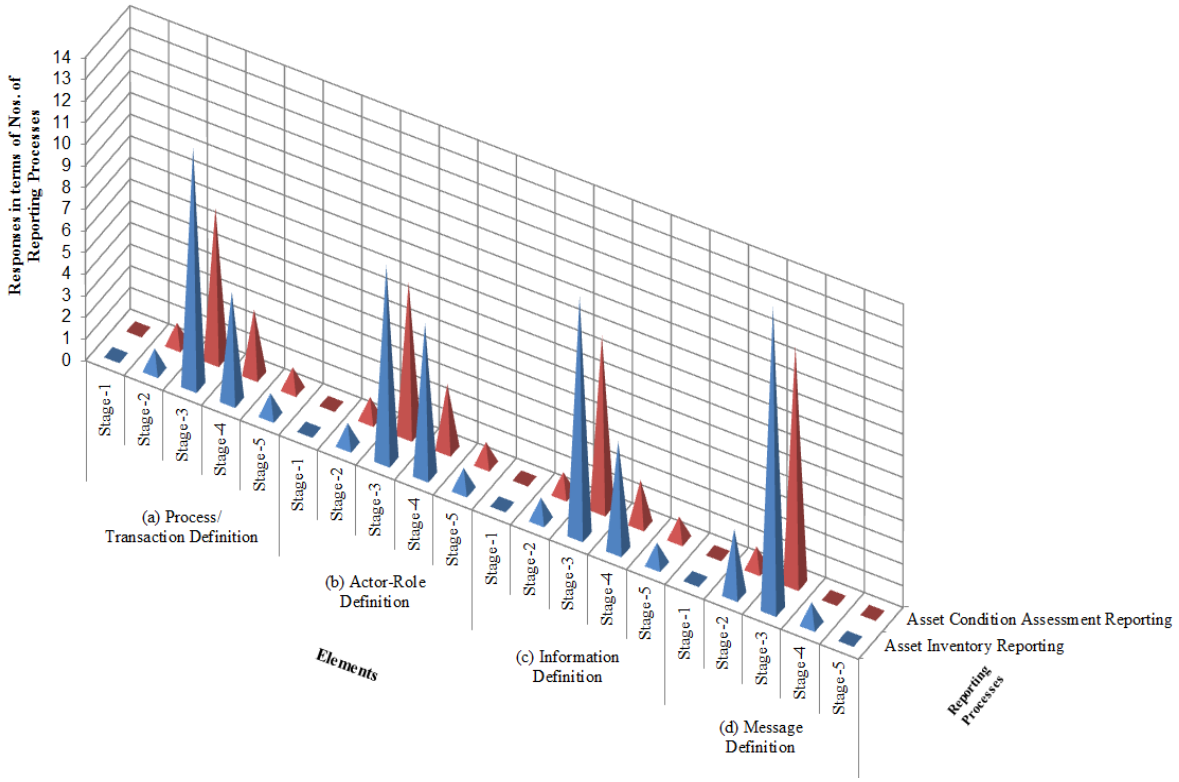

Figure 3: Benchmarking results showing the asset inventory and condition assessment reporting processes studied, the elements evaluated, and the number of instances found for each maturity stage.

i. Maturity Level of Asset Inventory and Condition Assessment Reporting Processes

Typical maturity levels of both processes were calculated with zero samples (0%) was assessed at maturity level 1, infancy, where participants are not aware of the four elements including; process/transaction map, actor role, information, and message definition. Few of the samples (8%) were assessed at maturity level 2, preliminary, where participants have awareness about these four elements but don't practice it. The most common maturity level (65%) observed was level 3, reactive, where participants use ad hoc ways to define these elements. Around a quarter samples (21%) reported to be in level 4, proactive, where participants standardize process, actor role, information, and message definitions. Few samples (5%) were found to be at higher maturity level 5, integrated, where participants standardize these four elements and monitor it for continuous improvement. This distribution gives an overall average maturity level of 3.24, indicating that practitioners are aware of the main elements of

process formalism while also using these elements to define processes but that these process definitions are most commonly ad hoc, and rarely being standardized and monitored for continuous improvement.

ii. Comparison of Asset Inventory and Condition Assessment Reporting Processes

Although there was no significant difference found between the average maturity level of 3.29 and 3.19 assessed for asset inventory and condition assessment reporting respectively, with the higher value indicative of the fact that most of the municipalities are involved in the exchange of the asset inventory information rather than asset condition assessment information. Possible reasons may include the Canadian legislation related to the implementation of Public Sector Accounting Board Standard - PSAB 3150, requiring municipalities to report their tangible capital asset information annually in a consistent manner. Second, the asset condition assessment information are often contracted out to consultants so municipalities may have less direct involvement in these processes in terms of collection, storage, and exchange of condition assessment information.

Comparison of Different Elements

It has been observed that the three elements including; transaction map, actor-role, and information definition have yielded similar results with an average maturity level of 3.35, whereas the message definition was found to be 13% lower with an average maturity level of 2.92, representing that message format specification is not a widespread industry practice. The reason can be current practice of human-to-human communications where message are interpreted by humans rather than computers.

iv. Overall Interpretation of Results

Overall results of the survey shows that presently infrastructure organizations are engaged in defining communication process but that it is done on ad hoc basis in most of the organization. Process standardization and its' continuous improvement is minimal. Certain organizations were assessed at a higher maturity level indicated that higher level of formalization is possible when organizational environment is conducive, (e.g., management support, trained staff, availability of latest IT technologies).

These findings indicate that the industry currently does not practice the higher degree of process formalization, which is required if these communications are to be implemented in advanced computer based information systems. We claim that higher level of process formalization is required in order to support deployment of more advanced communication information systems. Moreover, we have not collected evidence to support an assertion, we hypothesize that higher level of process formalization would also lead to better management practices and better outcome of our infrastructure systems.

4.5 Phase 5 – Reporting

A final report was compiled and made public through reporting to concerned authorities and publication.

5. CONCLUSION

For efficient management of infrastructure systems, more advanced communication information system are required to be implemented. In order to support such deployment, works and communication processes are to be formalized to a higher degree of formalism. In order to assess the maturity and to the benchmark the degree to which these processes are formalized, an Infrastructure Management Process Maturity Model (IM-PMM) has been developed to assist organizations position themselves on the process maturity continuum. The IM-PMM developed as part of this research work has five maturity stages along three elements (process/transaction map definition, actor role definition, and information definition) to benchmark work processes; whereas one element (message definition) has been added to benchmark

communication processes (transactions). The IM-PMM has been applied in the domain of infrastructure management to benchmark asset inventory and condition assessment reporting processes using face-to-face interview survey approach. Results of the survey indicate that practitioners are engaged in defining communication process, but that processes are formalized on ad hoc basis in most of the infrastructure organizations, while standardization and process continuous improvement is minimal.

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