A conceptual framework for tracking design completeness of Track Line discipline in MRT projects

E. Eray[a], C.T. Haas[a], D. Rayside[b], M. Golparvar-Fard[c]

[a] Civil and Environmental Engineering Department, University of Waterloo, Canada
[b] Electrical and Computer Engineering Department, University of Waterloo, Canada
[c] Department of Civil and Environmental Engineering, The University of Illinois at Urbana-Champaign, USA
E-mail: eeray@uwaterloo.ca, chaas@uwaterloo.ca, drayside@uwaterloo.ca, mgolpar@illinois.edu

Abstract –

Tracking design completeness during the early phases of complex construction projects is a vital need for project participants to measure their progress. It is also a challenge, because design completeness depends on both geometric details and engineering information related to the model. Tracking level of development (LOD) of the designed objects is a partial solution that focuses on level of geometric detail of the design elements. However, engineering analysis, documents and process records behind the design are thereby neither assured in terms of completeness nor related to the elements. To address this aspect of the problem, the Construction Industry Institute (CII) published Model Maturity Index (MMI) definitions and the Model Maturity Risk Index (MMRI) Toolkit which aim to help management and engineering teams to provide accurate and timely information about design progress and productivity in building and industrial type construction projects. In this research, new MMI definitions and a related MMRI table is developed for the Track Line discipline in MRT projects by conducting a literature review on track line design and by seeking related experts opinions. Semi-automated assistance for populating the MMRI table using an interface management system integrated with a BIM is also described but is not the main focus of the paper. More accurate engineering progress measurements should be facilitated by the research results.

Keywords –

Instructions; Design Completeness, Mass Rapid Transit Projects, Track Line

1 Introduction

Measurement of the design progress is an evolving challenge in today's 3D modeling dominated design environment [1]. Improvements in the software engineering and computer science fields extended traditional 2D and 3D technical design drawings into more intelligent visual modeling processes in construction industry. Today, Building Information Modeling (BIM) philosophy which can be defined as crating a virtual prototype of the system, is getting more and more important in the construction industry [2]. The main idea behind BIM is creating an intelligent model of the project which includes not only graphical details, but also engineering information of the system such as material data, wind force, cost, schedule, and facility management information, etc. [3].

Today, there are several 3D modeling software options on the market that engineering design can be done on the shared design files among the project stakeholders. Although these improvements bring huge flexibility and power to the construction industry such as automatically superimposing different design files and being able to detect clashes, creating walk-through views of the design models, and estimating projects' quantity takeoff automatically, etc., it is hard to measure engineering design progress during the design phase of the projects.

Traditional design progress measurement technique was counting the completed engineering drawings and completed issued-for-construction files. However, it is hard to perform this technique on 3D models, since 3D design is an evolving process on the same design files. Measurement of design process becomes even harder on complex construction projects, since many project participants are involved in the design of the project.

There are different approaches and tools for measuring design progress in both the literature and industry today. One of these approaches is tracking Level of Development (LOD) of design elements in the model. Mainly LOD definitions are focusing on graphical details on the design elements. However design progress is not only related with the graphical details and representation, it is also related with engineering information added to the model, and documents and process records behind the design. Another approach to measuring design progress, which focuses on engineering information added to the model, is tracking Model Maturity Index (MMI) levels of the project disciplines. Both LOD and MMI level approaches are explained in the literature review section of this paper in detail.

Also, there are several Building Information Modeling (BIM) maturity assessment tools available today that help users to measure their project performance on BIM implementation. Arup, which is a global engineering and design firm, developed one of these BIM maturity assessment tools in 2014 [4]. The main purpose behind Arup's BIM Maturity Measurement (BIM MM) tool is to assess the BIM implementation maturity in projects and compare it between different projects. Although BIM MM tool provides a measurement on "maturity", the usage area of this tool is different than measuring design maturity of the project itself. Therefore BIM maturity tools will not be further explained in this paper.

This paper is part of an ongoing research project related with measuring design progress on complex capital projects. The main focus in this conference paper is on explaining currently used methods for tracking design progress, and introducing a conceptual semi-automated framework for tracking design completeness of Track line discipline in Mass Rapid Transit (MRT) projects. The novelty of this research is developing methods to fill the knowledge gap on design progress measurement for a class of projects that doesn't have specific design maturity definitions. Briefly, the validation approaches of this research are: creating functional demonstrations, getting experts' reviews, and compare developed measurement framework quantitatively with existing systems. Presenting quantitative results from the proposed framework at this time is beyond the scope of this conference paper.

2 Literature Review

2.1 Level of Development (LOD)

Generally, 3D models of construction projects range between a conceptual drawing to a fully detailed and coordinated construction model. One way of measuring design completeness in construction projects is tracking Level of Development (LOD) level of the elements on the model. In 2008, the American Institute of Architects (AIA) released a contract document, "AIAE202-2008 BIM Protocol Exhibit," which defines Level of Development (LOD) and LOD levels, which are related primarily to amount of design detail in the model. According to the AIA, LOD 100 represents a conceptual drawing, while LOD 500 is the as-built model; LOD gets higher during the design phase of the project and reaches its highest level during the construction phase [5]. In 2017, The Level of Development (LOD) Specification which follows CSI Uniformat 2010 organization and LOD schema developed by AIA, is released by BIMForum. In this specification, general insight and definitions of LOD levels for the design elements specified in Uniformat 2010 is provided [6].

Mainly LOD level definitions are related with the graphical details on the design elements on the model. In other words, as the accuracy of the design of the elements gets higher, the LOD level of that elements also gets higher in the model. However, there is no such LOD level of the complete design model. LOD levels are defined only for elements on the model. It cannot easily or consistently be aggregated to total LOD level for project [7,8].

LOD can be added as a shared parameter to the models created on Autodesk Revit to track design progress of the project. During the design phase, LOD level of the elements can be arranged manually by the design team according to the LOD definitions that they created for their project' design elements. When each element's LOD level is defined on the model, the project team can track changes on these levels to see progress in their projects.

2.2 Model Maturity Index (MMI)

Most of the engineering progress in the early phases of complex capital projects is not graphical-design related, and such progress must be captured as well in order to have a complete idea about the progress in the project. Examples of such engineering processes are diverse and include geotechnical studies, mechanical and control systems design, and structural systems analysis.

Similar to the AIA, the Construction Industry Institute (CII) published metrics to measure progress in model-based engineering projects in 2017. These metrics are called Model Maturity Index (MMI) and they are focusing on engineering information added to the 3D model, and documents and process records behind the design. Similar to LOD, MMI definitions have levels ranging between MMI 100 which mainly refers to a conceptual design, to MMI 600 which indicates that facility management data is included to that discipline.

Until today twelve sets of MMI definitions which are namely: Piping, Structural, Instrumentation, HVAC, Equipment, Civil, Electrical, Fire Protection, Layout, Foundations, Buildings, and P&IDs, have been established by CII. Each of these definitions is providing a clear set of modeling requirements for each MMI level in that discipline to fulfill. The MMI levels are calculated per discipline per location on the 3D model, and calculations are done by the Model Maturity Risk Index (MMRI) tool developed by CII [9].

While LOD levels are mainly related to the design detail on the model, MMI levels are related to the amount of the information in the model. In other words, both graphical and non-graphical information associated with the project is reflected with MMI levels. Another difference between LOD and MMI levels is, LOD is mainly related with details on the design of the model elements, while MMI levels are prepared for design disciplines in the project.

2.3 Model Maturity Risk Index (MMRI)

The Construction Industry Institute (CII) developed Model Maturity Risk Index (MMRI) tool that includes questionnaires for each discipline that they defined MMI definitions. By filling these tables for a specific location in the project, MMI levels per discipline in that specific location can be calculated. It also provides percentage of remaining work to achieve higher MMI level within the discipline in specific location too.

The questionnaires in the MMRI tool have inter-disciplinary relationships between the disciplines too. Mainly the questions on the tool are based on the information added to the model such as site plan, geotechnical investigation, design parameters, equipment data, clash detections, etc. The user of the tool needs to select appropriate answer from drop down menu which includes answers as Yes, No, Not applicable, Design Specified, Loaded, Confirmed, etc. for each question. Each of these answers would have connections with different MMI levels and also weights on MMI level calculation. As an example Foundation is a discipline which CII provided MMI definitions and MMRI table. The questionnaire for Foundation in the MMRI tool has questions about the size and location of the design components. While the answer of "preliminary design" to these questions has connection with MMI 100, the answer of "design specified" has connection with MMI 300.

The main usage area of the tool is expected to be a guide showing current maturity of the model and required modeling effort of specific disciplines in different locations on the project. The project team can have better communication in model reviewing meetings by filling the questionnaires, and obtaining current MMI levels of the specific modeling disciplines in different locations.

3 Tracking design progress of Track Lines in Mass Rapid Projects

Mass Rapid Transit (MRT) systems such as Light Rail Transit (LRT), Bus Rapid Transit (BRT), Subways, etc. are important for solving the traffic congestions and mobility of the people in the crowded cities. These MRT projects are generally considered as complex projects due to their size, engineering design and construction complexity, financial approach, contract type, and delivery method.

Although these projects can be considered as linear projects where there are many identical units that are repeated, the graphical details and engineering information added to the model would change location to location on the design file. According to the expert's opinion from railway industry, it is hard to track design progress in MRT projects since design details and engineering information added to the models are not always similar all around the project. In other words, there would be locations such as stations or areas between stations, where the design model is close to the as-built version, while others locations are still in conceptual design phase.

In this research paper, new conceptual MMI definitions and an MMRI table is defined for the Track Line discipline on Mass Rapid Transit (MRT) projects. Although type of track lines is different in heavy rail and light rail systems, a generalized definition that can be applied on different type of track line systems will be created. However, in order to provide specific examples related with the MMI definitions and MMRI table, among different type of MRT projects, the main focus will be on Light Rail Transit (LRT) projects.

LRT projects are a subdivision of mass rapid transit systems and according to the American Public Transportation Association (APTA), the definition of LRT system is "an electric railway system characterized by its ability to operate single or multiple car trains along exclusive rights-of-way at ground level, on aerial structures, in subways or in streets, able to board and discharge passengers at station platforms or at street, track, or car-floor level and normally powered by overhead electrical wires". According to the report published by International Association of Public Transport (UITP) in 2015, LRT and tramway systems are operated in 388 cities all around the world. Europe is the richest region in terms of the number of the LRT projects. A total of 206 cities in Europe had LRT or Tramway system in-service. Eurasia follows Europe with 93 cities having LRTs [10].

Track lines on LRT projects would be different than on other types of MRT projects' track lines, since the main difference of the LRT projects is that the light rail vehicle (LRV) would have the ability of operation in mixed traffic on the street when it is necessary [11]. Therefore, track line types used in LRT projects are generally thinner and they can be used in mixed traffic conditions. In LRT projects, different type of tracks such as ballasted track, direct fixation track, embedded track, etc. are used [11]. Although there are many differences on design of these various track lines on MRT projects, generalized definitions for measuring design completeness of the track line discipline in different type of projects will be created.

3.1 Proposed MMI definitions for Track Line Discipline

Light Rail Transit (LRT) projects can be divided into many different disciplines. In this research, a model LRT project is divided into 14 disciplines which are namely Administration, Procurement, Quality Management, Earthwork, Track line, Structural, Operations/ Maintenance, Mechanical, HSE, Signaling, Civil, Electrical, Telecommunication, and Multidiscipline. Among these disciplines, Track Line discipline is selected for this research to establish new MMI definitions.

In order to create MMI definitions for Track Line disciple, currently available MII definitions provided by Construction Industry Institute is studied, literature on Track Line design is researched in detail, and main design components that can be used for tracking design is selected. The created conceptual MMI definitions for Track Line discipline can be seen on Table 1. This could be further disaggregated and used for each track line section.

Table 1 Conceptual Model Maturity Index Level Definition for Track Line Discipline

MMI Level	Definition
100	Generic model of the site plan, route, and topographic maps are created. Existing conditions have been quantified and graphically represented.
200	The preliminary geotechnical investigation report has been received. The engineering team decided type of tracks to be utilized. Track line components graphically modelled with preliminary size and configuration, as follows; - Site plan, topographic maps and surveys - Horizontal and Vertical layout design - The route of the project - Track components - Track ballast/bed design Design performance parameters, as defined by the project, are associated with model design components as graphic or non-graphic information.
300	The geotechnical investigation report has been received and confirmed. Project-specific layout specifications and track line specifications are attached to the related components. Track line components graphically modelled with design-specified size and configuration, as follows; - Site plan, topographic maps and surveys - Horizontal and Vertical layout design - The route of the project - Track components - Track ballast/bed design Project plans and permits have been submitted to AHJ (Authority Having Juristiction). The environmental and remediation requirements have been submitted to AHJ.
350	Track line components graphically modelled with confirmed size and configuration, as follows; - Site plan, topographic maps and geotechnical investigation - Horizontal and Vertical layout design - The route of the project - Track components - Track ballast/bed design Project plans and permits have been confirmed by AHJ The environmental and remediation requirements have been confirmed by AHJ.
400	Track line components graphically modelled with approved size and configuration, as follows; - Site plan, topographic maps and geotechnical investigation - Horizontal and Vertical layout design - The route of the project - Track components - Track ballast/bed design The IFC (Issued for Construction) drawing package and specifications have been submitted. Project plans and permits have been approved by AHJ.

	The environmental and remediation requirements have been approved by the AHJ.
500	As built: as build conditions are graphically represented in the model
600	FM-enabled: as-built models are supplied with Facility Management information as outlined by project scope

3.2 Proposed conceptual MMRI table for Track Line Discipline

Although Track Line related MMI definitions are at the conceptual phase, a conceptual MMRI table for the Track Line discipline is created to explain how design progress will be calculated with this method.

To create the MMRI table for the Track Line discipline, first the CII MMRI tool is reviewed in detail and seven main categories that would be used in Track Line design are selected among the existed tables. The selected categories are namely; Project data, Design components, Track supports, Routing, Specifications, Related Studies and Permits, and Submittals. Then, fourteen criteria according to the defined MMI level definitions are created under selected categories. In order to be consistent with existing MMRI tables, some of the defined criteria is selected from CII' MMRI tables, while some of them are defined after conducting a literature review and by seeking related experts' opinions on track line design. Developed conceptual MMRI table for Track Line discipline is presented on Table 2.

Applicability column will be added to the right end of the developed MMRI table with the options of "Not Applicable, Yes, No, Loaded, Confirmed, Design Specified, Approved, etc. In order to obtain MMI level of Track Line discipline for a specific location on the project, the applicability of each criterion on the Table 2 is required to be filled with these options for that specific location on the project.

In the MMRI tool developed by CII, these tables require manual entry, and each criterion in the table is connected to an MMI level definition. By these connections, after filling these tables for the project, it would show the MMI level result of that discipline in the specified location. In this research, created MMRI tables are filled with semi-automated assistance by using Building Information Modeling and Interface Management systems data per location. This paper is part of an ongoing research related with measuring engineering progress in complex capital projects by integrating Building Information Modeling and Interface Management Systems. According to the CII Interface Management Implementation Guide, an interface management system is defined as "the management of communications, relationships, and deliverables among two or more interface stakeholders" [12]. By integrating these two systems, some automated assistance to fill MMRI tables can be created. However, details of BIM and IM system integration and semi-automated assistance by using these systems will not be described in detail in this paper. As a general example; geotechnical investigation reports can be tracked over the IM system by checking interface agreements, and request for information system data between civil works and infrastructure stakeholders of the LRT project, since they would share that information with each other over these systems. Similarly, track line layout design related criterion or Track ballast/bed design related criterion can be answered by using LOD levels of the related elements on the BIM file.

Table 2 Conceptual MMRI table for Track Line Discipline

Categories	Code	Criteria
Project Data	C1	The geotechnical investigation is ______
	C2	The site plan, topographic maps and surveys are ___
	C3	Existing conditions have been quantified and graphically represented
Design Components	C4	Horizontal layout design is_
	C5	Vertical layout design is___
	C6	Model of track line components is created with approximate size, material, and location
	C7	Design performance parameters, as defined by the project, are associated with model design components as graphic or non-graphic information
Track supports	C8	Track ballast/bed design is_
Routing	C9	The routing of the track lines has achieved a status which is: _
Specifications	C10	Project-specific layout specifications are____ _
	C11	Project-specific track line specifications are
Related Studies and Permits	C12	Permitting requirements are
	C13	Environmental and remediation requirements are
Submittals	C14	The IFC (Issued for Construction) drawing package and specifications have been submitted

Similar with the CII MMRI tool, the proposed table for the Track Line discipline would provide a MMI level result for each specific section on the project after filling the applicability column. As an example; when the criterion "Existing conditions have been quantified and graphically represented" is filled with "Confirmed" while all others are only "Loaded", MMI level would be 100, but even though Project Data and Design Component related criteria are in the status of "Confirmed", while Track Support and Routing related criteria are in the status of "Loaded", MMI level would still be 200 for that area. In that case, when Track Support and Routing related criteria obtain the status of "design confirmed", then the result of the MMRI table for that specific area on the project would change to MMI 300.

An example filled MMRI table for the Track Line discipline in a hypothetical LRT project station area is presented on Table 3.

Table 3 An example filled MMRI table

Location: CNS Station		
Categories	Criteria Code	Applicability*
Project Data	C1	Confirmed
	C2	Confirmed
	C3	Confirmed
Design Components	C4	Design Specified
	C5	Design Specified
	C6	Design Specified
	C7	Design Specified
Track supports	C8	Loaded
Routing	C9	Loaded
Specifications	C10	Loaded
	C11	Loaded
Related Studies and Permits	C12	Loaded
	C13	Loaded
Submittals	C14	No
MMI Level		**200**

4 Conclusion and Future Work

In this paper, a conceptual framework for measuring design progress on Track Line discipline in Mass Rapid Projects is proposed. The proposed framework contains new Model Maturity Index definitions for the Track Line discipline and a related MMRI table to measure design progress. New MMI definitions and an MMRI table is developed by conducting a literature review on track line design and by seeking related experts' opinions.

An example filled MMRI table is also presented after explaining the proposed framework. Semi-automated assistance for populating the MMRI table using an interface management system integrated with a BIM is also described but is not the main focus of this paper. As future work, the calculation method behind the CII MMRI table will be investigated and applied to this research.

5 Acknowledgements

The authors would like to thank the Natural Sciences and Engineering Research Council of Canada (NSERC) for their financial support through the Collaborative Research and Development Grant, and also would like to thank Coreworx Inc. for their in-kind contributions.

References

[1] Poirier, E.A., Staub-French, S. And Forgues, D., Investigating model evolution in a collaborative BIM environment, *In Proceedings of 5th International/11th Construction Specialty Conference*, 2015, Vancouver, Canada

[2] Azhar, S., Khalfan, M., & Maqsood, T. (2015). Building information modelling (BIM): now and beyond. *Construction Economics and Building*, *12*(4), 15-28.

[3] Shan, Y.; Goodrum, P.M. Integration of Building Information Modeling and Critical Path Method Schedules to Simulate the Impact of Temperature and Humidity at the Project Level. *Buildings* 2014, 4, 295-319.

[4] Azzouz, A, Copping, A, Shepherd, P and Duncan, A. Using the ARUP BIM Maturity Measure to Demonstrate BIM Implementation in Practice. *In*: P W Chan and C J Neilson (Eds.) *Proceedings of the 32nd Annual ARCOM Conference,* 5-7 September 2016, Manchester, UK

[5] American Institute of Architects, E202-2008: Building Information Modeling Protocol Exhibit, 2008

[6] BIMForum "Level of Development Specification 2017" On-line:http://bimforum.org/lod/, Accessed: 13/01/2018

[7] Yoders, J., Defining level of development for BIM and IPD projects. On-line: https://csengineermag.com/article/defining-level-of-development-for-bim-and-ipd-projects/, Accessed: 13/01/2018.

[8] Boton, C., Kubicki, S. and Halin, G. The Challenge of Level of Development in 4D/BIM Simulation across AEC Project Lifecyle. A Case Study. *Procedia Engineering*, 123, pp. 59-67, 2015.

[9] CII RESEARCH TEAM 332, *Measuring Progress and Defining Productivity Metrics in Model-based Engineering.* Project Report, 2017.

[10] International Association of Public Transport (UITP), 2015. Light rail in figures. On-line: http://www.uitp.org/sites/default/files/cck-focus-papers-files/UITP_Statistic_Brief_4p-

Light%20rail-Web.pdf, Accessed: 13/01/2018

[11] National Academies of Sciences, Engineering, and Medicine. *Track Design Handbook for Light Rail Transit*, Second Edition. Washington, DC: The National Academies Press, 2012.

[12] CII RESEARCH TEAM 302, *Interface Management Implementation Guide.* The University of Texas at Austin, USA: Construction Industry Institute, 2014.