Use of a WBS Matrix to Improve Interface Management in Projects

David K. H. Chua, M.ASCE[1]; and Myriam Godinot[2]

Abstract: Many researchers agree that smoother construction would result from better communication between designers and constructors about specific requirements and constraints for construction that can be incorporated into the design. The same principle can be generalized to apply to all the phases of a construction project (design, equipment procurement, transport, delivery, installation, and testing, as well as hand-over activities), to the different partners (main contractors, subcontractors, and suppliers), and even internally to the teams working on different parts of a system for the same contractor. Specific requirements and constraints at work interfaces that are technical, organizational, temporal, and geographical in nature have to be made transparent so that they can be managed and resolved to avoid unnecessary reworks and delays. This paper proposes to use the work breakdown structure (WBS) concept to improve work interface management. In the manufacturing industry, the WBS concept is well exploited by crossing a horizontal breakdown of production activities with a vertical breakdown of final products, thus obtaining a WBS matrix, which is more complete and useful than the classical WBS tree. In this paper, the WBS and interface management concepts are first clarified. Then, it is proposed to transpose the WBS matrix concept into the construction industry and to analyze, in a case study, how it may be used to improve interface management. The case study involves the construction of a segment of a mass rapid transit system comprising many specialty trades spanning track works, power supply, signaling, passenger vehicles, and control.

DOI: 10.1061/(ASCE)0733-9364(2006)132:1(67)

CE Database subject headings: Project management; Internet; Construction management; Communication.

Downloaded from ascelibrary.org by Mississippi State Univ Lib on 07/06/19. Copyright ASCE. For personal use only; all rights reserved.

Introduction

From the systems perspective, a project can be viewed as an assemblage of organizations, teams, work, information, and other attributes that have to be integrated to achieve project objectives. Today, projects are becoming increasingly complex with greater specialization in multiple disciplines, which naturally form interfaces between work divisions in the project with each autonomous organization or even team having its own objectives. However, from the perspective of the project as a whole, the efforts of these subsystems have to be tightly coordinated to ensure that the system objectives are adequately achieved. The problem is further compounded with the notions of fast-track and concurrent engineering, in which successive activities are reorganized to be performed simultaneously. This would require that autonomous teams work simultaneously on separate yet dependent modules of the project, increasing the potential for interface error and the likelihood of integration problems. This is the essence of the function and purpose of interface management.

Each subsystem can be highly dependent on the others. The flow of design parameters, work instructions, space scheduling information, and resource use must be coordinated across the abstract boundaries between these subsystems. In a sense, these attributes of one subsystem form the interfacial constraints of the other subsystems. Inadequate control of these constraints could lead to work disruptions and reworks due to interfacial mismatch.

The work breakdown structure (WBS) concept has been extensively discussed and widely recognized as a powerful project structuring tool wherein a project is hierarchically organized into smaller units for better performance control. This paper exploits the general familiarity with this concept and extends its features to form a matrix for integrated product and activity perspectives. The paper includes a set of reporting forms for interface definition through control and conflict resolution.

Accordingly, this paper will first define and explain the concept of interface management. It will then elaborate on the concept of the WBS matrix. A case study will be used to explain how the WBS matrix management package can improve interface management. The case study is a project that involves the construction of a segment of a mass rapid transit system comprising many specialty trades spanning track works, power supply, signaling, passenger vehicles, and control. The ability to manage the many interfaces among the diverse specialized work divisions will determine the overall success of the project.

[1]Associate Professor, Dept. of Civil Engineering, National Univ. of Singapore, Singapore 119260. E-mail: cvedavid@nus.edu.sg

[2]Research Scholar, Dept. of Civil Engineering, National Univ. of Singapore, Singapore 119260.

Note. Discussion open until June 1, 2006. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on June 22, 2004; approved on January 31, 2005. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 132, No. 1, January 1, 2006. ©ASCE, ISSN 0733-9364/2006/1-67–79/$25.00.

Downloaded from ascelibrary.org by Mississippi State Univ Lib on 07/06/19. Copyright ASCE. For personal use only; all rights reserved.

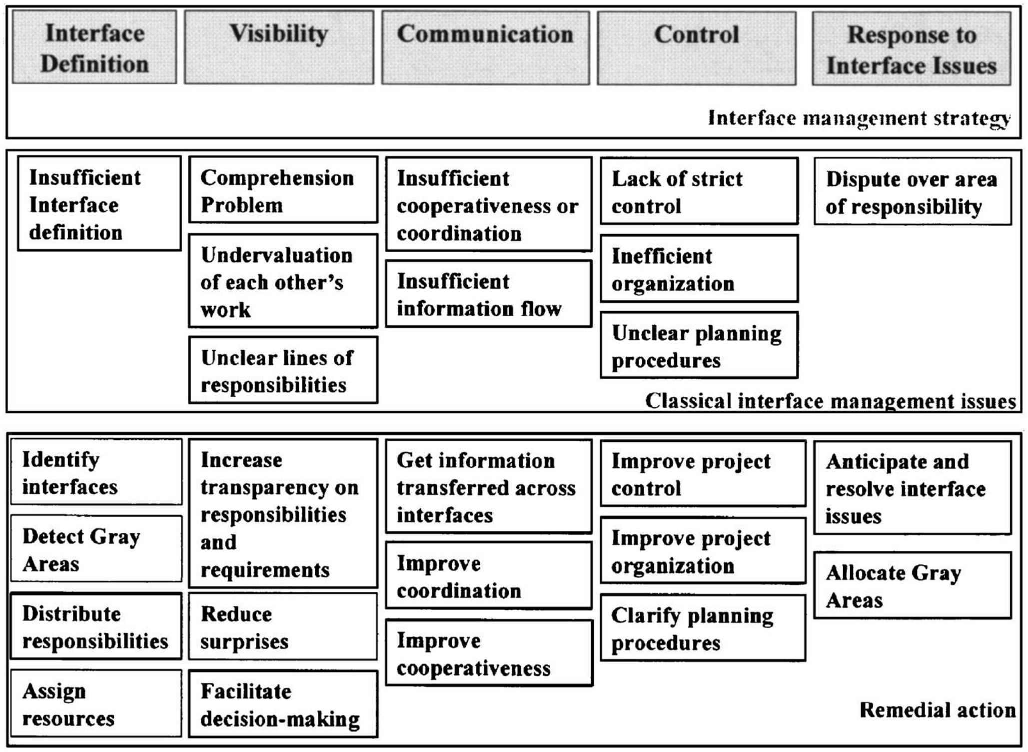

Fig. 1. Five functional aspects for interface management

Interface Management and the WBS Matrix: Presentation

Interfaces: Definition and Classification

The use of the interface concept in the context of project management followed the development of the system approach, which defined organizations as systems of mutually dependent variables (Wren 1967). When organizations must cooperate to serve a larger system, they have to satisfy both their own objectives and the system objective. Thus, projects are made of subprojects whose interfaces are necessary to determine if integration can be achieved (Morris 1983). Interfaces arise from the division of work into parts executed by different people or organizations (Stuckenbruck 1983).

Interfaces can be internal, if the work concerned is done within one organization, or external, if different organizations collaborate (Healy 1997). For most authors (Wren 1967; Stuckenbruck 1983; Healy 1997), it is also important to differentiate:

- time interfaces that are triggers conditioning the transition from a certain kind of activity to another;
- geographical interfaces that separate on-site and off-site work;
- technical interfaces that set the limits of a system's subcomponents;
- organizational interfaces that keep human groups or persons apart.

Interfaces can also be characterized according to the level of compatibility of the parties they separate (Healy 1997). In the best situation, there is a perfect match between interfacing parts, with physical and operational compatibility, seamless data transmission, etc. This situation is very difficult to obtain. More frequent is the partial match, with some commonalities existing between the interfacing parts in terms of work practices or specifications. In the case of total mismatch, work practices are entirely different and there is no agreement between parties. In practice, each boundary shows interdependencies with different degrees of mismatch.

Main Steps of Interface Management

Many researchers have studied the issues and mechanisms of interface management. Töpfer (1995) mentions many interface problems that hamper the collaboration of an interdisciplinary team. Managing *internal interfaces* and managing *external interfaces* involve different skills and are equally essential to successful project management (Healy 1997; Stuckenbruck 1983). *Time interfaces* also require careful management to smoothly move a project from conception to delivery (Caron et al. 1998; Morris 1983; Stuckenbruck 1983). Failure to properly manage *technical interfaces* can also result in reworks, time wasting, and financial loss (Sundgren 1999).

Although specific types of interfaces have been addressed, there has not been an explicit common framework for developing interface management systems. Nevertheless, it is proposed here to group the various strategies used to manage these interfaces into five functional aspects as depicted in Fig. 1 to provide this framework. The first four aspects deal with the prevention of interfacial problems, while the last manages the problem when it surfaces. The middle section of Fig. 1 depicts the interface issues that could arise as a result of deficiencies in the above strategies. The bottom section suggests the corresponding remedial actions.

The temporary nature of projects makes it necessary to define interface details at the onset, using a precise technical definition of the work and the allocation of responsibility for the work (Stuckenbruck 1983; Healy 1997). The second functional aspect is to improve transparency (or visibility) of project requirements. For the autonomous teams, increased visibility of project require-

J. Constr. Eng. Manage., 2006, 132(1): 67-79

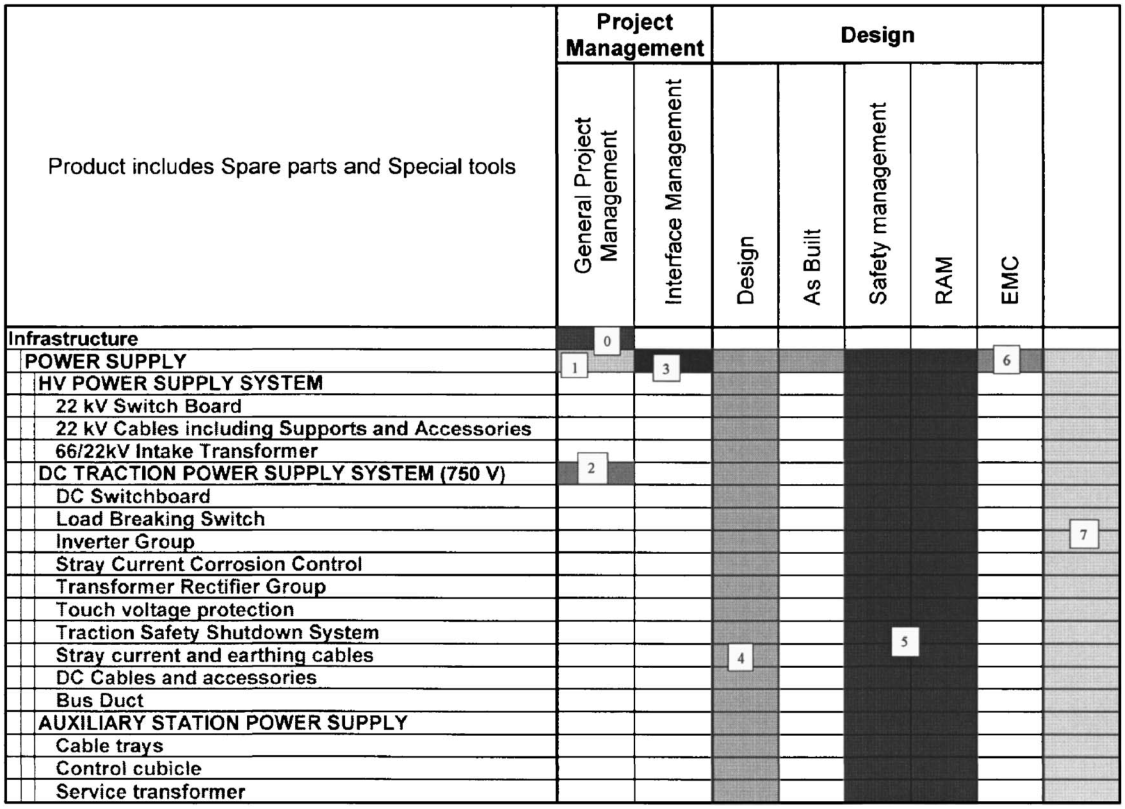

Fig. 2. The WBS matrix (part of the WBS matrix developed for the case study of a mass rapid transit line)

ments promotes greater accountability of performance and deliverables so that the dependencies across interfaces can be smoothly coordinated. Visibility can be achieved with clear lines of responsibility and authority, strict control, and organizational checks and balances (Morris 1983).

Several possible interface management organization schemes are available to help project managers achieve liaison between continuously interfaced subsystems, such as liaison positions, task forces, special teams, and coordinators (Morris 1983). But ultimately, interface management is essentially a communication task wherein adequate communication flows and coordination among the diverse teams are necessary for full technical integration of a system (Healy 1997). Interfaces are generally managed through meetings, which must gather technically knowledgeable, committed, and empowered people for each interface. In this regard, the interface management system must provide information and facilitate the process for communicating, controlling interface issues, and resolving interface conflicts when they arise.

The proposed WBS matrix for interface management has been developed based on the above framework to provide the five functional aspects. The concept is first explained in the next section followed subsequently by its implementation in a pilot case study.

Definition of the WBS Matrix Concept

A WBS is generally seen as a way to organize work hierarchically so that project managers can control performance (Ayas 1997; Globerson 1994; Tiner 1985) by subdividing end objectives into successive smaller subdivisions (Bachy and Hameri 1997). This decomposition can be either activity- or product-oriented (Colenso 2000), and both, as well as many combinations of them, have been considered (Christensen and Thayer 2001; De Heredia and Santana 1991; Lanford and McCann 1983; Matthews 1986; Reilly 1993; Ruskin and Estes 1995; Saynisch 1983; Smith and Mills 1983; Tiner 1985; Warner 1997).

The diverse approaches all recognize the need for a systematic breakdown of the project into smaller elements for better control and that both product and activity views of the project can be beneficial. Sometimes, interface issues arise from the product perspective, and at other times, they arise from the work-activity perspective. Moreover, people actually think about both activities and products when describing a project (Albert 1995). To reconcile the need for this dual view in a single interface management system, the WBS matrix concept is adopted herein. In this way, a consistent approach for defining and managing the interfaces can be established.

The WBS matrix concept was first approached in a research paper by Bachy and Hameri (1997). The model of the WBS matrix adopted herein extends the Bachy and Hameri model to incorporate all the steps of a construction project, including design, procurement, construction, testing, etc. An example of a WBS matrix for the construction of a mass transit system is shown in Fig. 2, which will be further elaborated in the case study.

First, a vertical product breakdown structure (PBS) and a horizontal activity breakdown structure (ABS) are established to describe, with the level of detail required, the end product to be delivered and the activities to be performed during the course of the project. The PBS is crossed with the ABS, resulting in what is called a WBS matrix. The cells of the WBS matrix body are then regrouped into work packages (WPs) corresponding to a particular activity or set of activities to be performed on a particular

J. Constr. Eng. Manage., 2006, 132(1): 67-79

Downloaded from ascelibrary.org by Mississippi State Univ Lib on 07/06/19. Copyright ASCE. For personal use only; all rights reserved.

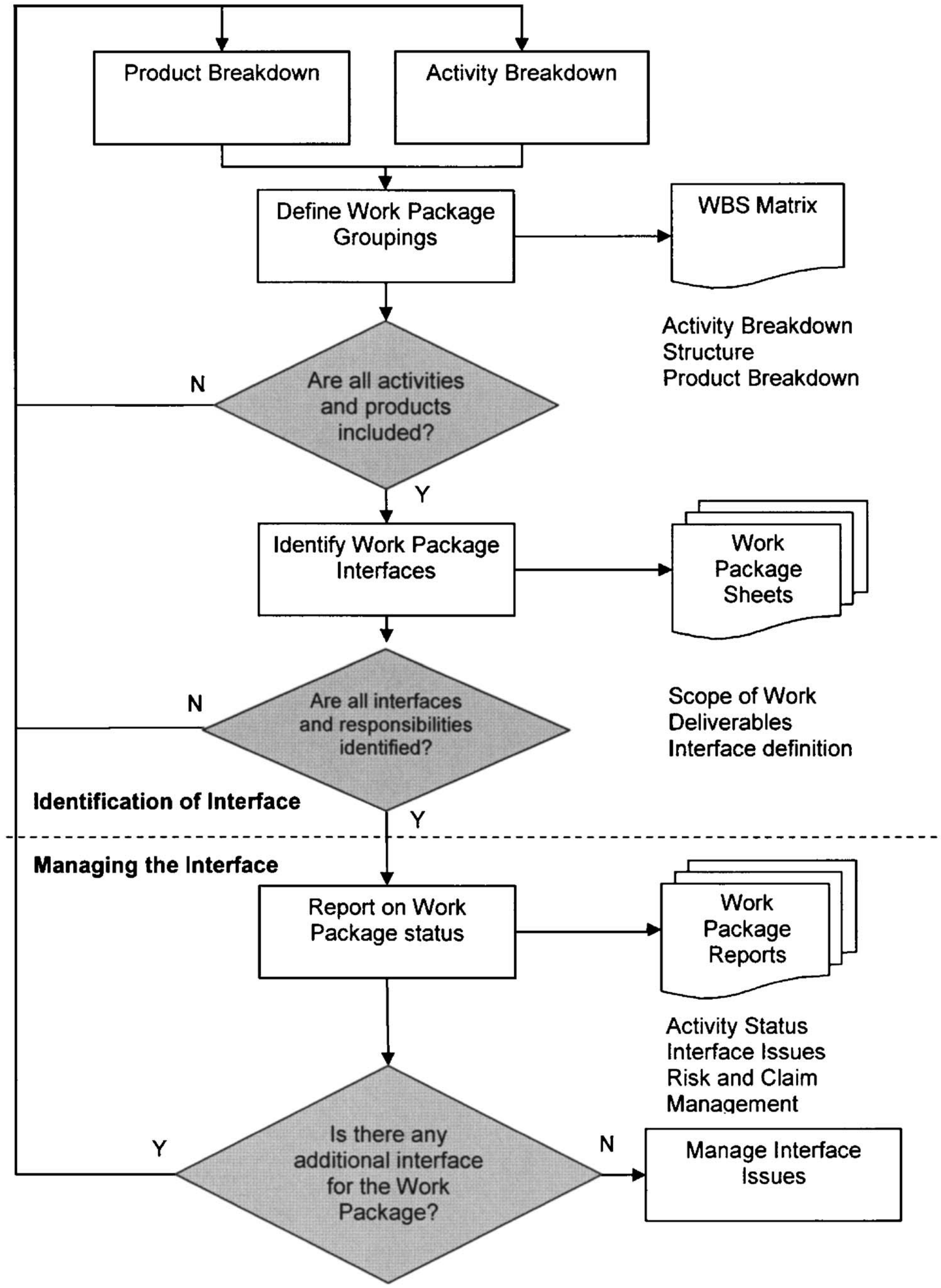

Fig. 3. WBS matrix management package

product or set of products. The formation of WPs is denoted in Fig. 2 by the number attributed to them (e.g., work package 6 is for EMC in the power supply system). The WBS matrix is supplemented with a package of WP sheets and WP reports that help manage the interface as described in Fig. 3.

After the WBS matrix has been established, each WP is clearly defined in a separate WP sheet. The WP definition includes the scope of the work, the interface issues, the deliverables, and the schedule and budget objectives. During project implementation, reporting is done at the WP level using a WP report, which summarizes the progress of the WP and highlights the interface problems that have arisen or could arise. Claims and risk issues are also important to include in the reports. While the WBS matrix and WP sheets are prepared as early as possible in the project (during the tender phase for instance) and then only partially and occasionally revised when needed, WP reports should be prepared weekly to provide up-to-date information for monitoring and managing WPs.

The WBS matrix management package as proposed has several outstanding features. The matrix provides a compact summary of the relationship of the WP to the product modules and work activities, providing a more precise definition of the work scope brought about by the clear separation of products from activities. This gives the project manager more precise control over the project by presenting activity-oriented work and product-oriented work in one simple format.

J. Constr. Eng. Manage., 2006, 132(1): 67-79

Downloaded from ascelibrary.org by Mississippi State Univ Lib on 07/06/19. Copyright ASCE. For personal use only; all rights reserved.

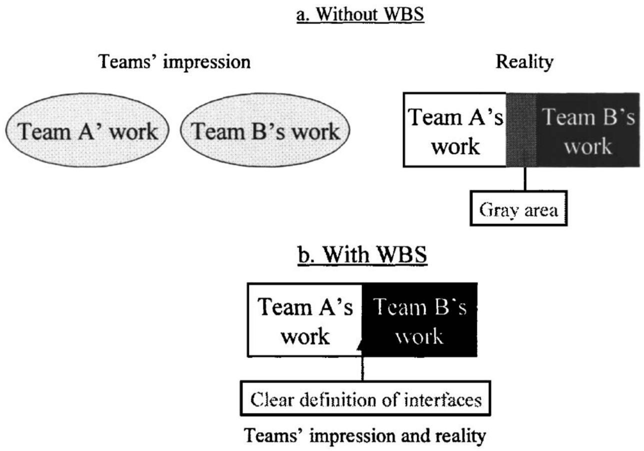

Fig. 4. Interface definition with and without WBS

Using the WBS Matrix as an Interface Management Tool

Two phases, as demarcated in Fig. 3, can be identified regarding the use of the WBS matrix management package as an interface management tool. The first phase is the development of the WBS matrix and WP sheets. This provides opportunities to define interfaces and bring transparency to the whole project organization. The second phase is the use of the WBS package, once it is finalized, as a management tool for control and resolution of interfacial issues.

WBS Definition Phase

Making of a WBS matrix provides a framework to clearly identify interfaces from both the product and activity perspectives and to allocate responsibilities across these interfaces. While subdivision of large components or project phases is done naturally, the interfacing of subcomponents or tasks is usually not addressed. By formalizing the product and activity breakdowns, the WBS allows the project manager to point to the interfacial boundaries between systems managed by different teams, and further, to plan the organization of work across them. Moreover, by formalizing in the WP sheet the precise scope and function of each WP, the matrix identifies how WP teams will interact with each other in terms of general communication, information and document exchange, and collaboration on common tasks. More than simple delineation of boundaries between parties, the WBS thus defines the whole process of interface management at these boundaries.

The responsibility allocation task is the first step toward identifying gray areas at the interfaces. Gray areas can be defined as tasks or activities that are contractually included in the overall scope of the project but are under no clear responsibility in the project team. They are common at interfaces, where work definition is the most difficult. The bulk of a team's work is usually better defined than the work's limits, the team's interactions with other teams, the team's share of responsibilities, etc. Some tasks to be completed by several teams simultaneously or with feedback from each other, while other work can be performed by one team alone but has not been allocated to any of them.

Fig. 4 summarizes this aspect of WBS interface management, showing, as in (a), that teams do not readily think about interfaces. They concentrate on the bulk of their own work, assuming that the interfacing party is taking care of the work at interface, and no problems are identified (teams' impression). In reality, the allocation of work among teams does not perfectly cover all the work to be performed, creating a gray area at the interface. Two teams eligible for carrying out an activity, for example, may expect each other to do it, so in effect none of them do it. This situation is not sustainable and, if discovered too late, can only be resolved with considerable expense in cost, time, and efforts. On the contrary, when the WBS is used, the gray areas are identified and resolved before they become critical Fig. 4(b).

The role that the WBS can play in preventing these situations is essential. First, it provides a formal approach to defining organizational and work interfaces. Also, as noted earlier, the key to identifying and resolving the gray areas is responsibility allocation, often using acknowledgment sheets to confirm a commitment to complete a task ascribed in the work package sheet. A gray area is identified if the work is not taken up in the acknowledgment sheets. Gray areas are progressively eliminated as they are detected and resolved.

WBS Management Phase

After the WBS has been defined, its first use is to establish transparency of the work responsibilities. Transparency is of paramount importance in construction projects. Leiringer (2000) identified two critical phases in which transparency of work definition can be improved. First, some performance failures can be traced back to insufficient recognition and sharing of project needs and priorities by all project members at the start. Project teams fail to recognize the full extent to which the work that lies ahead of them affects the performance of other teams. Second, during construction, transparency of the underlying processes and flow of information is critical when dealing with changes to schedule and design.

In this respect, the proposed WBS matrix provides a framework to promote transparency through its WP sheets, thus clarifying the scope of work and removing any ambiguities at the interfaces. Moreover, each project team's objectives are clearly established. The interface requirements and deliverables also determined for each WP provide the transparency for the underlying interaction of processes and information flow.

The basis for control comes through the WP reports benchmarked against the schedule, budget, and deliverables objectives specified in the WP sheets. The WP reports also facilitate the communication of interface issues identified in the WP sheets. In this way, interface problems can be anticipated and then resolved before they become bottleneck constraints impeding the progress of the WPs.

Essentially, the WBS matrix management package has incorporated interface management into an integrated project control in which the performance of WPs is constantly tracked and managed. In this way, interfaces become part of the daily monitoring activities of managers at all levels, so that the monitoring of interfaces and anticipation of interface problems increase at all management levels. The project team should then have a better grasp of the development of time, organizational, and technical interfaces.

Case Study

This section will explore how the WBS matrix has been implemented in a transportation system project. The case studied here

Downloaded from ascelibrary.org by Mississippi State Univ Lib on 07/06/19. Copyright ASCE. For personal use only; all rights reserved.

J. Constr. Eng. Manage., 2006, 132(1): 67-79

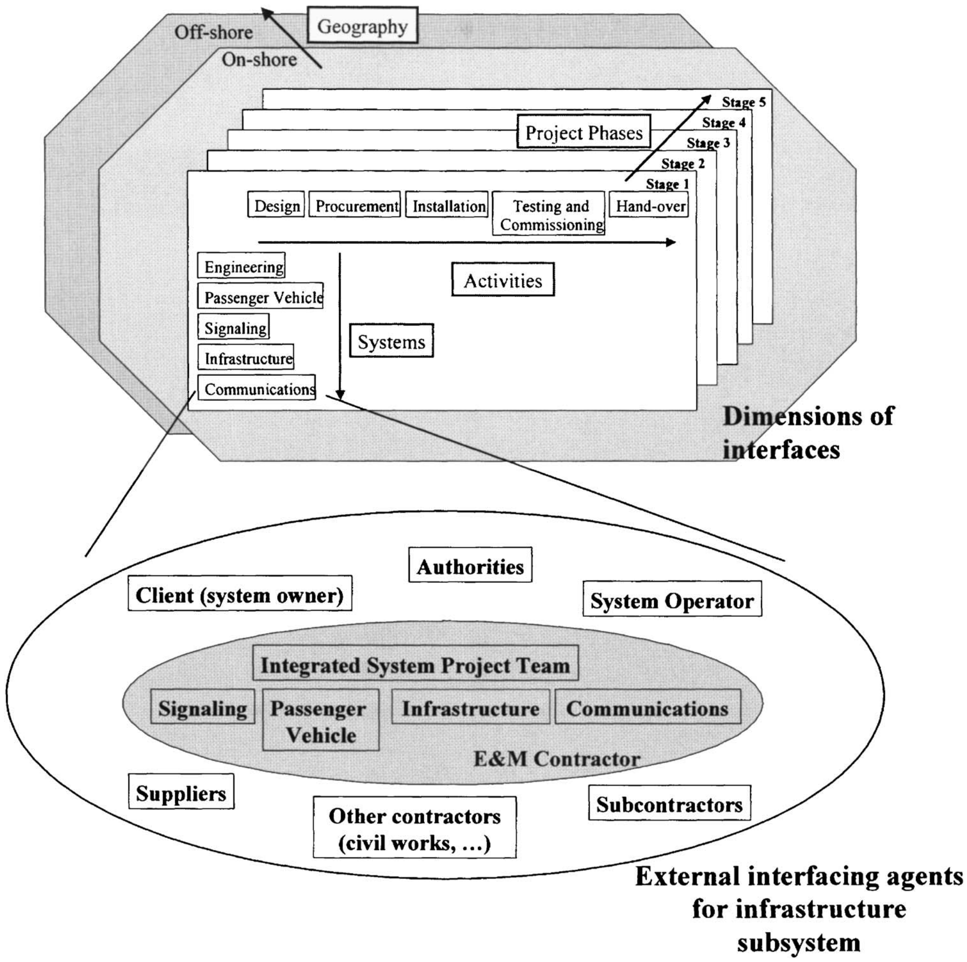

Fig. 5. Interfaces in the MRT line project

is a fully automated 35 km-long mass rapid transit (MRT) line in Singapore that was built in five stages. The contract for the design, manufacture, supply, installation, testing, and commissioning of the transportation system's electrical and mechanical systems was awarded to a single contractor, called "the main E&M contractor" herein. In addition, this contractor was responsible for integrating the subsystems it provided with other E&M subsystems, training the future operating staff, as well as postcommissioning activities such as warranty, reliability analysis, etc. The MRT line project involved a very complex system that required the careful integration of various subsystems involving diverse engineering disciplines. When fully operational, the system was fully automatic and driverless, further complicating the interface and requiring very stringent testing procedures for each subsystem. Numerous interfaces exist as depicted in Fig. 5 and further detailed in Table 1.

This paper focuses on the internal interfaces of the system. As illustrated in Fig. 6, the project team was organized into five technical "subsystems." One of these was the engineering subsystem, which was responsible for the technical project management, including system design and performance, operation, technical interfaces, electro-magnetic compatibility, reliability, availability, maintainability, and safety of the system (RAMS), as well as testing and commissioning. The other four subsystems were responsible for the design, construction, installation, testing, and commissioning of the main project deliverables—namely, passenger vehicle, signaling, infrastructure, and communications. All these subsystems were under the overall responsibility of a project management team.

At the subsystem level, further detailed internal interfaces were defined. For instance, in the infrastructure system, track work, depot, and power supply were allocated to different teams. Many teams were thus formed and had to integrate their work and manage their organizational and technical interfaces so that the various subsystems at all levels were functionally and technically in compliance with each other.

Geographical interfaces arise from the necessity of having a team abroad, where the main company of the main E&M contractor was based, and a team on site, where the project was implemented and where an increasing number of activities were carried out as the project advanced. Not only did the time interfaces comprise the usual phases of a typical construction project, but also the development of the MRT was completed in five stages so that each stage had to be managed simultaneously.

The external interfaces of the subsystems involved the other subsystems as well as other contractors working on the project such as civil work contractors, electrical services contractors, etc. The activities involving such interfaces were considered as transverse (i.e., involving other subsystems). Table 2 summarizes the interface considerations of the transverse activities identified for the subsystems comprising design, configuration management, installation, site safety, testing and commissioning, reliability and maintainability demonstration test (RMDT) validation, and warranty.

J. Constr. Eng. Manage., 2006, 132(1): 67-79

Downloaded from ascelibrary.org by Mississippi State Univ Lib on 07/06/19. Copyright ASCE. For personal use only; all rights reserved.

Downloaded from ascelibrary.org by Mississippi State Univ Lib on 07/06/19. Copyright ASCE. For personal use only; all rights reserved.

Table 1. Summary of Interfaces in MRT Line Project

Type of interfaces	Internal	External
Organizational	Between subsystem: management team, passenger vehicle, signaling system, infrastructure, communications systems	Civil works contractors
	Inside a subsystem, between teams, including -For passenger vehicle, on-board traveler information system equipment -For signaling, integrated supervisory control system, maintenance management system, and operations control center; -For infrastructure, track work, depot, and power supply -For communications, access management system, station traveler information system, automatic fare collection interface, and platform screen doors	Other E&M contractors (tunnel ventilation and environmental control, station electrical and environmental control, station electrical services, fire protection, escalators and lifts, automated fare collection, signage and graphics, station control room and RATIS)
	Between companies of different nationalities inside the contractor	Suppliers and subcontractors Client System operator
Technical	Between subsystems: -Passenger vehicle -Signaling system -Communications system -Platform screen doors -Operations control center, including automatic train supervision -Integrated supervisory control system -Maintenance management system -Power supply -Track works -Depot and facilities -Automatic fare collection interfaces -Access management system -Travelers information system	Between the contractor's E&M system and civil works Between the contractor's E&M system and other E&M systems Between externally and internally supplied components
Geographical	Between the local work and the work abroad Between the work on site and the work in the office	
Time	Between phases of the project (design, construction, etc.) Between the five stages of the MRT line	

Building the WBS Matrix Management Package for the MRT Line Project

The company had already developed a system interface management and integration plan for general interface management, which was made up of methodologies and procedures to control and integrate cross-discipline interface activities; define work sharing; and control, manage, and resolve interface issues. Combined services drawings for structural, electrical, and mechanical systems give an integrated representation of all services provided under the project. Evidently, the company was not a novice to the challenges of interface management. In this project, the company decided to implement the WBS matrix for the project and subsystem levels to enhance the definition and visibility of the interfaces. In particular, a fully integrated WBS matrix management package according to Fig. 3 was developed for the infrastructure subsystem as a pilot program.

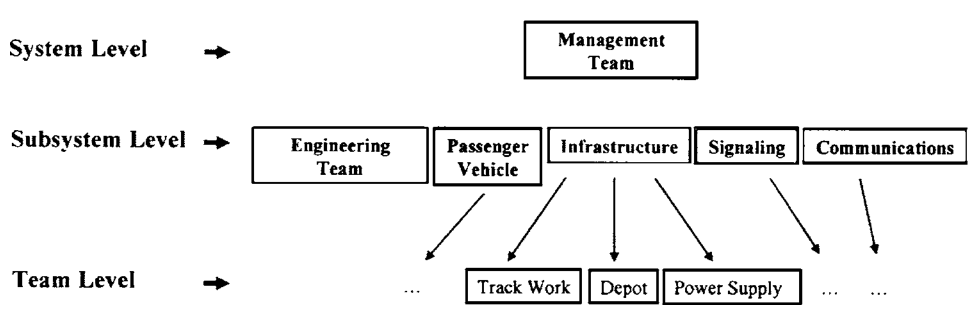

Fig. 6. Project subsystems

J. Constr. Eng. Manage., 2006, 132(1): 67-79

Table 2. Transverse Activities of Subsystems

Activity	Description	Type of interface involved: Organizational	Technical	Geographical	Time
Design	Production of design documents	Coordination of teams designing an integrated system	Design of intricately related systems	Coordination of teams working from different countries	End of activity to be coordinated with procurement phase
Configuration management	Document configuration management, integration configuration management, and installed product configuration.	Management of common computerized systems	Management of common computerized systems	Coordination of teams working from different countries on the same system	Activity is necessary all along project life
Installation and site safety	Methodology and procedures, installation, coordination of works, safety management.	Coordination of use of sites areas and works trains	Installation of intricately related systems	Different installation procedures in different places, zones in staging area	Beginning and end of activity to be coordinated with design and testing phases, respectively, several stages of the line to be installed simultaneously
Testing and commissioning	Testing plans and procedures, off-site testing, on-site testing.	Collaboration on testing of subsystems' interfaces	Testing of functional and physical interfaces between components		Beginning and end of activity to be coordinated with design and hand-over phases, respectively, several stages of the line to be tested simultaneously
RMDT validation	Tests and statistical analyses proving that reliability and maintainability objectives are met	Coordination of teams for corrective action taken, collaboration of design and RMDT teams	Cause of technical failure has to be identified		Beginning and end of activity to be coordinated with installation and testing phase, respectively
Warranty	Maintaining the installed system in good operating order.	Duration of warranty period depends on all systems' acceptance			Beginning and end of activity to be coordinated with installation and testing phases, respectively

Downloaded from ascelibrary.org by Mississippi State Univ Lib on 07/06/19. Copyright ASCE. For personal use only; all rights reserved.

Figures 7(a and b), respectively, show only a part of the PBS and ABS for the infrastructure subsystem. The subsystem is mainly responsible for track work and the power supply. Altogether 81 product elements were crossed with 29 activity elements to form the WBS matrix with 46 WPs, a portion of which is shown in Fig. 2.

Each of the WPs is precisely defined by the WP sheet as shown in Fig. 8. In each of these sheets (one for each WP) the scope of work and the deliverables are described, thus clarifying the WP managers' objectives and increasing the visibility of project requirements and responsibilities. A list of interfaces involved with the WP is defined. These can be technical interfaces if the WP involves components to be interfaced with other subsystems or human interfaces if inputs are simply needed from other parties. This list clarifies the flow of documents, information, and responsibilities through the different teams. Time interfaces are prescribed in terms of delivery objectives for each of the main tasks involved and for each of the project's stages, expressed in the form of milestones.

The remaining item in the WBS management package is the WP reports. These reports serve the purpose of regularly informing project members on the status of a WP. A typical WP report comprising several components is shown in Fig. 9. One component reports on achievements since the preceding report and on-going activities. Another identifies the problems encountered in relation to interfaces, schedule, budget, deliverables, and resources. This is accompanied by proposed actions for resolving the problems. A component for managing risk and claims is used for identifying new potential individual and mutual risks and variations with respect to the WP. WP schedule and budget sheets are also incorporated into the WP reports giving the details for the schedule and budget for the work items within the WPs.

Interface Management

As mentioned earlier, the basis for removing gray areas in the interfaces is the clarification of work responsibilities. The following procedure was put in place to achieve this objective: For each transverse activity, a WBS matrix was constructed with detailed activity breakdown. The work for each relevant cell of this WBS matrix was allocated to one of the subsystems. This detail in the WBS was necessary to clarify the scope of work issues and to ensure that all activities in the group were covered. Moreover, the detail had to be sufficient to avoid partial allocation of work in the cell so that ambiguity in the interface boundaries could be eliminated.

Fig. 10 shows a portion of the acknowledgement sheet used for tracking the allocation of responsibilities for the transverse activity "warranty." Codes were inserted for cross referencing to the product and activity breakdown structures. If a responsibility was acknowledged, the WP number that included the activity represented by the cell was specified, as depicted in Fig. 10. For

J. Constr. Eng. Manage., 2006, 132(1): 67-79

(a)

Infrastructure			
	POWER SUPPLY		
		HV POWER SUPPLY SYSTEM	
		DC TRACTION POWER SUPPLY SYSTEM (750 V)	
		AUXILIARY STATION POWER SUPPLY	
		OTHER MISCELLANEOUS	
	DEPOT		
		DEPOT WORKSHOP STORE	
		MACHINES & TOOLS	
	TRACKWAY		
		BASEMENT EARTHWORK AND CONCRETE	
			Concrete
			Walkway
			Cable troughs
			Drainage (clayware drain, grating, É)
			Embedded pipes
		SPECIAL ITEMS	
		TRACKS	
		STRAY CURRENT MESH AND JUMPER BOX	
		CONDUCTOR RAIL	
		WILD	
		OTHER MISCELLANEOUS	
	SITE WORKS LOGISTIC FACILITIES		
		TW HEAVY EQUIPMENT	
		TW LIGHT EQUIPMENT	
		TRIP HEAVY EQUIPMENT	
		STAGING AREA	
		OTHER MISCELLANEOUS	

(b)

Project Management		Design					**Industrialisation**	External Sourcing				Off-site Testing				Installation				Site Test and Commissioning					Logistic support		Warranty & Defect liability Period	
General Project Management	Interface Management	Design	As Built	Safety management	RAM	EMC		Procurement	Developpement Testing	Factory Acceptance Tests		SIP	IFAT Group 1B	VTT testing		Site Heath & Safety	Mock-up	Equipment installation	Operation and maintenance of temporary assets	Site Tests	Integrated Test & Commissioning level 1	Integrated Test & Commissioning level 2	Tests Running	Trial Running	Training	O&M Manuals/Asset registration	Warranty, Care of the works & Defect liability Period Activities	RMDT Validation

Fig. 7. (a) Product breakdown structure (PBS); (b) activity breakdown structure (ABS)

various reasons, subsystems sometimes did not readily accept to perform the activities higher level management had expected of them. A duplication of effort or an absence of a take up for any of the cells would highlight a gray area that needed to be resolved.

The following are some outstanding examples of gray areas revealed for the various phases (transverse activities) of the project. For confidentiality, the specific details have been omitted. With respect to the installation phase, the coordination of technical teams on site was the most delicate issue detected. Installation of some equipment would require some specialized trains. One group, here called G1, was responsible for the track work. Because G1 needed these trains for its own track-laying activities, it was to coordinate the use of the trains for the other groups needing them. Two main areas, A and B, were distinguished for the installation of track works (according to the ABS). G1, which was directly responsible for area A, thought that no trains were necessary in area B and, therefore, expected installation works in B to be coordinated by another team. G1 also did not expect to be responsible for the organization of installation work for the other groups after they have finished using the trains. These omissions were detected through the acknowledgement sheets.

In a related aspect regarding coordination of site safety in some areas and activities, G1, with its specialization on the use of the special trains, had assumed responsibility for the train safety every time they were used but did not expect to be responsible for general safety whenever these trains were not used. Accordingly, the safety training it conducted was confined to the use of these trains. Safety training related to consortium and system-wide contractor safety rules hence had to be carried out by other parties, but none were identified prior.

The testing and commissioning phase was another example in which the many interfaces between different groups posed gray areas. One important step of this phase was the preparation of system interfaces test procedures for tests performed between any two systems to ensure they would be compatible when integrated. These tests occurred after individual system testing and required the participation of both groups in the integration. Because these were technical interfaces, all the groups assumed that the procedures were to be prepared by the group, here called G2, which was responsible for the management of all technical interfaces for the system. On the contrary, G2 expected the technical groups would collaborate for each interface because these groups had the necessary technical skills and were going to conduct the test on site. The WBS matrix exercise revealed this interface problem so that it was resolved early without the adverse repercussions on the overall test schedule had it been left undetected.

J. Constr. Eng. Manage., 2006, 132(1): 67-79

Downloaded from ascelibrary.org by Mississippi State Univ Lib on 07/06/19. Copyright ASCE. For personal use only; all rights reserved.

PROJECT	MRT Line		WP Code:	WP03200.M000
Title	Power Simulation		WP 2	
Group	Power Supply		Includes all below EWP as defined in EWP Ma	
Issue	A		03200 .M000	
Issue date	janvier 31, 2003			
Responsible	XX			
Scope of work description				
Production, according to contract requirements and to contractual design schedule, of all documents related to power simulation (including management of data at interface with others); These documents include the design data necessary to traction equipment sizing. Get client acceptance on design. Identify and provide PM with all input data related to claim/variation order management.				
Reference items (docs...)				
Interfaces		Description		
Data book (including Rolling Stock data), speed profile, operation manual		Input from Engineering Subsystem		
Traction line diagram, LV consumptions		Input from Power Supply Subsystem		
Delivery Objectives (as for PS design)		Preliminary	pre-final	Final
Duration	Stage 1 Stage 2 Stage 3	octobre 2, 2001	janvier 30, 2002	juillet 2, 2002
	Stage 4 Stage 5	To be defined		
Cost Objectives	Budget Cost (man hours): Budget Cost (KEuro):			
Deliverables		Description		
Power Simulations		Traction Power Supply Simulations. D.C. Traction Short-Circuit Calculations.		
Frequency of reporting	Monthly			
Scope Change Record	Issue	Modifications		
Associated means (resource, equipment & materials) Power simulation software (ELBAS)				
Comments				
Work Package Manager	XX		Approved by	ZZ
Signature			Signature	Subsystem Manager
Sub-Subsystem Managei	YY		Approved by	TT
Signature			Signature	Asian Area Manager

Fig. 8. Typical WP sheet

The exercise of attributing responsibilities to activities, although obvious most of the time, regularly reveals delicate interface problems created by poorly defined responsibilities. Following the detection of the gray areas, project managers resolve conflicts with negotiation and discussion on the financial and schedule impacts for the unexpected activity.

Implementation Issues Learned in the Case Study

The main problem encountered during the implementation of the WBS matrix on the MRT line project was related to the timing of its introduction. Unfortunately, although a PBS was done early in the project life, the full WBS matrix was only implemented for the case study when all the teams were already at the design phase of the first stage. As the staff had already settled into the original set of procedures for reporting and budget and schedule management, it was difficult for them to adapt to the new system.

Moreover, the budget structure was already set up, but not exactly according to the WBS developed later. The initial budget structure had comparatively few categories of expenses, and detailed monitoring of the project was difficult. The number of categories of expenses increased from 12 to 46, allowing greater visibility of project finances and thus improved the control for the managers. Despite the clear advantage, because contracts had already been awarded according to the original budget structure, the switch to the new budget control system was complicated.

These complications could have been avoided had the WBS matrix been set up prior to the budget structure. The hierarchical structure of the PBS and ABS creates much flexibility in using the WBS matrix at the early stages of the project, when there is less clarity on the product and activity structures. The WBS structure can evolve as more details are known, as the project progresses.

Another significant problem encountered was increasing the ownership of the process. The new process was launched from the top, by high-level managers who were convinced of the good that the WBS matrix could bring to the project management. Although this unequivocal support for the implementation of the WBS from the upper management is a positive element in the study, clearer

J. Constr. Eng. Manage., 2006, 132(1): 67-79

Downloaded from ascelibrary.org by Mississippi State Univ Lib on 07/06/19. Copyright ASCE. For personal use only; all rights reserved.

PROJECT	MRT Line	WP number	0	Responsible	ZZ
Group		Title	Infrastructure subsystem project management	Issue date	31.01.03

ACTIVITIES
Achievements since last report
WBS Structure and WPS scope, dates, inputs/outputs : validated by WPS leaders
PR3 held on 06.01.03
PGR held on 29.01.03
Submission of Stage 4-5 VO proposal
Submission of price extra concrete and Roller Chairs
On-going activities
WBS : building the reporting process and tools (WBS report, GMS, budget sheets)
Update of PMP
Preparation of TW Construction Seminar (march 03)
Negociation with client on various issues

ISSUES		
Issue with interfaces (communication, coordination and document transmission with other parties, technical interfaces, etc.)		
Interface concerned	**Description of issue**	**Action Proposed**
Wheel/rail interface	PV wheel profile NA : impact on turnout development testing	PV action towards client
Issue with schedule		
Schedule item concerned	**Description of issue**	**Action Proposed**
Civil work delay stage 1	Announcement by client of potential 6 months delay	Impact on VO under review with client (management team)
Issue with budget		
Budget item concerned	**Description of issue**	**Action Proposed**
Issue with deliverables		
Deliverable concerned	**Description of issue**	**Action Proposed**
Specific component design	Technical and commercial issue with supplier / possible alternative supplier	Confirm choice of alternative supplier and get client acceptance
Issue with resources		
Resources concerned	**Description of issue**	**Action Proposed**
RAMS	Secure RAMS engineer to address RAMS issues after FD until RMDT	Investigate for available resource in department

RISK AND CLAIM MANAGEMENT
New potential individual risk
New potential mutual risk
Wheel/rail interface
New potential variations
Third rail gaps at escape shafts
COMMENTS of WP manager (including possible changes to be done in WP or WBS)
COMMENTS from Team Manager or Subsystem Manager

Fig. 9. Typical WP report

communication about its benefits could have drawn more commitment from all levels of staff. However, the ownership problem was progressively resolved during its implementation and people eventually increased their participation.

In terms of participation, Richman (2002) and Verzuh (1999) recommended that the entire project team be involved in the development of the WBS matrix. This should start with a launch meeting in which the purpose of the WBS matrix is explained, the program of implementation presented and discussed, and staff are assigned specific roles in the WBS matrix development. At each step of the WBS matrix definition, at least the team managers should be involved earlier. The PBS and ABS require their par-

J. Constr. Eng. Manage., 2006, 132(1): 67-79

Downloaded from ascelibrary.org by Mississippi State Univ Lib on 07/06/19. Copyright ASCE. For personal use only; all rights reserved.

PRODUCT	SUBSYSTEM	PROJECT'S REQUIREMENTS	PBS	ABS	SUBSYST. ACKN.	Is or will be included in Subsystem's WPS nb:
Passenger vehicle	PV	care of the work for the date of commencement of the works until 14 days after the start of the warranty period	01	V100		
Trainborne TRAVELLER INFORMATION SYSTEM - TTIS	TTIS	care of the work for the date of commencement of the works until 14 days after the start of the warranty period	0191	V100		
Signalling & Controlling	SIG	care of the work for the date of commencement of the works until 14 days after the start of the warranty period	02	V100		
INTEGRATED SUPERVISORY CONTROL SYSTEM - ISCS	ISCS	care of the work for the date of commencement of the works until 14 days after the start of the warranty period	027	V100		
OPERATION CONTROL CENTRE (OCC)	OCC	care of the work for the date of commencement of the works until 14 days after the start of the warranty period	028	V100		
Power supply	PS	care of the work for the date of commencement of the works until 14 days after the start of the warranty period	03	V100	YES	40
Communications	COM	care of the work for the date of commencement of the works until 14 days after the start of the warranty period	04	V100		

Fig. 10. Acknowledgment sheet for allocation of responsibilities

ticipation to avoid wasting time on unnecessary iterations of the structure definition. As Verzuh (1999) insists, "participative planning not only creates more accurately detailed work breakdowns, it can also encourage higher levels of commitment to the project." For WP definition, WP managers would need to be involved earlier too, so that they understand what is at stake and how the WBS can benefit them. Before proceeding to the reporting phase, there should be another meeting to ensure uniformity and consistency in using the WP reports.

Conclusions

The WBS matrix concept was proposed to facilitate representation and management of interfaces in rather complex projects. The case study of a company using the WBS for the management of an MRT project demonstrated that the WBS matrix can be used for improving interface management. The matrix is supplemented with the management package comprising WP sheets and WP reports. The structure was developed to achieve the five key functions for an effective interface management system: definition, transparency, communication, control, and response to interface issues.

The WBS matrix was able to progressively eliminate the gray areas in the interfaces of the many adjoining subsystems and works by more clearly defining interfaces and unambiguously allocating responsibilities. Transparency of project requirements and deliverables for each WP is better realized with a WBS, which in turn promotes work performance within the WPs and improves collaboration and smooths work flow across WPs. Communication across interfaces, control, and the anticipation and management of interfaces issues were facilitated through the integrated WP sheets and reports.

The present WBS system for the case study has been implemented using simple Excel sheets that most managers at all levels use regularly and is easy to understand and manage. Having also been designed for project control, the WBS matrix does not impose interface management as an additional task, but rather should be viewed as a necessary part of a sound integrated project management. Nevertheless, further development is necessary to deploy the system on the Internet for improved communication and information management.

References

Albert, N. (1995). "Developing a useable work breakdown structure." *Parametric cost estimating handbook*, 1st Ed., Appendix B. ⟨http://www.jsc.nasa.gov/bu2/PCEHHTML/pceh.htm⟩.

Ayas, K. (1997). "Integrating corporate learning with project management." *Int. J. Prod. Econ.*, 51, 59–67.

Bachy, G., and Hameri, A.-P. (1997). "What to be implemented at the early stage of a large-scale project." *Int. J. Proj. Manage.*, 16(4), 211–218.

Caron, F., Marchet, G., and Perego, A. (1998). "Project logistics: Integrating the procurement and construction processes." *Int. J. Proj. Manage.*, 16(5), 311–319.

Christensen, M. J., and Thayer, R. H. (2001). "The work breakdown structure." *The project manager's guide to software engineering's best practices*, IEEE Computer Society, Los Alamitos, Calif.

Colenso, K. (2000). "Creating the work breakdown structure." *White Papers*. ⟨http://www.aisc.com/us/lang_en/library/white_papers/Creating_a_Work_Breakdown_Structure.pdf⟩.

De Heredia Scasso, R., and Santana Larenas, G. (1991). "Project-breakdown structure: The tools for representing the project system in project management." *Int. J. Proj. Manage.*, 9(3), 157–161.

Globerson, S. (1994). "Impact of various work-breakdown structures on project conceptualization." *Int. J. Proj. Manage.*, 12(3), 165–171.

Healy, P. (1997). "Interfaces." *Project management: Getting the job done on time and in budget*, Butterworth-Heinemann, Port Melbourne, Vic., 267–278.

Lanford, H. W., and McCann, T. M. (1983). "Effective planning and control of large projects—Using work breakdown structure." *Long Range Plann.*, 16(2), 38–50.

Leiringer, R. (2000). "Construction process models—Enabling a shared

J. Constr. Eng. Manage., 2006, 132(1): 67-79

Downloaded from ascelibrary.org by Mississippi State Univ Lib on 07/06/19. Copyright ASCE. For personal use only; all rights reserved.

project understanding." *Int. Group for Lean Construction Eighth Annual Conf.*
Matthews, M. D. (1986). "Networking and information management: Its use by the project planning function." *Information and Management*, 10, 1–9.
Morris, P. W. G. (1983). "Managing project interfaces—Key points for project success." *Project management handbook*, D. I. Cleland and W. R. King, eds., Van Nostrand Reinhold, New York, 3–36.
Reilly, N. B. (1993). "The work breakdown structure." *Successful systems engineering for engineers and managers*, Van Nostrand Reinhold, New York, 45–68.
Richman, L. (2002). "Creating a work breakdown structure." *Project management step-by-step*, Amacom, New York, 75–78.
Ruskin, A. M., and Estes, W. E. (1995). "Work breakdown structure paradigms and processes." *What every engineer should know about project management*, M. Dekker, New York, 221–236.
Saynisch, M. (1983). "Project management system for a large international project." *Proj. Manage. J.*, 1(2), 115–121.
Smith, L. A., and Mills, J. (1983). "Reporting characteristics of automated project management systems." *Proj. Manage. J.*, 1(3).
Stuckenbruck, L. C. (1983). "Integration: The essential function of project management." *Project Management Handbook*, D. I. Cleland and W. R. King, eds., Van Nostrand Reinhold, New York, 37–58.
Sundgren, N. (1999). "Introducing interface management in new product family development." *Journal of Production and Innovation Management*, 16, 40–51.
Tiner, W. D. (1985). "Subdivision of work on construction projects." *Proj. Manage. J.*, 3(1), 13–18.
Töpfer, A. (1995). "New products-cutting the time to market." *Long Range Plann.*, 28(2), 61–78.
Verzuh, E. (1999). "Work breakdown structure." *The fast forward MBA in project management*, J. Wiley, New York, 101–119.
Warner, P. (1997). "How to use a work breakdown structure." *Field guide to project management*, D. I. Cleland, ed., Van Nostrand Reinhold, New York, 74–89.
Wren, D. A. (1967). "Interface and interorganizational coordination." *Acad. Manage J.*, 10(1), 69–81.

Downloaded from ascelibrary.org by Mississippi State Univ Lib on 07/06/19. Copyright ASCE. For personal use only; all rights reserved.

J. Constr. Eng. Manage., 2006, 132(1): 67-79