Achieving Lean Design Using Design Interface Management Tool

Senthilkumar Venkatachalam[1], Koshy Varghese[2] and C Y Shivaji[3]

ABSTRACT

The design and construction on infrastructure projects were earlier done in sequence. However, the rapid rise in the infrastructure requirements and accelerated project schedules produced tremendous pressure on the construction organizations to adopt concurrent and fast-track techniques. This resulted in suboptimal utilization of resources and increased wastes to meet the schedule in the construction and design phases. Lean principles are used to plan the wastes reduction in the construction phase which was a common demand in the past. Research studies show that the design phase has more impact on the overall project planning and wastes reduction than the subsequent phases. Many methods have been devised to plan the design phases. Of these, the Design Structure Matrix (DSM) has shown a lot of application potential. This paper discusses a server based DSM tool called 'diMs' implemented on a design project to achieve lean design through managing the processes. The paper also discusses the waste reduction using 'diMs' tool compared with the conventional design practices with an example case study.

KEY WORDS

Lean design, DDSM, diMs, design interface management.

INTRODUCTION

Recently, many construction contracts are based on the EPC (Engineering Procurement and Construction) model which gives the contractor the sole responsibility for the EPC phases. This facilitates the use of innovative approaches such as fast track and lean principles in design and construction. The application of lean principles in the construction phase was a common demand in the past. The design phase was given low priority in the overall planning of a construction project until recently. But in reality, design has greater influence on the overall success of the project as the decisions made in the design phase would impact the later stages of the construction (Austin et. al., 1999).

Lean design encourages the Elimination of wastes & Non- value adding activities in design process (Javier and Alacorn 2002). There are seven/eight wastes identified

[1] Research Scholar, Civil Engineering Department, Indian Institute of Technology Madras, Chennai, India -600036, Tel:+91-44–22575255, Fax:+91-44-2257 4252, Email: vsenthil@iitm.ac.in

[2] Professor, BTCM Division, Civil Engineering Department, Indian Institute of Technology Madras, Chennai, India – 600036, Tel: +91 -44 -22574257, Fax:+91-44-22574252, Email: koshy@iitm.ac.in

[3] Deputy General Manager (Design), DIAL Project, L&T ECC, Delhi, India, Tel: +91 - 44 – 2257 5255, Fax: +91 - 44 - 2257 4252, Email: cys@lntecc.com

by the researchers in the area of lean product development which are as follows; overproducing, waiting, conveyance, processing, inventory, motion, correction and making do (Morgan and Liker, 2008; Koskela, 2004). These wastes exist in the construction design process also. The wastes in the form of the designer's time, effort, resources and construction rework due to design error etc are examples. Hence the design process needs to be effectively modeled. Extensive research has been carried out in modeling the design process and has resulted in the usage of tools such as directed graphs (digraphs), General Evaluation Review Technique (GERT) and Petri-Nets(Petri 1962). These graph-based representations are powerful but they also have some practical limitations (Whitfield et al., 2001).

A matrix based representation called the Dependency Structure Matrix (DSM) was proposed as a compact tool for representing and managing the design process (Steward 1981). Though sophisticated tools have been developed to implement the DSM concepts, the applicability of DSM based methodologies in the real world practices are limited (Colin Gray and Salam Al-Bizri, 2004; Senthilkumar and Varghese, 2008). A DSM can be formulated to capture dependencies at various design levels such as component, team, activity, parameter etc. The progress of the design and its interface with construction is based on the release of the drawings. Hence, the formulation of drawing DSM and its use for design sequencing at a macro level forms a key aspect of design management in the construction projects. However, the designers cannot formulate the 'Drawing DSM' (DDSM) directly as its size is large. Moreover, the identification of interfaces directly in DDSM is tedious and requires significant investment in the designer's time. Hence, a structured methodology is necessary to identify the interfaces and manage the size of the large DDSM. A modified DDSM formation methodology called 'diMs' has been proposed from the field studies (Senthilkumar and Varghese, 2008), as there are no specific guidelines on the decomposition of construction projects to reduce the DDSM size. Further, an automated server based tool has been developed based on the diMs methodology. The objective of this paper is to demonstrate the utility of the "diMs" tool and illustrate the wastes reduction obtained with a case study example.

The paper is organized in six sections; the second section outlines the proposed design management methodology "diMs". The third section introduces the details of the prototype tool. The fourth section explains the case study for the "diMs" implementation. A comparative study on the design wastes between the "diMs" implemented design and the conventional design is demonstrated in the fifth section. This is followed by a summary and discussion in the last section.

'diMs' METHODOLOGY – AN OVERVIEW

The 'diMs' methodology is implemented in three stages as shown in Fig 1. These are as follows: 1.Entity – Identification, 2.Interface- Identification and 3.Interface-Management. The procedure to implement diMs methodology is based on the following steps. (Refer- Senthilkumar and Varghese, 2009 for detail).

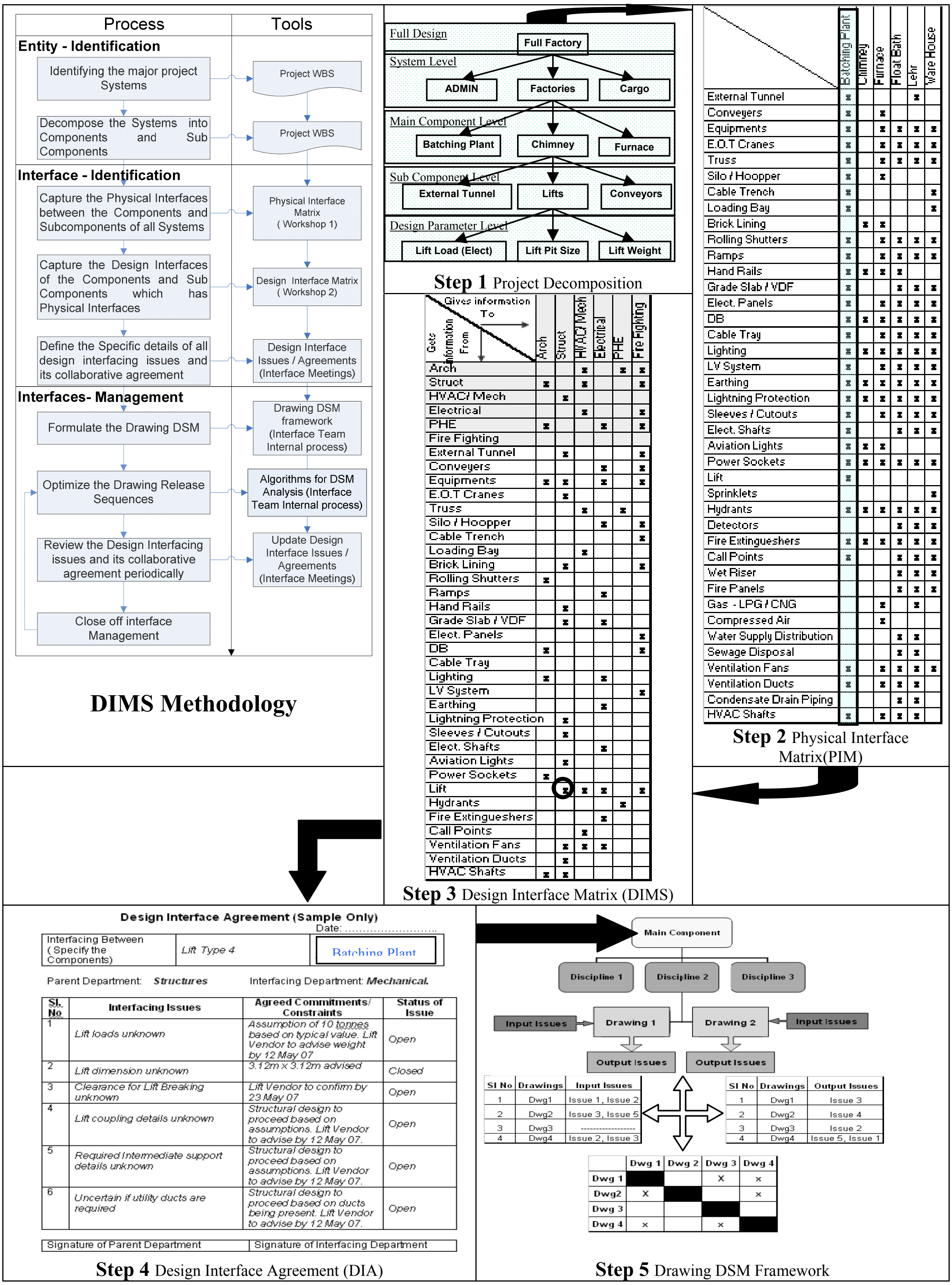

Figure 1: diMs Methodology (Ref: Senthilkumar and Varghese 2008)

1. In the Entity-Identification stage, the project is decomposed into various entities. The entities identified are systems, main components, subcomponents and teams.
2. In the Interface-Identification stage, the teams involved are required to identify their interfaces with other teams through workshops or brainstorming sessions. The design interfaces between teams can be effectively identified by enumerating the "physical interfaces" between various systems, components and subcomponents. As a result, the physical interfaces are identified for high abstraction levels in the hierarchy through Physical Interface Matrix (PIM).
3. From PIM, the design interfaces among design teams are identified in the next step through Design Interface Matrix (DIM).
4. Then, each discipline enters the detailed interfacing issues in the form of Design Interface Agreement (DIA).
5. Finally, the drawing and issue relationships are identified through mapping the interface issues with drawings as input/output. The Drawing DSM is developed on the basis of the framework in step 5 of figure1. The developed DDSM can be further analyzed (Partitioning and Tearing) for sequencing and other design decision making processes.

The DDSM development process is incremental, voluminous and requires interaction between multiple members of the design group. Hence a server based software tool was developed to reduce the time and effort required for the interface management process through this methodology.

"DiMs" PROTOTYPE TOOL – AN INTRODUCTION

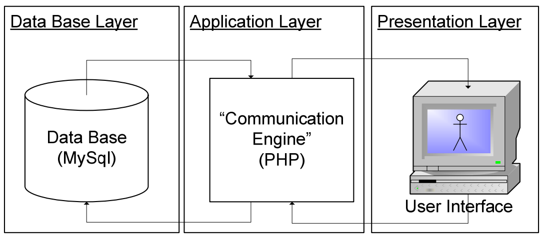

Figure 2: Software Architecture of "diMs"

A server based automated tool has been developed to facilitate the utilization of the "diMs" methodology. The system is supported with a relational database, a communication engine (which allows active integration of the input data, the 'diMs' processes and the output data) and an effective user interfaces. The software architecture of the system is shown in figure 2. The tool features multiple user authorization levels, access from distributed locations, automated alert messages through system generated e-mails, report creation etc. The system can be hosted on the server at the design office and the interfaced data can be accessed from anywhere through web.

CASE STUDY – IMPLEMENTATION OF "DiMs" TOOL

The "diMs" prototype was implemented in the Airport Services Building design. This design had a lead time of 3 months. There were 6 design disciplines involved other than the stakeholders such as the client, subcontractors, consultants, vendors etc. The project was executed in fast track mode (the construction starts more or less in parallel with the design).

Initially, the team members were introduced with the “diMs” terminologies and the methodology followed by a training session. The kick off meeting was arranged to start the process. The team members gave the input for diMs during the kick off meeting. The participant’s understanding on the tool and the concept were assured by interacting with them daily. A weekly meeting was decided (Interface Meeting) for discussing the unresolved interface issues or the issues which requires utmost attention. The participants were also advised to raise all their interface issues and responses only through the prototype. The following steps illustrate the implementation of the tool.

1. The “diMs” process starts with the identification of entities such as systems, main component and subcomponents through the workshop. The details such as the name of the entities, dates associated with them (construction date) and the design durations are also been specified. Figure 3 shows the entity definition page.

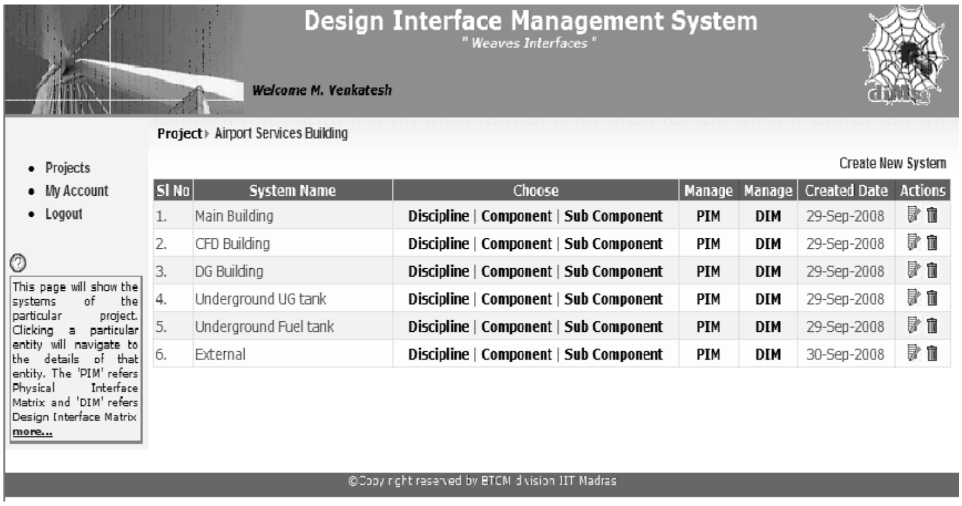

Figure 3: Snap Shot of Entity Definition Page in “DiMs”

2. The system generates the framework for PIM automatically from the defined entities. PIM is a dynamic matrix and it gets updated when an entity is added / removed from the Data Base to accommodate the frequent scope change in fast track projects. During the first session of the workshop, the users were asked to identify physical interfaces between the already defined main component and subcomponent in the PIM structure. Figure: 3, shows the developed PIM.
3. The system generates the DIM structure automatically from the PIM. During the second session of the workshop, the design interfaces were captured through the ‘DIM’ framework by each team. This workshop facilitates the interface identification process as the participants from all the teams were present in the common working forum (workshop). The physical interfaces forms the basis for the designers to identify the design interfaces. Figure: 4 shows the generated DIM. Different color symbols are used to differentiate the interface status.

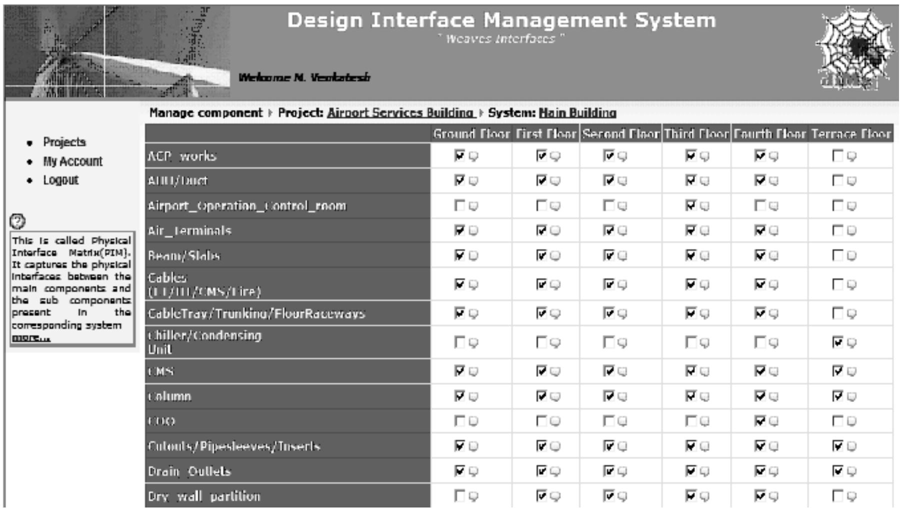

Figure 4: Snapshot of PIM in "DiMs"

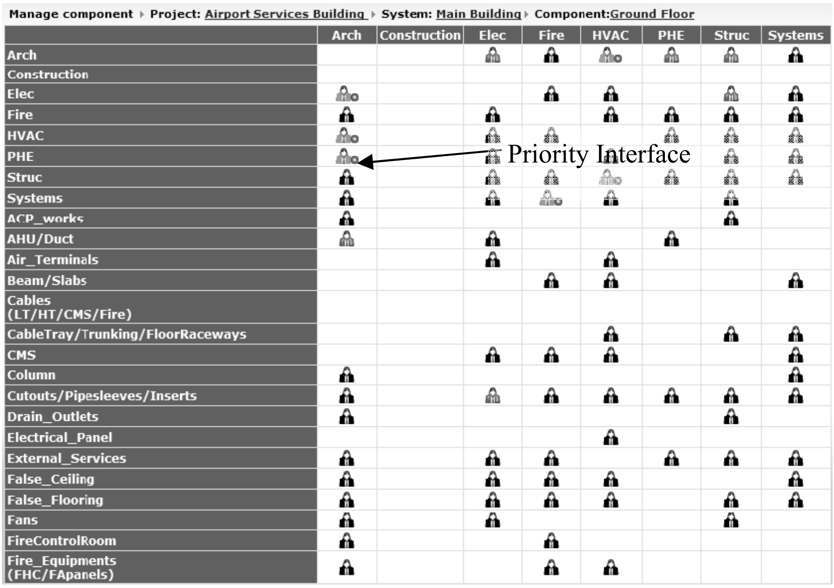

Figure: 5 Snapshot of DIM in "DiMs"

4. The corresponding interfacing teams were notified by a system generated email when an issue is generated. In response to the e mail, the responses were made through response window (similar to the issues popup).
5. These responses are updated in the DIA accordingly through the system database. The DIA has the following details of the interface issues 1. Interface issue 2. Initiator 3. Responder/ Responders 3. Responses 4. Status, 5. Deadlines etc. Similarly the DIM is updated with colored symbols based on its status. The

priority interfaces[4] (identified based on construction schedule) are notified with the red blink to assist the designers in resolving the issues.

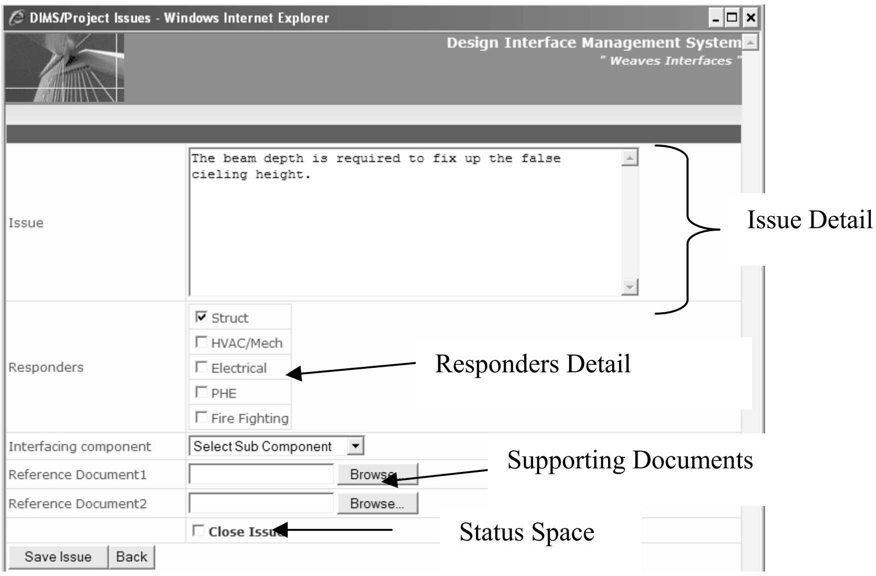

Figure: 6 Snapshot of Issue Definition Popup window in "DiMs"

6. Though the users interact through web, weekly interface meeting interactions were required especially when an interface issue required collaboration among three or more teams. Further the priority issues were also resolved during these meetings to meet the construction schedule. Hence the weekly interface meeting was mandatory. The interface discussions in these meetings are facilitated with the system generated report by each team. Each team has two types of issues, 1. Issues which need to be resolved by others and 2. Issues which need to be resolved by own. Further, the above two categories are grouped in two types; 1. Priority issues and 2. Non priority issues. The categorized report can be generated through the report generating page with filtering options in the system as shown in Figure 7.
7. Finally, each design team mapped the generated issues as input/ output with each of their drawing. The system generated the DDSM using the issues-drawings relationships established in the above step. This approach of mapping the interface issues as input /output reduce the effort required in identifying the drawing dependencies directly in DDSM as in the case of conventional DSM methodologies.

Even though the DDSM formation and the partitioning were included as a part of the "diMs" tool, the users were highly depending on "PIM", "DIM" and "DIA" to manage their design. As the construction was pulling the design, the designers were forced to resolve the interface issues according to their construction requirements. Since the prioritization of drawing release had been done according to the

[4] The interfaces, which need to be resolved to meet the construction schedule.

construction schedule (Construction Pull Design), the partitioned DDSM based on the design constraints were ignored.

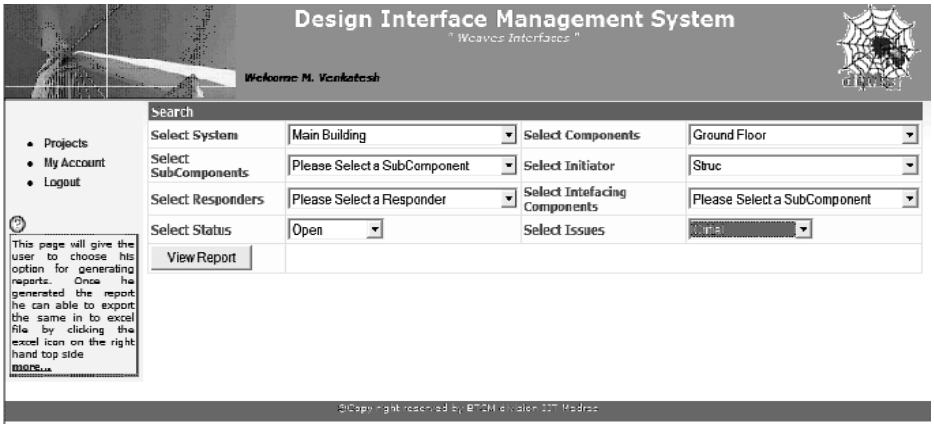

Figure 17: Report Page in 'DiMs' for Glass Factory Design

DESIGN WASTES ASSESSMENT – COMPARATIVE ANALYSIS WITH EXISTING PRACTICE

The first author assessed the design wastes generated during the design process. This "diMs" used design process is compared with the existing design process. The improvements observed based on the comparative study are justified through multiple sources of evidences (Robert K. Yin, 2003) of this case study. The evidences include a questionnaire interview, documentation analysis, archival records, participatory observation and interviews. The comparative study starts with the establishment of the assessment criteria. The assessment criteria includes the number of revisions, amount of delay, duration of design interface process, the number of site rework, the number of clashes etc. The structured questionnaire with assessment criteria was circulated to two categories of responders. The first category is the users of the "diMs" tool and other category is the designers who didn't use "diMs" methodology (used conventional design management methods). Thirteen responders were identified in each category and the proportion of responders in terms of experience and disciplines are same in both the categories. The criteria were assessed through the response in terms of five point Likert scale (presented in bottom of table 1). The responses are tested for the improvements of the design management through the assessment criteria using independent samples - T tests. The hypothesis test results are shown in table 1.

The above mentioned questionnaire survey results are supported using archival data and available records such as NCRs, Document Control Index etc of the two categories of designs. This is shown in Table 2. The improvements were noted in the area of: 1. Reduction in revisions, 2. Increase in productivity, 3. Reduction of submission delay etc. In addition, the reasons for the improvements were asked to the designers through interview. The designers felt that these improvements are based on the encouraged collaborative decisions made using the tool through the weekly meeting and communication capabilities of the tool. The designers believed that the delay had been totally eliminated because of the tool's color coded issue status symbols and email alerts. The designers also added that the reduced response time and the cycle time for the interface issue increased the productivity of the designer and the draftsmen. Further, the system also reduced indirect wastes such as the cost of hardcopies, postal charges, time taken for postages etc. In addition, the utilization of the web based automated tool, eliminates the temporal and geographical barriers for the interface information flow.

Table 1: Questionnaire Survey Results Against the Wastes Assessment Criteria

Sl. No	Assessment Criteria	Hypothesis Result	Mean Value from Questionnaire	
			With “diMs”	Without “diMs”
1	Frequency of Clashes Detected.	Ho - Rejected	2.33	3.46
2	Frequency of Design Rework Occurred.	Ho - Rejected	2.45	3.61
3	Frequency of Drawing Revisions Happened	Ho - Rejected	2.25	3.54
4	Frequency of Site Queries Obtained.	Ho - Rejected	2.5	4.08
6	Frequency of delay Occurred.	Ho - Rejected	2.33	3.31
7	Average Overall Interface Time*	---------	3.0 days	8.5 days

(Independent samples T –test)

Note:

Null Hypothesis = Ho - No Change in Assessment Criteria,

Alternate Hypothesis = H1 - There is a Change in Assessment Criteria

*** -** Measured in Days

Scale

1. Never
2. Sometime
3. Average
4. Often
5. Very Often

Table 2: Archival Data and Available Record Analysis for Wastes Assessments

No	Assessment Criteria	With “ diMs”	Without “diMs”
1	Total Area	3850 m^2 (G+ 4)	4600 m^2 (G+2)
2	Design Durations	3 months	4 months
3	Number of Design Disciplines Involved	6 +	6 +
4	Total number of Drawings Released	143	102
5	Number of Revisions on Arch and Structural Drawings in %	15 %	48 %
6	Number of Delay in First Submissions	Nil	29
7	Productivity (Drawings/ Engineer or Drafter)	14.3 Dwgs /Engineer 17.8 Dwgs / Drafter	10.22 Dwgs/ Engineer 12.27 Dwgs / Drafter
9	Number of Site Rework Due to Design Error	1	6

SUMMARY AND DISCUSSIONS

The lean principle of reducing wastes and improving quality in design has been addressed by better interface management and information flow methodology. The “diMs” methodology is demonstrated through an airport building design case study. The web based information communication, email notifications and alert messages reduce the cycle time of design iterations which in turn helps to reduce delay. The integrated project database encourages the improved sharing of information during its design life. This eliminates the redundant activities and design data input mismatch among the designers, saves the designer's time, reduces the wastes and increases their productivity. The comparative study shows that the design management is improved and the design wastes are reduced. Though the designer is required to spend more time at the initial stages, the overall interface management time is reduced by the reduction of rework, revisions.

The use of DDSM in modeling the design process of fast track construction project has not been explored, as the designers were satisfied with the interface information flow management and the alert mechanism of the tool through PIM, DIM, DIA and Reports. Further study is required to explore DDSM analysis in decision making for the design drawings sequencing.

ACKNOWLEDGEMENT

The authors wish to thank L&T ECC division, India and its designers for their assistance and support to carryout the research study.

REFERENCES

Austin, S.A., N. Baldwin, B. Li and P. Waskett (1999), "Analytical Design Planning Technique for programming Building Design", *Structures and Building*, 134(2), 111-118

Colin Gray and Salam Al-Bizri. (2004), "Modelling for Planning Building Design – A Critique of Available Approaches", Proceedings of *COBRA- The international Construction research conference of the Royal Institution of Chartered Surveyors*, Leeds Metropolitan University, UK, 7-8 September.

Javier Freire and Luis F. Alacorn. (2002), " Achienving Lean Design: Improvement Methodology", ASCE *Journal of Construction Engineering and Management*, Vol 128 (3), 248-256

Koskela, L. (2004), "Moving on – beyond lean thinking", Salford, UK

Morgan., James. and Jeffrey. K. Liker. (2006) "The Toyota Product Development System: Integerating people, Process and Technology", Productivity Press.

Petri, C.A. (1962), "Kommunikation mit Automaten, Ph.D. thesis, Institute f□ ur Instrumentelle Mathematik, Bonn.

Robert K.Yin. (2003), "Case study Research Design and Methods" Third edition, *Sage publications*.

Senthilkumar, V. and Varghese. K. (2009), "A Structured Methodology to Formulate Drawing Dependency Structure Matrix (DDSM) for Construction Design", *Journal of Architectural Engineering and Design Management*. Accepted for publication in next issue

Senthilkumar, V. and Varghese, K. (2008), "Design Interface Management System (dims) for Construction Projects", *10th International Design Structure Matrix Conference, DSM'08,* Stockholm, Sweden, 11 – 12 November.

Steward, Donald. V. (1981) "The Design Structure System: A Method for Managing the Design of Complex Systems", *IEEE Transactions on Engineering Management*, vol. 28, 71-74

Whitfield, R.I. Duffy, A. H. B. Wu, Z. and Meehan, J.(2001), "Intelligent Design Guidance", *International Conference on Engineering Design ICED 03*, Stockholm, Aug. 19-21.