THE WORK BREAKDOWN STRUCTURE MATRIX:
A TOOL TO IMPROVE INTERFACE MANAGEMENT

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SUMMARY

The Work Breakdown Structure (WBS) is a way to decompose a project into smaller elements to be able to better control and manage its content. This thesis proposes the use of the WBS methodology to improve interface management in complex construction projects. Interfaces are mainly of four types: technical interfaces, time interfaces, organizational interfaces and geographical interfaces. It is argued that interfaces can only be properly managed if the following conditions are met: interfaces are properly defined, the project team has the means to communicate well and has visibility on project requirements, project activities are well controlled and potential interface issues are solved in a timely fashion. This contributes to a project environment where products flow from one activity to another without constraints, a situation the lean construction theory has argued produces faster and less costly projects. It is proposed to use a project management tool based on the WBS methodology to support interface management. Instead of the classical tree-like WBS, the tool is based on the WBS matrix, a concept successfully used in the context of product assembly in manufacturing. It extends the notion of WBS matrix to non-manufacturing projects and applies it in the case study of a complex transportation project to assess its benefits in terms of interface management. The main Electrical and Mechanical Contractor of a Mass Rapid Transit line project, involving numerous phases and systems, could observe the positive results of the use of the WBS management package to improve interface management. This package complements the WBS matrix with Work Package Sheets, Budget Sheets, Schedule Sheets and Work Package Reports, to place the work package at the center of all project and interface management aspects, to

reach a more complete project definition and higher control capacity. While the first two elements are found to provide assistance to the project team in the field of interface definition, the last three help them prevent, monitor and solve interface issues all along the project implementation. This contributes to a project environment where the products flow from one activity to another without constraints, a situation the lean construction theory has argued produces faster and less costly projects.

The WBS developed in the case study stayed at a relatively strategic level, and does not describe activities and systems in great details, nor does it manage the corresponding small-scale interfaces. It provides for a first layer of interface management, preventing the greatest mistakes or omissions from having too great consequences at all levels of management. However, this process could certainly be successfully completed by tools of lower-level management such as the IPS (see section 4.4.2.2) or the Last Planner. Further research is thus necessary to integrate the use of the WBS with other lean construction tools and exploit it at its maximum capacities.

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ABBREVIATIONS

ABS Activity Breakdown Structure

BOT Build Operate Transfer

DSM Design Structure Matrix

E&M Electrical and Mechanical

EWP Elementary Work Packages

IFAT Integrated Factory Acceptance Test

IPS Integrated Production Scheduler

ISCS Integrated Supervisory Control System

MRT Mass Rapid Transit

OBS Organizational Breakdown Structure

PBS Product Breakdown Structure

RAMS Reliability, Availability, Maintainability and Safety

RMDT Reliability and Maintainability Demonstration Test

SICD Subsystem Interface Control Documents

SITP Subsystem Interface Test Procedures

TRIP Track-Related Installation Program

WBS Work Breakdown Structure

WILD Wheel Impact Load Detection

WP Work Package

WPS Work Package Sheet

KEYWORDS

Work Breakdown Structure, Interface Management, Lean Construction, Project Control, Visibility.

CHAPTER 1: Introduction

1.1 Background

Production process rationalization has radically transformed the manufacturing industry in recent years (Fially and Revelo, 2002). In particular, a new vision, developed at the Toyota Motor Company in Japan, reinterpreted the production phenomenon as a flow of materials and/or information from raw material to the end product, going through processing, inspection, waiting and moving stages (Koskela, 1992). This differs from the traditional conversion model in that it takes account of the last three, non value-adding, activities (inspecting, waiting and moving), and aims at reducing their impact on production time and cost.

Following the progress that transformed the manufacturing industry with the application of the lean production theory, the lean construction theory was devised to pursue, in the construction industry, the same objectives. It argues that construction projects could attain better productivity at a lower cost if the way construction is looked at was fundamentally changed to take into account and reduce non value-adding activities, as it was done in the production industry. In particular, ways are found to avoid redesigns and reworks, and to improve project management with the objective of smoothening the transitions between construction activities.

The lean construction theory is fundamentally based on several concepts that are said to improve the soundness of project management in this context. In particular, communication, transparency and production control are of paramount importance in construction project management. As will be shown in this thesis, they are also intricately related to a wider process some have called interface management, during which organizational, technical, temporal and geographical interfaces are carefully and continuously defined, monitored and managed all along the project life. However, few tools have tried to help managers directly focus on interfaces and manage them on a daily basis. Interfaces are usually described in static documents that do not evolve with the project, letting managers deal with interfaces just by following their instinct and displaying their communication skills. When some efforts are made to provide a model, which is the case of IDEF0, its complexity usually makes it difficult to use as a daily management tool and specific training is necessary (Malmstrom et al., 1999).

At the same time, many scheduling and cost monitoring tools are devised to address the issue of project control. These are rarely integrated, letting team members report on all these project aspects separately, without coordination and therefore without giving its full value to the information provided. This makes the process of interface management even harder to envisage.

Finally, the Work Breakdown Structure (WBS) concept has been extensively discussed and widely recognized as a powerful project structuring and management tool. However, the literature remains somewhat vague regarding practical application of its advantages.

1.2 Research scope and objectives

As managers constantly struggle with their workload and time constraints, interface management needs to be integrated in a sound and efficient project control system if it is to be performed. This thesis proposes to use the Work Breakdown Structure (WBS) concept for large scale construction projects management, not only to define the scope of a project, but also to integrate all aspects of project control and reporting, and to be the basic tool for a full interface management.

This thesis thus has the following objectives:

1) to gain a better understanding of the concept of interface management and its relationships with lean construction principles, the context in which interface management can be optimized and the ways it can be improved;
2) to gain insights into the current uses and applications of the WBS concept;
3) to propose to use the WBS concept in order to facilitate project control integration while laying a sound basis for interface management;
4) to observe, in a case study, how the proposition is actually implemented and refine the framework linking the WBS to interface management strategies;
5) to propose solutions for issues encountered.

In particular, this thesis will develop the concept of a WBS matrix management package. A WBS matrix, formed by crossing a Product Breakdown Structure (PBS) with an Activity Breakdown Structure (ABS), will thus be completed by work definition documents, the Work Package Sheets, as well as monitoring and reporting tools such as the Budget Sheet, Schedule Sheet and Work Package Report. This thesis intends to show how the WBS matrix management package thus formed can be used to facilitate several aspects of interface management and support lean construction principles, in theory as well as in practice.

1.3 Methodology

As highlighted by Handfield and Melnyk (1998), the scientific theory-building process is made of five steps: observation, empirical generalization, building of theories, generation and testing of hypotheses, and logical deduction (see Figure 1.1).

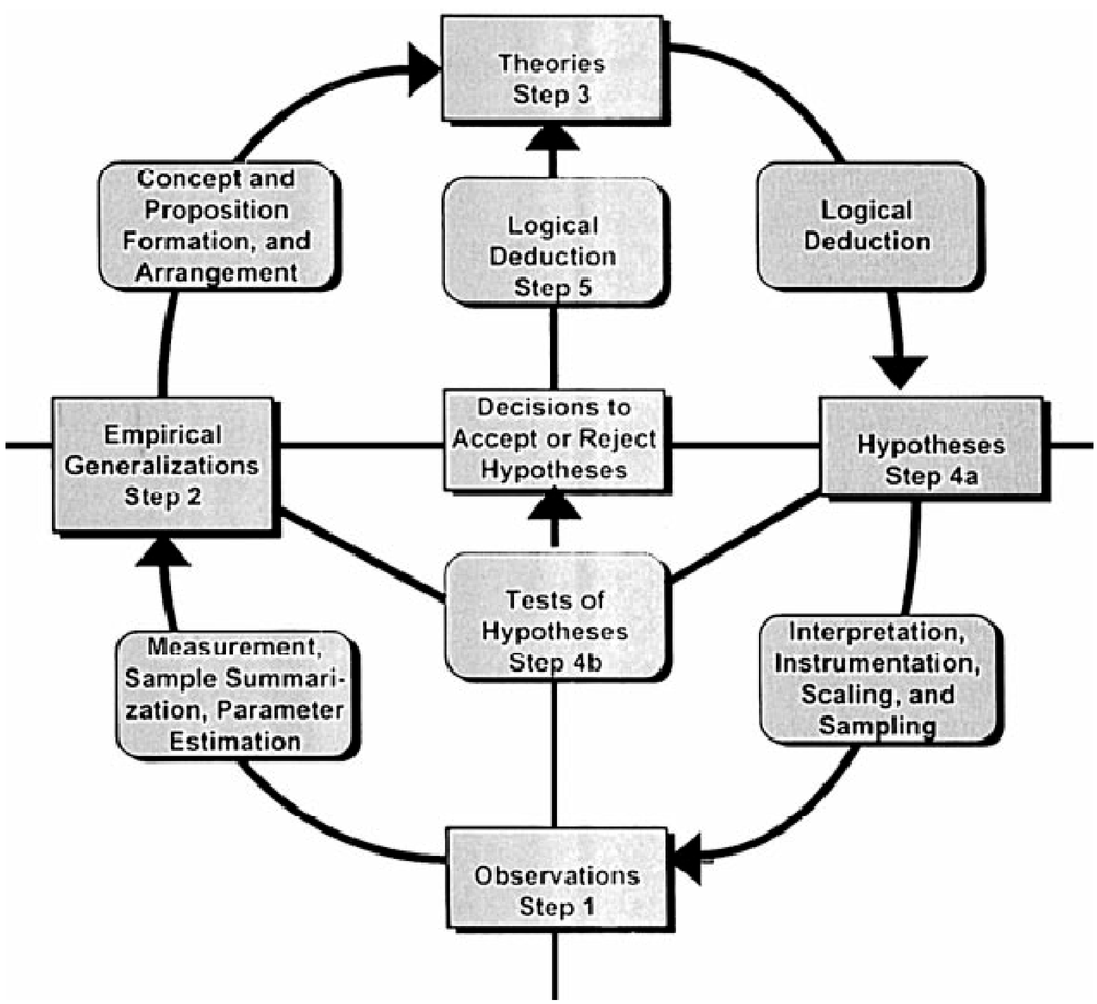

Figure 1.1:The Principal Information Components, Methodological Controls, and Information Transformations of the Scientific Process. Taken from Handfield and Melnyk (1998).

This thesis intends to partially answer the question of the possible uses of a WBS matrix management package to facilitate interface management, by performing the part of the cycle related to empirical observation (step 1 on Figure 1.1), which corresponds to the description of phenomena.

This thesis will therefore have three main parts:

- **Literature review**, with the objective of gathering experts' opinions on the two key concepts studied: the WBS and the concept of interface management;
- **Presentation of a new concept** for the construction industry: the WBS matrix, and proposal to use it to improve interface management;
- **Case study**, involving observation of how a WBS matrix was used in a real case to improve interface management.
- **Hypothesis generation**, deducing from the case study a general framework showing the variety of ways the WBS can be used to improve Interface Management;

Pongpanich (1999), lists data collection sources and their respective strengths and weaknesses: these are documentation, archival records, interviews, direct observations, participant observations and physical artifacts. In this thesis, it was decided to use existing documentation, interviews and participant observation. The other sources were not available in the company where the case study was done.

It can be noted that, by highlighting key concepts and proposing hypotheses, this thesis actually leaves observation to perform more advanced research steps, but more case studies are needed to perform true empirical generalization and hypothesis testing.

Validity and reliability are of primary importance if the research results are to be usable. As recalled by Pongpanich (1994), external, internal and construct validity must be checked. Internal validity, referring to the ability to determine cause and effect relationships, is guaranteed by the observation of a real time case study, which enables the observer to track cause and effect. Construct validity, related to the establishment of the defined construct's theoretical territory and it's consistency with other recognized constructs, is ensured by the literature review. External validity will only be completed when other case studies are done, as highlighted in chapter 6. Finally, reliability is improved by the use of several sources to collect data, such as interviews, internal reports and working documents, minutes of meetings, personal observation, and informal conversations.

1.4 Thesis organization

Chapter 2 will explain the concept of interface management and of Work Breakdown Structure (WBS) as they are commonly defined, through extensive literature review on the subjects. Then, it will introduce the concept of WBS matrix, which resolves common issues of project definition encountered with usual tree-like WBSs. Chapter 3 will propose to use an integrated management tool based on the WBS matrix as a basis for interface management and facilitation of lean construction principles application. In Chapter 4, a case study will explain in more details how this tool helped improve interface management in the project of a Mass Rapid Transit line in Asia, and will help refine the framework proposed. Issues encountered will also be described. In Chapter 5, a software will be proposed to simplify the definition and management of the WBS and further facilitate management of interfaces. Chapter 6 will offer concluding remarks and make recommendations regarding possible further research to integrate the WBS with other lean construction tools.

CHAPTER 2: Definition and Presentation of the concepts used

This chapter presents the concepts of interface management and of Work Breakdown Structure (WBS), as they are described in the literature. After a description of interface issues, it proposes the interface management framework based on five main strategies that will be used in the following chapters. The concept of WBS and the ways it can be used are then presented.

2.1 Interface management: definition and implementation

2.1.1 What is an interface?

2.1.1.1 Definition

The use of the concept of interface in the context of project management followed the development of the system approach, which views organizations as systems of mutually dependent variables (Wren, 1967). Morris (1983) defines a system as "an assemblage of people, things, information or other attributes, grouped together according to a particular system objective" that may be broken down into several levels of subsystems with corresponding sub-objectives. When autonomous organizations must cooperate to serve a larger system, they have to satisfy both their own objectives and the system objective (Wren, 1967), hence the importance of project integration.

This perspective first lead to the development of project management in itself. It also lead to the understanding that projects need clear objectives and are made of sub-projects whose interfaces are important to determine (Morris, 1983). As pointed out by Stuckenbruck (1983), increasingly complex projects need greater specialization (differentiation) and tighter coordination (integration). An adequate trade-off between the two must be found for each project. Interfaces arise from the division of work into parts executed by different people or organizations.

Simply put, **an interface is "the meeting point between organizations"** (Wren, 1967). It is created "when people, organizations or systems must meet in support of one another."

Healy (1997) gives a more precise definition, an interface being "a boundary where an interdependency exists across that boundary and where responsibility for the interdependency changes across that boundary". Boundaries usually are determined by the arrangement of people and organizations, while interdependencies are more technical. Morris (1983) considers the degree of differentiation between subsystems regarding organization structure, interpersonal orientations, time horizons and objectives as important determining elements for the size of an interface.

For Buede (1999), interfaces are seen more as physical systems than as organizational limits, for he describes an interface as a connection resource between systems' components or among systems. More precisely, "interfaces have inputs, produce outputs and perform functions. An interface can be as simple as a wire or conveyor belt or as sophisticated as a global communication system" (p50). However, this point of view is not the one retained by most management researchers, who consider interfaces as an abstract concept used to specify the definition of a system, rather than as one of its physical components.

As the definitions mentioned earlier show, an interface only appears when systems need to be coordinated to form an integrated whole. The function of an interface thus appears to be the transfer of information, regardless of the organizational or technical contexts considered. In this context, information is understood in a general sense, going from design parameters to instructions or scheduling information on space use. The definition of an interface adopted here therefore is the following: **"an interface is an abstract boundary between components of a system, through which information must be transferred so that the system can function as a whole."**

To address the variety of interface issues, the best way to manage interfaces may be to consider them from the different perspectives affecting system integration. This leads to the following classifications of interfaces.

2.1.1.2 Classification of interfaces

Several types of classifications of interfaces are available.

First, interfaces can be **internal** if the work concerned is done within one organization, or **external** if different organizations collaborate (Healy, 1997). As Stuckenbruck (1983) points out, any project is linked to external agents such as top management, client or line managers, that make up external interfaces.

For most authors (Wren, 1967; Stuckenbruck, 1983; Healy, 1997), it is important to differentiate four types of interfaces.

Time interfaces are triggers conditioning the transition from a certain kind of activity to another. As highlighted by Browning (2001), “the interfaces are what give a process its added value (versus a mere collection of activities).” To enhance the quality of processes, it is possible to artificially create time interfaces and to introduce them into the project planning with the concept of downstream customer, in order to focus people on what they should pass on and how they should do so (Healy, 1997). Time interfaces also exist at the micro-activity level, in particular in the construction industry (Howell and Laufer, 1993). Indeed, construction subcycles interact because of the intermediate products and process requirements that link them, causing delays when information or physical output of a subcycle are needed for the following one. Another interaction exists if resources are to be shared by two or more activities.

Geographical interfaces separate on-site and off-site work.

Technical (or technological) interfaces set the limits of a system’s subcomponents. They can be functional and physical.

Social (or organizational, or management) interfaces keep human groups apart. Under this category, it is possible to differentiate personal or people interfaces from organizational interfaces (Stuckenbruck, 1983). According to Browning (2001), inter-team interfaces provide “the greatest leverage for improving the organization.” Morris (1983) identifies three types of organizational integration methods: **pooled integration** guarantees coordination of interfacing people by imposing certain rules and standards to be respected, **sequential integration** aims at scheduling interdependencies and **reciprocal integration** makes parties adjust to each other.

A third classification distinguishes **static** and **dynamic** interfaces (Morris, 1983).

Static interfaces link continuously on-going subsystems. These include interactions between the usual three levels of management (top-level institutional management, middle-level strategic management level and lower technical level), as well as interactions between management activities such as project definition, organization, provision of adequate infrastructure and logistics to accomplish the project, etc.

On the other hand, dynamic interfaces are the ones that separate the four characteristic life-cycle subsystems of a project: pre-feasibility/feasibility, design, full-bodied implementation/production and phasing out. Dynamic interfaces are the most important as early errors propagate in the whole project. They can serve as check points for performance monitoring.

Another way of classifying interfaces is according to the level of compatibility between the parties they separate (Healy, 1997). The best situation is when there is **perfect match** between interfacing parts, with physical and operational compatibility, seamless data transmission, etc. This situation is very difficult to obtain. A more frequent situation is the **partial match**. However, this situation is difficult to identify as it has the appearance of a perfect 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 totally different and there is no agreement between parties. In practice, each boundary shows interdependencies with different degrees of mismatch. Howell and Laufer (1993) have a similar approach to linkages between subcycles of a production process. A linkage is **tight** if there is no slack between the steps of an operation, and **loose** if there is a "buffer" (such as storage capacity) reducing the necessity of an interaction. The buffers are one of the concepts devised by the lean construction theory to reduce waiting times in the construction process sequence.

Interfaces can also depend on the type of contract used for the project. For instance, Chen Chuan (2002) studied the application of interface management to China's BOT projects and proposed a 4-step procedure to manage key interfaces between processes involved in such projects.

2.1.2 How to manage interfaces?

2.1.2.1 Definition of interface management

Interfaces are an important part of a system, and must be considered as such if a project is to be successful. They give systems their added value and provide great leverage in systems architecting (Rechtin, 1991). They also are, as noted by Buede (1999, p.296), “the most common failure point on systems”. Thus, interfaces are often considered as difficult project elements to manage. For instance, regarding organizational interfaces, Töpfer (1995) notes that the collaboration of an interdisciplinary team requires the resolution of comprehension problems, the reduction of frictional losses, an efficiently functioning organization and clearly structured planning procedures. Typical problems of interface are related to the difference in technical languages and ways of thinking, disputes over areas of responsibilities, insufficient interface definition, limited possibilities of influencing each other or need for protection from each other’s influence, insufficient cooperativeness and information flow, as well as undervaluation of each other’s work in terms of quality and quantity. Similarly, Hoedemaker et al. (1999) argue that the development of concurrent engineering, a popular way of reorganizing successive activities so that they can be performed simultaneously, has caused many interface issues, requiring engineers to work simultaneously on modules, increasing the potential for interface errors and the likelihood of integration problems. Management of interfaces appears as a necessary activity requiring focused attention from the people in charge.

The beginnings of interface management followed the earlier development of the system perspective (Morris, 1983). Interface management consists in partitioning the project into subsystems, identifying the interfaces that require specific management attention and indicating the ways for managing them. Healy (1997) defines interface management as "the management of the interdependencies and responsibilities across the boundary of the interface."

More practically, for Stuckenbruck (1983), interface management is part of project integration, which is defined as "the process of ensuring that all elements of the project (tasks, subsystems, components, parts, organizational units and people) fit together as an integrated whole which functions according to plan." Consequently, interface management consists in "identifying, documenting, scheduling, communicating and monitoring interfaces related to both the *product* and the *project*".

For Wren (1967), there are three linking processes enabling interface management: communication, balance and decision-making. **Communication** is formed of the control and coordination mechanisms that link system decision centers. **Balance** is the mechanism of equilibration that enables systems to keep their structural harmony. **Decision-making** affects production and participation in the system. From the decision of taking part in a system, two problems can arise: the system's loyalty to its original goals and the need for intersystem coordination.

In the definitions mentioned, some issues are directly related to the existence of interfaces, while others are created by the overall inefficiency of the systems considered. To reflect the complexity of interface issues, the following original definition of interface management is adopted here: "**Interface management is the process of creating or identifying interfaces, maintaining transparency over their definition, defining and enforcing the rules of their functioning, optimizing system efficiency to trigger their full coordination, and resolving interface issues, so as to guarantee the system's overall functional unity.**" The following paragraph will describe how, in practical terms, interface management is usually done.

2.1.2.2 The five pillars of interface management

Many researchers have studied the mechanisms of interface management, and their findings will be summarized hereafter. Researchers unfortunately usually address only one type of interface (organizational, technical, etc.) at a time, and it is somewhat difficult to extract a clear, common framework of practical interface management from these works. Nevertheless, it is proposed here to group the strategies used to manage these interfaces into five functional aspects, thus forming the framework of interface management that will be used in this thesis. Figure 2.1 illustrates this framework and is built as follows. The top part of the figure displays the five strategies that were found in the available literature to help manage interfaces. The first four, dealing with the prevention of interface issues, are interface definition, visibility on project requirements and responsibilities, communication across interfaces and general project organization and control. The last one is the response to and management of interface issues, once they have appeared. These strategies will be described in more detail hereafter. The central part of the figure recalls the interface issues mentioned in the previous paragraphs, classified accordingly. The lower part proposes a series of remedial actions for classical interface management issues, which will also be described later in this thesis.

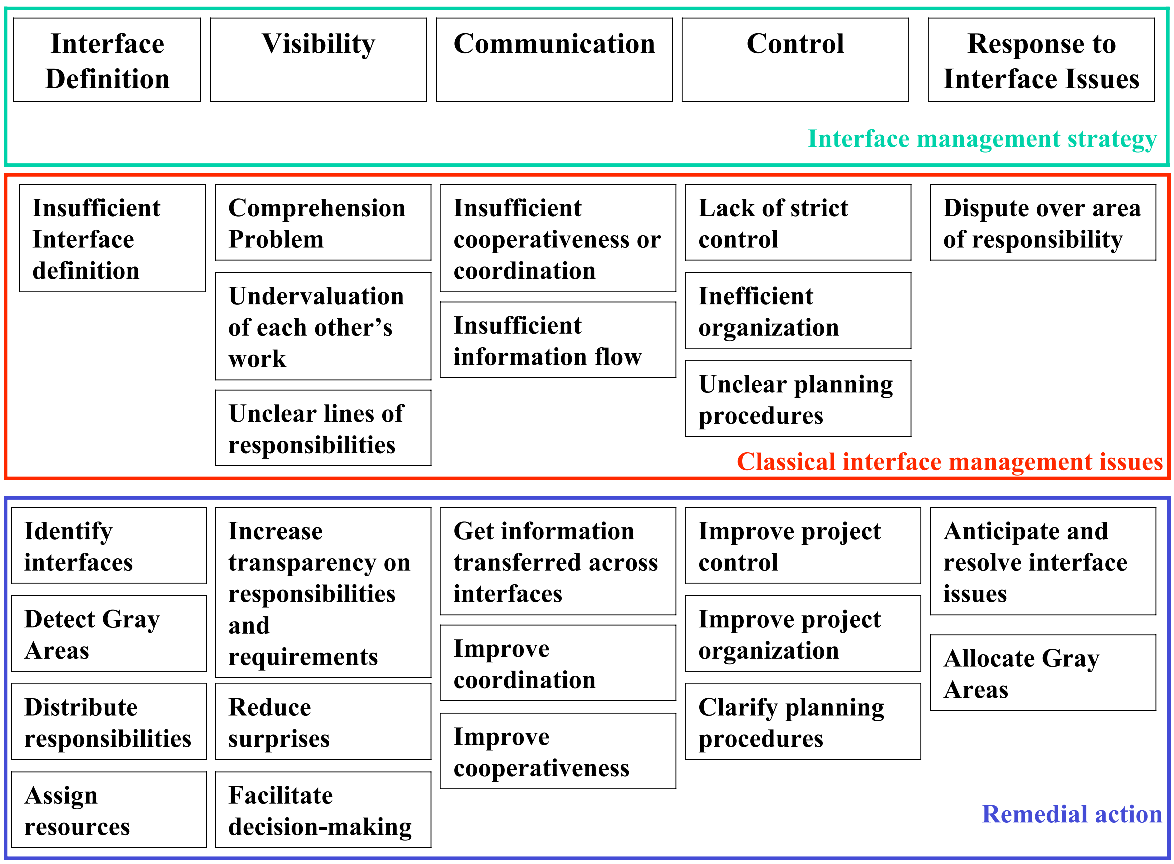

Figure 2.1: The five strategies leading to sound interface management

- **Interface definition**

The first step of sound interface management is to identify the different types of interfaces in a project and find where they should be drawn. The temporary nature of projects makes it necessary to get all possible interface details at the same time; there is no second chance as in the manufacturing industry (Healy, 1997). Morris (1983) specifies that boundaries should be positioned where there are many discontinuities in technology, territory, time or organization. Different reasons explain the need for definition of the various types of interfaces.

First, failure to properly define **technical interfaces** can result in important time wasting and financial loss. In a case study of two Swedish firms, Sundgren (1999) shows that the comprehensive design and testing of a technical interface between a product family platform and the various unique end-product subsystems that are linked to it can avoid technical inadequacies and subsequent losses of time in redesign, as well as substantial financial losses. Technical interface management is thus instrumental in the application of lean construction principles.

Secondly, **organizational interfaces** must also be properly defined. Careful organizational interface definition can be fruitful for time management. Töpfer (1995) takes the example of the manufacturing industry to argue that responsibilities should be carefully distributed between disciplines and interferences minimized, so as to create adequate conditions for interlinking and cooperation of all activities, simultaneous engineering, early integration of customers and suppliers, and total quality management, thus improving time management. This fits particularly well in the context of lean construction theory, which argues that customer requirements should be systematically considered all along the construction process and that quality is of utmost importance if reworks are to be avoided (Koskela, 1992). Simultaneous engineering consists in running activities that can be performed simultaneously in a new value chain, while activities that have to follow on from each other remain in a classical value chain, thus enabling to reduce the full product development time, to consider customer needs much earlier in the development and engineering phase of a product, and to eliminate failure causes through closer cooperation between disciplines (Töpfer, 1995). Interface definition, by clarifying responsibilities and avoiding interferences between teams, makes simultaneous engineering more feasible.

External and internal interfaces must also be addressed differently. As noted by Healy (1997), the number of external interfaces increases exponentially with the number of organizations involved, but many interfaces are not relevant or do not exist. Artificial boundaries, such as project life phases, can be introduced to reduce the number of open interfaces existing at one point in time: a new phase can only start when all the interfaces of the preceding ones are closed. The responsibility for external interface management resides in the project manager, while contractors, subcontractors, etc. are responsible for their own internal interfaces. Mesquita et al. (2002) highlight the necessity to maximize the exchange of information and well manage the interface with the client at the briefing stage, in order to avoid later design reworks. Internally, the organizational and technical boundaries and interdependencies can be identified, for instance, thanks to a Work Breakdown Structure (WBS), Product Breakdown Structure (PBS), Organizational Breakdown Structure (OBS), procurement plan, or project implementation plan (Stuckenbruck, 1983). The concepts of WBS and PBS will be explained in more details later in this thesis.

- **Visibility**

The second element of sound interface management consists in improving visibility on the project requirements and on the different responsibilities. Once interfaces have been identified, they should be kept clearly defined. This can be achieved through clear lines of responsibility and authority, strict control and organizational checks and balances. In particular, project management, project control, functional groups and subprojects should always be clearly separated (Morris, 1983). Visibility on project requirements can be improved by increasing specialized project teams' knowledge on what step precedes or follows their intervention on the product to be built, thus improving their estimation of what is expected from them and facilitating their coordination.

Stuckenbruck (1983) also addresses this issue when evocating the facilitation of project transfer. Project transfer is the movement of a project through the company organization, from conception to delivery. It can be the occasion for organizational conflict, information or technology loss, as well as rework, but these issues can be avoided by designating people who will evolve with the project or who can consult early developers thanks to their experience in the latest phases, thus again greatly supporting lean construction principles.

Visibility across external interfaces can also be improved. A very important external interface is the one involving a project's client. According to Healy (1997), well informing clients about upcoming choices facilitates decision-making and reduces delays. This client support task can be performed through a regular project reporting, with in-advance highlighting of decisions to be made and proposed recommendations to choose from to resolve potential issues. Ensuring client support for the project manager involves meeting the client's need for information, gaining agreement from the client on coming decisions and keeping surprises to the minimum in order to win the client's trust, which is essential for the project. Thus, visibility and transparency improve interface management.

Some tools can also be used to facilitate transparency of technical and organizational interfaces. Standardization can significantly reduce interface problems, although it is difficult to identify the needs for standardization before they come up (Healy, 1997). As agreed by Buede (1999, p. 296), standards facilitate the understanding of design and configuration information and its communication through interfaces. The use of common databases and unified terms and conditions of contract increases visibility on interfaces.

- **Communication**

Interface management is essentially a communication task (Healy, 1997). Stuckenbruck (1983) argues that communication flows among team members are a necessary condition for the full technical integration of a system. The Parade Game set up by Tommelein et al. (1999) also illustrates that coordination among trades on a construction site is very important. "Accordingly, contractors price their bids more favorably when they know that a skillful manager will coordinate their work with others on site." Similarly, Slaughter (1993) highlighted that better communication between manufacturers and builders would greatly facilitate innovation in the construction industry, and Gil et al. (2000) listed the advantages of implicating specialty contractors in the design of construction projects.

Two methods are available to manage organizations' interfaces: one is for each of them to coordinate with all the others; another is to designate an agency as the coordinator or interface manager, thus reducing the number of contact points (Wren, 1967). If interfaces are thought particularly difficult to manage, boundary task forces or liaison officers can be assigned to them (Healy, 1997). The role of the interface manager is to focus the authority on interfaces, obtain their coordination, get information transferred across them, solve rivalries and split commitments. More than formal authority, these tasks necessitate persuasion, negotiation and exchange of information (Wren, 1967). This can be the role of the project manager, who will transfer information between parties when there are communication barriers (Stuckenbruck, 1983), or the role of other parties that can help the project manager achieve liaison between continuously interfaced subsystems, such as, in increasing integrating power:

- liaison positions to facilitate communication between interfacing parties;
- task forces to perform a mission-oriented integration;
- special teams to perform a recurring problem-oriented integration;
- coordinators to facilitate communication;
- full project management to facilitate cross-functional coordination;
- the matrix organization to ensure maximum information exchange, management coordination and resource sharing.

The last two solutions have their pros and cons, but are not incompatible. The full project management type offers strong leadership and better unity in command, while the matrix organization is more economical on resources. A full-fledged project manager can be on top of a matrix structure (Morris, 1983).

Interfaces are managed through meetings, which must gather technically necessary, committed and empowered people for each interface, and them only. Interfacing people should always be introduced to each other, and can even been placed to work in the same offices to improve internal interface management. Similarly, mechanisms should be set up so that contact is maintained at the organizational level, in the case of external interfaces (Healy, 1997).

- **Project organization and control**

Interface management is also facilitated by a sound project organization and control.

Organization is the principal basis of sound interface definition. As explained by Stuckenbruck (1983), the critical actions of integration start very early in the project implementation, and consist in forming an adequate project organization. Indeed, integration demands that, at the top management level, the right organization type and form be set up, responsibilities and authority distributed, project managers and functional managers chosen, and resources assigned, which precisely corresponds to the process of project organization (Stuckenbruck, 1983). This forms the basis for clear lines of authority and thus, while supporting visibility on project requirements and responsibilities (see preceding paragraph), also directly facilitates interface management.

Project control is as necessary as organization for efficient interface management. Indeed, even if the right organization is set up, time interface management cannot be performed effectively without full project and interface control. Caron et al. (1998) thus argue that “the management of the interface between two successive phases is critical in guaranteeing the integration of the overall project." Each major project change point requires its own distinctive total management. For instance, wrong decisions can be made and cost largely overrun when sketchy designs receive strong political support and the decision to carry on with detailed design is not made taking all elements into account (Morris, 1983). This can be avoided if adequate control tools are set up, both on the cost and planning points of view. Similarly, at the procurement/construction interface, the tension between the need for an equipment safety stock to prevent construction interruption, and the financial costs of storing and handling the equipment, must be properly managed (Caron et al., 1998). More generally, the transitions from one stage to another should all be carefully managed in terms of planning, organization, direction and control, with all strategic parameters properly set (Morris, 1983). In particular, methods exist to monitor the state of time interfaces (e.g. Caron et. al, 1998).

Project control is not only necessary for time interfaces. Organizational interfaces often involve issues related to "conflicting needs for resources and personnel, or conflicting priorities for the use of facilities and equipment." (Stuckenbruck,1983). The occurrence of such problems can obviously be reduced by careful in-advance planning and control. Similarly, a procurement plan, specifying the suppliers of a project and the corresponding supplies, can help identify potential interfaces (Healy, 1997). More generally, all documents aiming at describing, planning, and monitoring the evolution of the project can help manage the interfaces it involves. Control also has to be coordinated with project organization and procedures that participate in the definition of interfaces. For instance, the identification of disciplines involved across organizational boundaries allows for pre-planning and better management of interfaces (Stuckenbruck,1983).

Technical interfaces equally require careful project control. As Morris (1983) highlights, “research has shown that time and again projects fail because the technical content of the program is not controlled strictly enough or early enough”. He thus argues that early firm control of technical definition is essential to project success and forms a central part of interface management.

- **Management of interface issues**

The four above-mentioned activities aim at reducing the risk for interface issues. However, when these issues do arise, they must be addressed properly, and the response will once again depend on the type of interface involved.

According to Healy (1997), **internal interface management** can be performed by a coordinating manager with the authority to act and to direct people; or by a project manager, responsible for all the tasks interfaced. However, for higher management controls both resources for the on-going project and staffing power for coming ones, internal interface management requires adequate negotiating skills from the person in charge.

External interface management cannot be limited to respecting contracts. For Stuckenbruck (1983), a way to overcome recurrent interface problems is to create networks of collaboration with other organizations in order to set up common practices. Healy (1997) identifies two ways of doing so: companies can partner, that is commit to work on many projects, thus developing common standards and processes of interface management; they can also simply commit to work in a spirit of cooperation.

Human interfaces issues obviously require a specific type of answer. The temporary nature and competitive environment of a project often create personal and organizational conflicts. These must be promptly solved by the project manager. A formal procedure of resolution can prove useful in this context (Healy, 1997). Morris (1983) argues that the amount of personal issues coming up depends on the management level of the persons involved and on the stage of the project. For instance, conflicts will be related to schedule and priorities at the beginning of the project, and to technical issues later on. Similarly, top level institutional managers often are in conflict with the outside world and need a political approach to get its agreement, while middle and technical level managers solve their conflicts with a more mechanistic approach.

2.1.2.3 Interface Management: a lean construction support tool

As mentioned in Chapter 1, interface management can be closely linked to lean construction theory. In particular, the pillars of interface management, as described in the preceding paragraph, show that interface management is directly supportive of the lean construction principles.

First, interface management improves communication and coordination among the different partners of a construction project, which the lean construction theory has repeatedly mentioned is direly needed. Mesquita et al. (2002) thus highlighted that developers and designers of a construction project insufficiently communicate, resulting in a situation where the design does not correspond to developers' hopes and need rework. By promoting better communication between all interfacing parties, interface management seeks to avoid such situations. A better collaboration between service providers of the reconstruction industry could similarly reduce project delivery time by 50% (Vaidyanathan, 2002). Riley and Horman (2001) argue that improved design coordination can minimize project uncertainty by decreasing disruption and reducing waste in the construction processes, thus practically implementing lean construction principles. More precisely, they found that investments in coordination typically pay for themselves by reducing conflict and field generated change order costs. Alarcon and Mardones (1998) concur with these findings, arguing that little interaction among design and construction and among specialists leads to suboptimal solution, lack of constructability and design and construction rework. To solve this issue, they propose a methodology based on better supervision, coordination, standardization and control, all of which form the basis of sound interface management as described previously. Thus, interface management, by improving communication and coordination, directly supports lean construction principles.

Secondly, a basic requirement of lean construction is for operations to be transparent[1], which interface management actively pursues. Koskela (1992) argues that "lack of process transparency increases the propensity to err, reduces the visibility of errors, and diminishes motivation for improvement". As argued by Vaidyanathan (2002), "if all the people involved in the project [can be made] to openly share information, the inefficiencies in the project can be substantially reduced, if not eliminated". Whelton and Ballard (2002) similarly argue that one of the solutions to process inefficiencies is the use of information and visualization techniques. Their case studies show that project definition

[1] See the Lean Construction Institute website: http://www.leanconstruction.org/about.htm

performance is largely impacted by issues such as lack of shared understanding of decision-making processes, socio-political factors dominating decision-making, poor information management and processing. Heineck et al. (2002) also highlight how increasing transparency and visibility of operations can improve work quality and staff motivation. Dos Santos et al. (1998) argue that "transparency is a fundamental step to construction companies searching for excellence in their production systems". They highlight that the lean construction model, by viewing construction as a flow, requires a bigger amount of information to be handled, making the application of the principle of transparency a key condition to be met for the model to be viable. Interface management, by promoting visibility and transparency on project requirements and responsibilities, directly supports this objective.

Project flow control, finally, also is a basic tool of lean construction, allowing information, material and work flows to be better cost-estimated and planned, whatever teams or work sites they go through (Ballard, 1994; Fiallo and Revelo, 2002). Interface management does support project control. Morris (1983) thus argues that "interface management relates to clear planning and the orderly management of relevant project systems and dimensions". For instance, an interface matrix for each phase of the project can help identify the importance of some interfaces more clearly and describe them precisely, so that resources can be allocated to each interface management task, taking into account the high needs of most critical interfaces (Stuckenbruck,1983). Controlling project costs is thus directly supported by technical interface management.

Thus, communication, transparency and project control are of paramount importance in construction project management and by fostering them, interface management is a central ally of lean construction principles. It should be noted here that interface management, as lean construction principles, can and should be performed at all project levels. Although many lean construction tools are devised for the management of lower level activities, the general concepts are also applicable at more strategic levels. It is in that sense that the notion of interface management developed here will support the lean construction philosophy.

2.1.3 Usual tools of interface management

As shown in the preceding paragraphs, interface management is a necessity and has to be integrated in the management of any project. The following section presents some tools that were defined to model and help manage interfaces in complex systems. There are mainly two: IDEF0 and DSM. They will be briefly described and their advantages and disadvantages will be summarized, based on available literature.

2.1.3.1 IDEF0

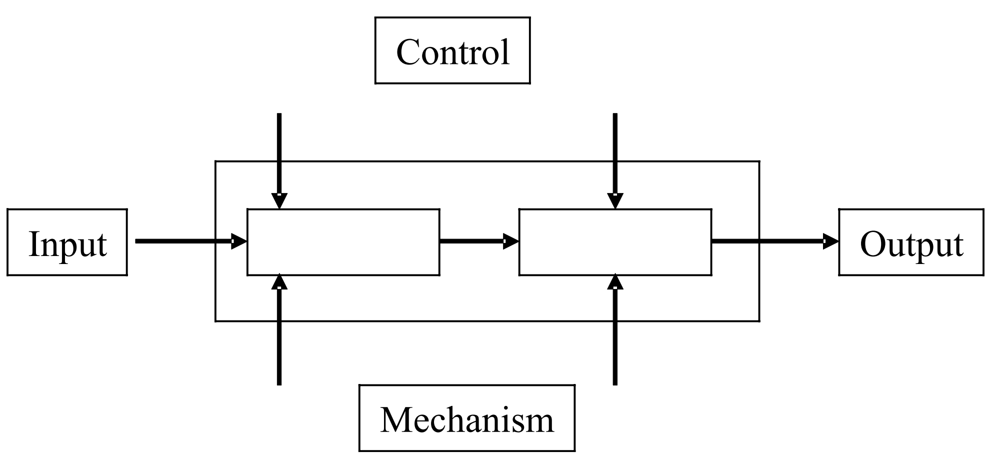

Figure 2.2: Elements of the IDEF0 Model

Integrated Definition for Function Modeling, or IDEF0, is a modeling technique that was devised by the US Air-Force in the 1970's (Buede, 1999, p.66). It was specifically developed for the modeling of information flow (Malstrom et al., 1999). Its principle can be summarized as follows (see Figure 2.2). An activity is represented by a box, and described by four arrows: the one pointing the left side of the box indicates its input (what will be changed), the one coming out of the right side indicates its output (result), and the two arrows pointing to the top and bottom of the box indicate the activity control (or constraints for performance), and mechanisms, respectively.

The use of four combined IDEF0 models (process, system, role and information models), can provide a good overview of the objects within an aspect, give a formalized picture of the entire process and enable the representation of the relationships in matrices (Malstrom et al., 1999). IDEF0 can be modeled and visualized using existing computing tools. Furthermore, as argued by Buede (1999, p.74 and 71), IDEF0 "has the advantage of being a good communication tool as well as having a standardized syntax and semantics that do not vary by organization and discipline". However, as it only models document-producing actions, it only captures activity goals such as minimizing cost or improving quality in a limited way (Malstrom et al., 1999). Moreover, it insufficiently models informal communication within a subprocess, parallel subprocesses and iterations between levels. Lastly, its complexity grows very fast with the amount of relationships to model, requiring both very detailed information as an input and time consuming analyzes for complete interpretation.

2.1.3.2 The Design Structure Matrix

As will be extensively shown in the following section and as argued by Browning (2001), understanding a complex system requires to decompose it into sub-systems, noting the relationships between them and noting the external input and outputs and their impact on the system. Smith and Eppinger (1997) summarize the essence of DSM matrix as follows. It consists of a square matrix where each row and its corresponding column are identified with one of the tasks. "Along each row, the marks indicate from which other tasks the given task requires input. Reading down each column indicates which other tasks receive its output" (see Figure 2.3).

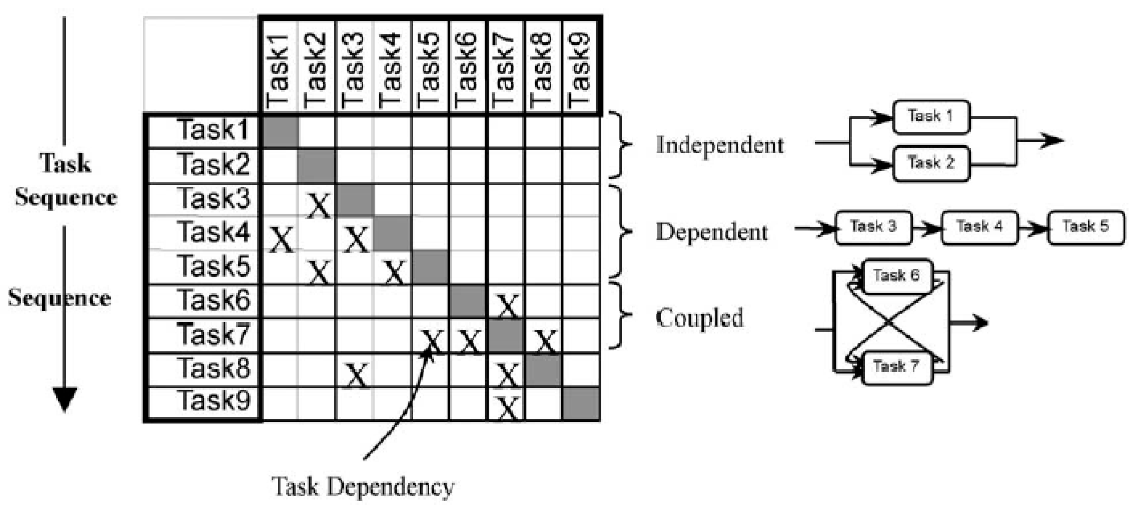

Figure 2.3: Sample task-based DSM matrix, with explanations on the relationships between tasks (taken from Chun-Hsien et al., 2003)

The Design Structure Matrix can be applied to four kinds of systems:

- component-based or architecture DSM for modeling systems architectures;
- team-based or organization DSM for modeling organization structures;

- activity-based or schedule DSM for modeling processes and activity networks, and;
- parameter-based or low-level schedule DSM for modeling low-level relationships between design decisions and parameters (Browning, 2001).

A component-based DSM represents the relationships between a system's components. Ordering the rows and columns of the DSM enables to perform an integration analysis, seeking to maximize interactions between elements within clusters while minimizing interactions between clusters. This can provide new insights into system decomposition and integration, demonstrate the rationale behind architecting decisions and promote architectural innovation. It also supports modularization, thus facilitating product development (Browning, 2001).

Similarly, working on a team-based DSM "highlights interteam interfaces", and documents the project's dependencies of information, responsibility, accountability, consultation and commitment, and facilitates communication on "alternative organizational structures and perspectives".

An activity-based DSM provides a concise, visual format for understanding issues such as activity coupling and rework by describing input/output relationships between activities and minimizing iteration once rearranged. Reconciling information gathered about people's inputs and outputs provides an opportunity to agree on interfaces and deliverables, thus greatly benefiting a product development organization and providing process visibility.

A parameter-based DSM, finally, is a bottom-up analysis of low-level activities of design. It can help companies develop a systematic approach to low-level design process planning and is particularly useful in the context of multidisciplinary design optimization.

Thus, Design Structure Matrices facilitate intelligent system decomposition and integration analysis. Chun-Hsien et al. (2002) argue that a DSM is visually simple, easy to manipulate with a computer and helps project scheduling and management. It also enables the identification of independent, dependent and coupled tasks and, although it cannot replace conventional scheduling techniques, can provide them with a useful input concerning the ordering of tasks. Dunbing et al. (2000) thus proposed a model exploiting the properties of the DSM matrix to find the order levels of activities and identify areas where more potential problems exist, thus reducing rework to a minimum. DSM is thus rightly viewed as a central support tool for application of the lean construction theory (Ballard, 2000).

Comparing IDEF0 and DSM for the modeling of information management processes, Malstrom et al. (1999) conclude that the DSM provides a good overview of the process, and is easy to explain and even to use on problems of all sizes. There is no need for expertise on the model, nor for special computer tools. The level of detail is easy to change and iterations can be easily modeled. The DSM helps identify problems and supports restructuring. However, one of the criticisms of the DSM model is that it does not model mechanisms and controls of information exchange as IDEF0 does.

This first section showed that interface management contributes to general project success, which can be defined in terms of functionality, project management, contractors' long term commercial success and termination efficiency (Morris 1983). Project control has been cited as a means to improve interface management. The second part of this chapter is devoted to a specific project control tool, the Work Breakdown Structure (WBS).

2.2 The Work Breakdown Structure

2.2.1 Definition of a Work Breakdown Structure

2.2.1.1 General definition

Many different definitions of a Work Breakdown Structure (WBS) exist in the literature, the difficulty just being to differentiate the various concepts researchers talk about with the same names.

The most general vision of a WBS is expressed in statements such as Tiner's (1985), for whom "the work breakdown structure is described as a method of 'defining and organizing' work so that project performance can be measured and controlled". Ayas (1997), in her work on corporate learning, gives a little more specific conception, defining the WBS as "the hierarchy of the required work to be performed to complete a project". Similarly, for Globerson (1994), project management and planning require the decomposition of activities into small segments, which is called a Work Breakdown Structure. Verzuh (1999), views a WBS as "the tool for breaking down a project into its components parts". The Program Evaluation and Review Technique (PERT) coordinating group views the "WBS as a family-tree subdivision of a program that begins with the end objectives, and subdivides them into successive smaller subdivisions" (Bachy and Hameri, 1997).

2.2.1.2 Representation

As pointed out by Christensen and Thayer (2001), a WBS can be represented in two logically equivalent ways: graphically or with text (see Figure 2.4).

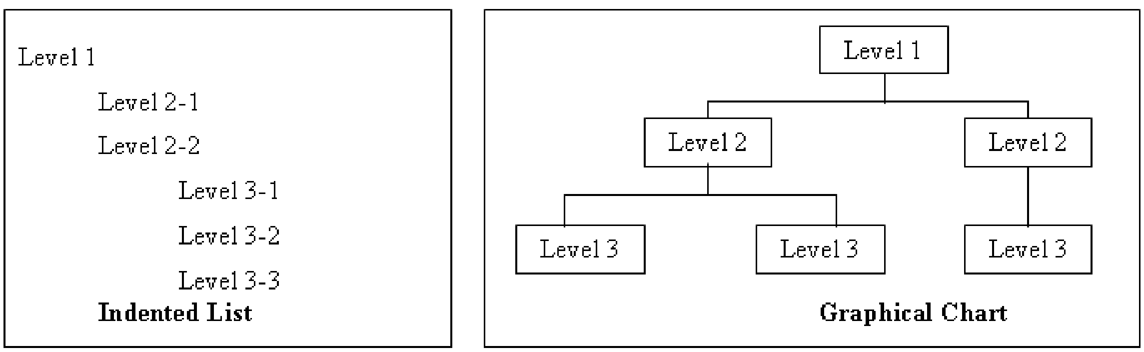

Figure 2.4: Correspondence between indented and graphical WBS[2]

A hierarchical chart WBS (see also Figure 2.5, Figure 2.6 and Figure 2.7) shows the relationships between higher-level products/processes and the lower-level products/processes that they contain.

[2] Taken from Gotland University website : http://teknik.hgo.se/prog/pro/WBS.doc

Similarly, indented list WBSs display the relationships between higher-level products/processes and lower-level products/processes in the degree of indentation in the list. Items with greater indentation are contained in items with lesser indentation.

Although they are theoretically equivalent, it is possible to find advantages to both representations. Verzuh (1999) thus argues that "the graphic WBS paints a picture that makes it easy to understand all the parts of a project, but the outlined WBS is more practical because you can list hundreds of tasks on it – far more than can be listed using the graphic approach."

2.2.1.3 Product- or activity-oriented breakdown?

It is interesting to see that, in the general definitions of a WBS mentioned above, there is no specification about how the treelike diagram called WBS is oriented. This means that when one wants to decompose the project into smaller parts, one has no idea whether to classify it by activities, by end product or by any other decomposition. As Taylor (1998) notes, "even writers who do espouse the virtues of WBS do not clearly explain the elements of it and how to develop them. The fact is that the literature is vague, often inconsistent and usually incomplete about WBS development". However, even in his own definition, the concept remains unclear, as a WBS is considered "a structured way of decomposing a project into its various components: hardware, software, services, documentation, labor, testing, delivery, and installation", therefore mixing products and activities. For Burke (1993), a project can be sub-divided using any of the following categories: project phase, location, disciplines, company departments, sub-contractors, technical, tasks, etc. For most authors however, a WBS is usually product- or activity-oriented (Colenso, 2000). The following examples show that both views, as well as many combinations of them, have been considered.

Smith and Mills (1983) adopt an activity-based approach, where “Work Breakdown Structures are a graphical representation of tasks in a project, broken down into a treelike or organizational chart that is used to define areas of responsibility and to track costs.” This can be illustrated by a sample WBS provided by the NASA website (Figure 2.5)[3].

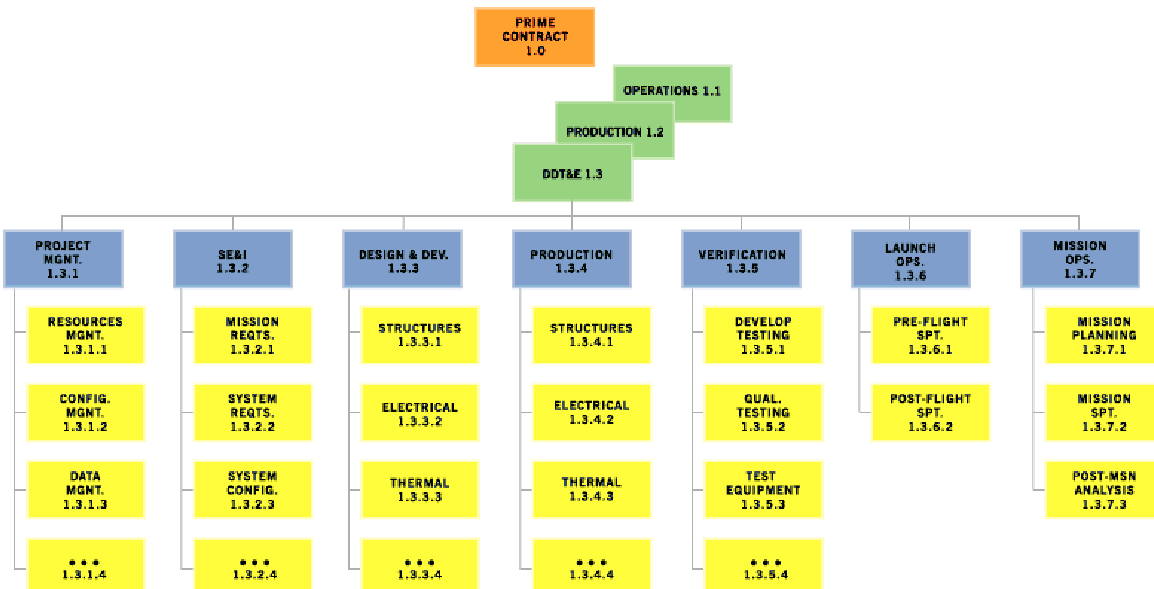

Figure 2.5: Sample activity-based WBS used in the NASA

Bachy and Hameri (1997), on the other hand, give a product-oriented definition of a WBS. They explain that, although traditional production organization is usually functionally oriented, more recent work focuses on product-oriented organization. Similarly, Stoehr (2001) describes the WBS as “a deliverable-oriented grouping of the work that has to be performed for a project”. Lanford and McCann (1983) give a more

[3] See website: http://appl.nasa.gov/perf_support/tools/wbs_samples.htm

specific definition, the Work Breakdown Structure being "a product-oriented family tree, from the final product at the top level, … down to the ultimate discrete pieces from which the system is assembled". This can be illustrated by a sample WBS provided by the NASA website (Figure 2.6)[4].

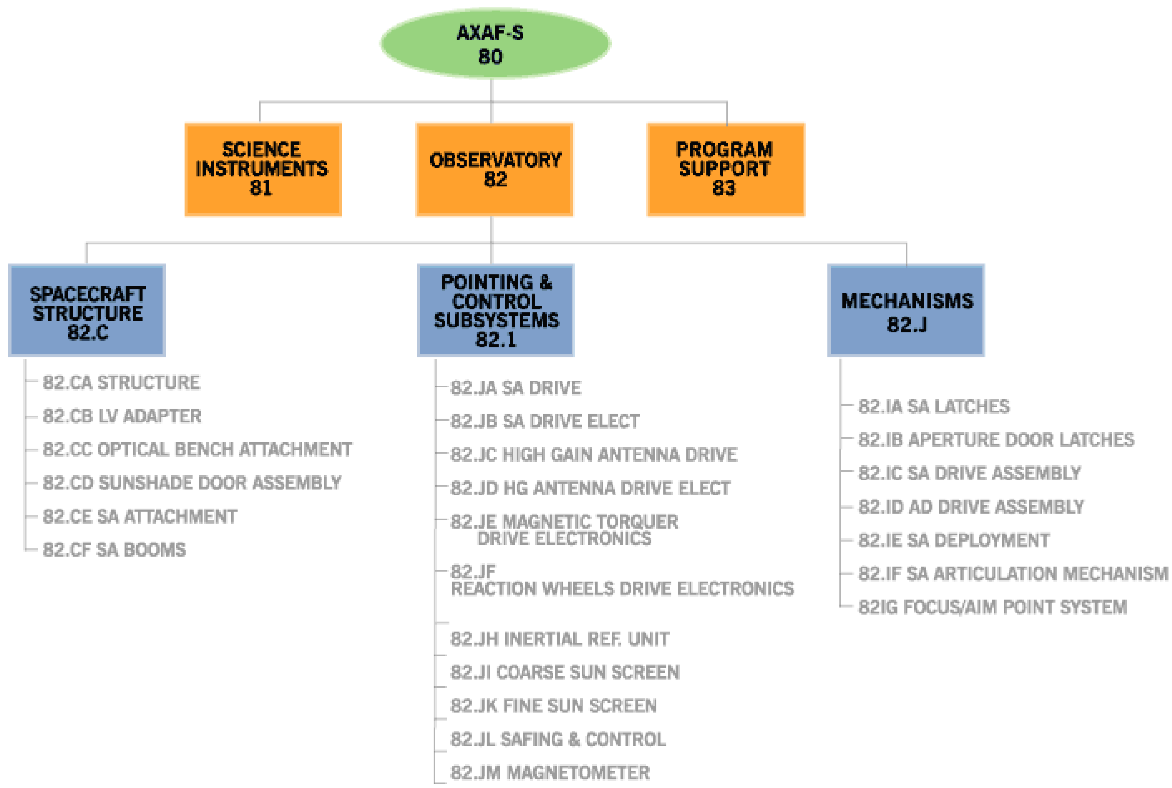

Figure 2.6: Product-Oriented WBS for the NASA's AXAF Spectrometer Spacecraft

Other researchers have adopted a third approach, where both activities and products can be found in the same decomposition. For instance, in the mind of Matthews (1986) the

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DD&T means Design, Development, Test and Evaluation.

[4] See website: http://appl.nasa.gov/perf_support/tools/wbs_samples.htm

DD&T means Design, Development, Test and Evaluation.

first level of WBS is activity-oriented while the second is product-oriented: an activity ("ground-system test") is decomposed into three product systems ("environment control", "hydrazine" and "payload mechanical system"). Tiner (1985) has a similar conception, stating that the WBS allows to identify not only major end *products*, but also detailed *tasks* required for their construction, responsible parties as well as schedule, technical and cost monitoring for each of these tasks. Products and activities are thus gathered under a single decomposition. This point of view is also adopted by Christensen and Thayer (2001), who list three types of WBS: product WBS (partitioning a large product into its components), process WBS (partitioning a large process into smaller processes) and hybrid WBS (beginning with either process or products depending on the point of view adopted or displaying both products and processes all on the same level). Similarly, for Warner (1997), a "work breakdown structure (WBS) is a visual model generated and utilized by the project team, which breaks down project requirements (end items, tasks and resources) into manageable work units."

Still another approach is adopted by Saynisch (1983). In the project mentioned, an urban mass transport system in Venezuela, the work is decomposed in both products *and* activities together at the same level (the first). One of the elements is an activity ("Project management and overall system", including project control, design, manufacturing, etc.), while the others are products ("passenger vehicle", "train control"). This can be illustrated by Figure 2.7, where level 2 of the WBS includes both products (air vehicle), and activities (management, evaluation, training)[5].

[5] See Website: http://www.acq.osd.mil/pm/paperpres/1097conf/albert/8

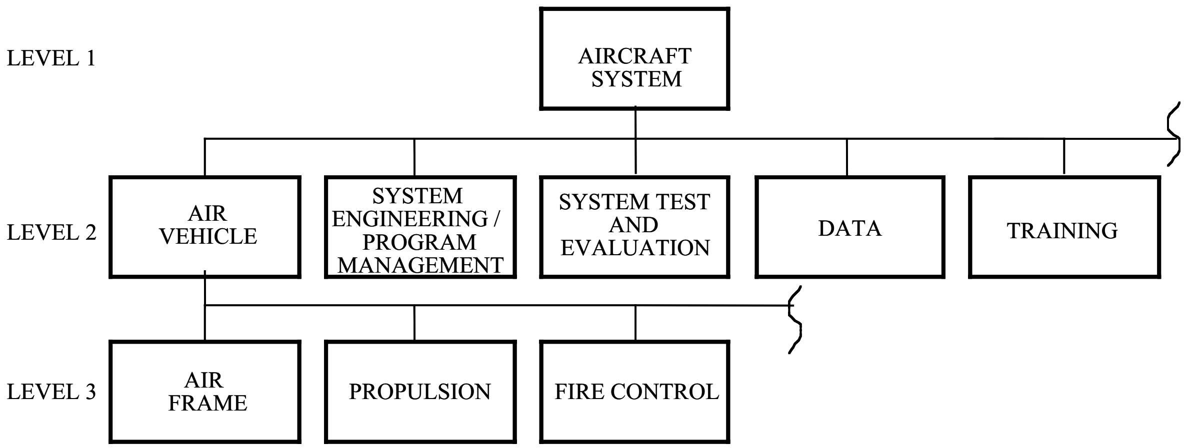

Figure 2.7: Sample WBS where both products and activities are found at the same level (used by MCR Federal, Inc., USA)

Reilly (1993) adopts a similar point of view, saying that the second level of the WBS should always list the five components always present in the development of any system: mission product, integrated logistics support, system testing, project management and systems engineering. It can be observed that the first component, a list of the elements of the complete entity to be created, is product-oriented, while the four others are activity-oriented. Lastly, Ruskin (1995) says that the WBS should decompose the system into a plan, requirements, and design (activity-oriented elements), but also subsystems, integrated system and validated system (product-oriented elements). It is interesting to see that there is a chronological sequence in this WBS, where different stages of the same system are represented on a common decomposition.

For de Heredia and Santana (1991), the concept is still different. The first six levels refer to the decomposition of the systems to produce or to build (project, areas, sectors, project units, subunits, and components levels), the seventh to ninth to activities (specialties, subspecialties and project stages levels) and the last one to the executing agent in charge (contractor level).

Finally, Richman (2002) unleashes all possibilities, recommending to use any categorization that makes sense for the project, be it product components, functions, organizational units, geographical areas, cost accounts, time phases or activities.

All these definitions, although not totally in disagreement regarding the general function of the WBS (which is to decompose the project scope into smaller parts to ease its management and control), clearly contradict each other in terms of practical implementation. As highlighted by Leavitt and Nunn (1994), “when carried out, each of these different patterns makes a specific type of information more accessible than the others, and some information may even become inaccessible”. This thesis will propose the use of a WBS matrix as a way to reconcile the need for product and activity approaches in the same tool.

2.2.1.4 The WBS matrix

The concept of WBS matrix, which will be explored in further detail later on, was first approached in research papers by Bachy and Hameri (1997) in the context of production. These researchers first define a Product Breakdown Structure (PBS) comprising a tree-like description of the product as well as a technical description and instructions on the manufacturing of each component. Similarly, an Assembly Breakdown Structure (ABS) describes the industrial, physical assembly of a system, comprising a description of the sequence of activities to complete the final assembly of the product. This Assembly Breakdown Structure does not include the design, procurement of components, testing of the system, etc. which are indubitably part of the project and should appear in a larger "Activity Breakdown Structure" as such. However, the concept developed is interesting in that, unlike the WBS definitions mentioned above, it clearly separates the ABS from the PBS. The concept of WBS matrix is then developed as by crossing them together.

It is interesting to see that, although this concept is mentioned in some companies' websites, it only concerns very isolated cases, not related with construction[6]. This thesis will contribute to filling this gap and generalize the use of the WBS matrix to other sectors, including construction.

Once the WBS matrix is done, its content is divided into **work packages**, "each of which is a unit of work needed to complete a specific job or process" (Bachy and Hameri, 1997). As in the case of the tree-like WBS, these work packages describe the work content of the corresponding low level tasks, the performance objectives and the resources required to accomplish them (Lanford and McCann, 1983). They should represent significant units of work, be unique and clearly distinguished from each other, and be mutually supportive of other detailed schedules and cost estimating functions (Tiner, 1985). Moreover, they should be under the responsibility of a single organization or individual (Globerson, 1994; Tiner, 1985).

2.2.1.5 Level of details of a WBS

All authors agree on the fact that a WBS must be adapted to the situation and flexible (Lanford and McCann, 1983). Regarding the necessary level of details for instance, there

[6] See : http://www.for.gov.bc.ca/hre/fpc/publications/work_bkdw.htm

is no specific rule to determine the size of a work package, as a balance has to be found between the need for project control and scope change management on one side, and administrative work on the other (Lanford and McCann, 1983; Bachy and Hameri, 1997; Globerson, 1994; Stoehr, 2001; The Hampton Group, 2000; Devaux 1999). Although this was ascertained for traditional tree-like WBSs, it can certainly be extended to the case of the WBS matrix.

Four to six levels of detail are commonly recognized to be an adequate number for large scale projects, with, as mentioned by Taylor (1998), the first three levels being typically managerial and the last three more technical. Devaux (1999) argues that only the first and last levels really are important, for the former is a proof that the project exists and the latter is the level at which work is actually done. Intermediate levels just serve the purpose of having summary reports or cost accounts at a higher level than the working one.

More technically, researchers recommend to adapt the level of details to the necessary accuracy of estimates, the level of details of the schedule and the cost breakdown, as well as the inputs, outputs and milestones to be quantified (Lewis, 2001; Leavitt and Nunn, 1994), and to take account of prior experience and seniority of the managers when sizing work packages (Rosenau, 1992).

2.2.2 Functions of a WBS

It has been explained that the WBS is a tool enabling project scope definition. This refers to the WBS development step, when the project team exhaustively defines all the activities necessary to produce all the components of a system. However, the WBS is not only useful at that stage. Once considered sufficiently detailed and rightly organized, it can serve as a project management tool (Stoehr, 2001; Saynisch, 1983; Reilly, 1993; Verzuh; 1999). More precisely, Springer (2001) highlights that "one measure of effective program planning and successful execution is the thoroughness of the steps involved in identifying, categorizing and allocating contractually stated and derived requirements", which is precisely the role of a WBS.

This paragraph details how such processes are said, in the literature, to be enhanced by the use of a WBS.

2.2.2.1 Time and cost control

As Lanford and McCann (1983) point out, "the large investment requirement, long project duration and variety of organizations involved has created a need for strong baseline planning and project control mechanisms." Using the WBS concept in the US defense since 1962 has brought clarity and transparency to project management and control, allowing for a more precise work definition (Lanford and McCann, 1983; Globerson, 1994). The concept gained its popularity from there and is now commonly cited as an effective tool to plan and control projects. Many quantities can be indeed controlled using the WBS, such as manhours, physical resources used, drawings completed, etc. (Burke,1993), and the WBS can become a baseline for time, cost and performance control, as well as for resource allocation (Bachy and Hameri, 1997; Stoehr, 2001; Warner, 1997; Richman, 2002). More specifically, Lewis (2001) identifies the steps involved in the use of a WBS for project control:

- tasks are identified and resources allocated to them;

- task durations can be estimated;
- costs and resource allocations can be totaled to develop the overall project budget;
- task durations can be used to develop the project schedule;
- performance can be tracked against these identified cost, schedule and resource allocations;
- responsibility for each element can be assigned.

The advantages of using the WBS for project control are the following.

First, the WBS increases the accuracy of time estimates by providing the high levels of details necessary to reduce padding, and thus lower the risk of funding issues (Lewis, 2001). It is more generally recognized as an efficient time control tool that can trigger successful project management (Verzuh, 1999) when combined with planning tools such as PERT and CPM, and the collective analytical effort of the team (Warner, 1997).

Similarly, Albert (1995) specifies several possible uses of the WBS in cost related issues, such as financial management, contract budgeting and cost estimating. Breaking the project down into smaller units increases accuracy on cost estimates, by augmenting the possibility and accuracy of comparison with similar units in other projects (Lewis, 2001).

The various levels of detail of the WBS also allow to roll the cost and time data of lower levels up to any of the higher levels (Lewis, 2001; Lanford and McCann, 1983; Tiner, 1985). Thus, it satisfies the different control needs of the various levels of management and stages of the project (Morris, 1983), and takes care of the fact that time control usually requires more details than cost control (Burke, 1993).

Research works viewing the WBS as a very efficient control tool are confirmed by field experience. An American university reportedly saved the equivalent of 1000 man-hours per year for a 60 person department by replacing several databases by an extensive WBS of around 800 work packages to track staff member work assignments[7]. The management found the tool a "solid project, cost and revenue reporting application". Similarly, for Colenso (2000), consultant in project management, the WBS "is the foundation for project planning and control. It is the connecting point for work and cost estimates, schedule information, actual work effort/cost expenditures, and accountability."

2.2.2.2 Technical control

Early firm control of technical definition is essential to project success (Morris, 1983). Exhaustive initial design and continuous configuration management ensure minimization of technical problems during implementation, and the WBS participates in this process. Albert (1995) confirms that "the WBS provides a framework for defining the technical objectives of the program", thus aiding to establish a specification tree, define configuration items and plan support tasks. It also facilitates scope change management (Stoehr, 2001) and, by creating measurable units of work, enables the monitoring of progress on each of them (Verzuh, 1999). The US National Aeronautics and Space Administration (NASA) uses the WBS as a means to define technical objectives, establish

[7] The solution for an extensive work breakdown structure project tracking system. http://www.tenrox.com/en/downloads/casestudies/CaseStudy_UAB.pdf

a specification tree, define configuration items, provide integrated logistics support and prepare and execute a test and evaluation plan for a project. The WBS is thus used as a complete technical management tool (NASA, 1994).

2.2.2.3 Future projects estimation and corporate learning

Developing a standardized project management methodology enables the recording of historical data on previous projects to facilitate management of future ones (Lewis, 2001). The WBS can support this process if a database of similar WBS elements is created throughout projects (Albert, 1995; Albert, 1997; Burke, 1993; Verzuh, 1999). The WBS thus becomes a tool for corporate learning (Ayas, 1997).

2.2.2.4 Information management and communication

The WBS is an excellent basis for information management and, further, networking (Matthews, 1986).

First, the WBS defines how data is to be broken out or summarized according to requirements at the various levels of management, thus structuring information. The WBS also identifies the information precedents of an activity and provides information that serves as the basis for detailed planning.

Lastly, as argued by the Project Management Institute, “the WBS elements assist the project stakeholders in developing a clear vision of an end product of the project and of the overall process by which it will be created” (PMI, 2001, p.4). It indeed facilitates communication by giving all partners a common understanding of project scope (Stoehr, 2001), project objectives and project control systems (Warner, 1997). It also encourages dialogue, clarifies ambiguities and project scope, and raises critical issues earlier on (Globerson, 1994). This process will itself breed excitement and commitment from team members (Kliem and Ludi, 1999).

2.2.2.5 Organizational structure definition

The WBS does not only serve as a control and communication tool, it can also form the basis of the organizational structure defined for a project and supports the assignment of roles and responsibilities to project team members (Stoehr, 2001). "The determination of the organizational structure and size of the project team must be based on a full understanding of the project, the scope of management effort required, and a technical knowledge of the work required to perform each management function involved in the project", which is exactly what the WBS provides (Halin and Woodhead, 1980, p.1997). Taylor (1998) confirms that once the project is broken down to a workable level of detail, the allocation of responsibilities is evident. The WBS, by giving staff both clear assignments and a sense of how they work fits into the overall efforts, will also increase motivation and commitment (Verzuh, 1999; Burke, 1993).

2.2.3 Problems associated with the use of a WBS

Although the literature is not extensive on what problems can be encountered when developing and using a WBS, empirical studies mention that the following are some key issues (Albert, 1997). First, the flexibility of the WBS can be difficult to implement. As argued above, the WBS is expected by operational actors to be able to change after contract award and to be described with quite a high level of definition, but this is not always easy to manage in reality. Secondly, WBS definition software sometimes have poor performance. Thirdly, organizational divisions of a single organization may not develop similar WBS. Lastly, all documents should reflect and be consistent with the WBS (Management Plan and Schedule, Bills of quantities, materials, etc.), which is not always done, thus complicating project management. However, these problems relate more to the implementation of the WBS than to its basic concept.

To summarize, the WBS enables management of time, cost and information. As Warner (1997) puts it, "to meet project objectives and satisfy customers, the project teams need a road map to allow them to attain good, fast and cheap. By breaking down project requirements into specific tasks and assigning them to a resource(s) to fulfill them, the WBS paves the way." The following section will propose to use it as the basis for sound interface management.

CHAPTER 3: The WBS matrix, an interface management tool

This thesis is based on the relatively new concept of WBS matrix. Although, as mentioned in section 2.2.1.4, the WBS matrix was first elaborated by Bachy and Hameri (1997) in the manufacturing industry context, its seems to have never been used in relation to the management of one-time projects. This thesis extends the notion of WBS matrix to non-manufacturing projects and applies it in the case study of a complex transportation project to assess its benefits in terms of interface management, thus introducing its use in the field of construction management. This section will present the concept of WBS matrix and assess its advantages in comparison with traditional tree-like WBSs.

3.1 Concept of the WBS matrix

Product Breakdown Structure \ Activity Breakdown Structure	Project management	Design	Procurement	Manufacturing	Construction	Inspection/testing	Hand-over activities
Foundations	1	6	11	11	17	17	20
...	1	6	11	11	17	17	20
Concrete-related works	1	6	11	11	17	17	20
...	1	6	11	11	17	17	20
Building and Structure frameworks	1	6	11	11	17	17	20
...	1	6	11	11	17	17	20
Construction Wet Trade finishes	1	6	11	11	17	17	20
...	1	6	11	11	17	17	20
Electrical and Mechanical Works	2	7	7	7	7	7	20
...	2	7	7	7	7	7	20
Architectural Work and finishings	3	8	12	15	18	18	20
Carpentry	3	8	12	15	18	18	20
Architectural Woodwork & Cabinetry	3	8	12	15	18	18	20
Metalwork	3	8	12	15	18	18	20
Stonework & Masonry	3	9	13	16	19	19	20
Partitioning & Paneling	3	8	12	15	18	18	20
Floor finishes	3	8	12		18	18	20
Wall Finishes	3	8	12		18	18	20
Ceiling Finishes	3	8	12		18	18	20
Glass & Glazing	3	8	12	15	18	18	20
Paintwork & Coatings	3	8	12		18	18	20
Roofing and Weatherproofing	4	10	14	14	14	14	20
...	4	10	14	14	14	14	20
External works and road works	5	6	11	11	17	17	20
...	5	6	11	11	17	17	20

Figure 3.1: Example of a WBS matrix for the construction of a house, with details shown for one PBS component and WP numbers displayed.

The concept of WBS matrix can be explained as follows (see Figure 3.1).

First, a Product Breakdown Structure (PBS) is established to describe the final product to be delivered at the end of the project. Its main components are first simply listed, then a second level of precision is added by listing the sub-components of each of them, and so on. For instance, the first level of the PBS for the construction of a house may include the foundations, the roof, the walls, the windows, the doors, the painting, etc.

The second level of the PBS will go down to a more detailed level, for instance including carpentry, floor, wall and ceiling finishes and paintwork in the breakdown of the part related to "architectural work and finishings". The list can go on until the appropriate level of detail is reached. It is possible to include, in the PBS, items that serve the purpose of implementing the project, and that have to go through a series of activities as much as the final product does. For instance, construction equipment has to be designed, purchased and delivered on site as other items of a building project, and including it in the PBS ensures that it will be managed properly.

Second, an Activity Breakdown Structure (ABS) lists all the activities to be performed during the course of the project. For typical construction projects, this list may include general project management, design, procurement and manufacturing of equipment, construction in itself, inspection/testing and hand-over activities. It can be broken down to higher levels of details if necessary, as described in Figure 3.1.

The PBS displayed vertically is then crossed with the ABS displayed horizontally, resulting in what can be called a WBS matrix. The cells of the WBS matrix body are then regrouped into work packages, corresponding to a particular activity or set of activities to be performed on a particular product or set of products. The formation of work packages is visualized by the color affected to them, which allows putting, in the same work packages, products or activity that are not displayed next to one another in the PBS or ABS (see Figure 3.1).

Rosenau (1992) advises organizations to always have several people prepare a draft WBS independently and simultaneously, in order to avoid discrepancies and oversights. This process can be supported by data gathered from other project managers who have done similar work, previous project reviews and existing WBS templates. Rosenau (1992) cautions that copying a prior project's WBS for a new project is inappropriate and that a new WBS should always be thought upon extensively if project success is to happen.

3.2 Advantages of the WBS matrix

3.2.1 Advantages in terms of work definition

One of the advantages of the WBS matrix is that is allows for a free and easy assembly of the WBS cells into work packages. For instance, taking the examples above, changing the repartition of work packages related to the same activity or the same product in the construction of a house is very easy. "Design of the foundations" will be changed into "Design of the foundations and the walls" just by changing the color of the WBS matrix cells related to the design of the walls. As long as the project manager finds it easier to manage practically, there is no disadvantage in changing the WBS. In comparison, visualizing this kind of change on a product-oriented tree-like WBS is not easy: work packages appear on a linear basis (the basis of the pyramid), and the grouping of two similar activities performed on different products into one will not be easily visualized. Similarly, the WBS matrix will facilitate the grouping of the work packages "inspection of roof" and "hand-over activities for roof" into "Inspection and Hand-over activities for roof" just by changing the color of the former, while this operation would be difficult to visualize on an activity oriented tree-like WBS, where the two initial work packages might appear far from one another.

Thus, using a WBS matrix aids in visualizing the work to be performed, therefore helping the project manager organize it as it seems natural, unobstructed by an activity- *or* product-oriented approach. Both approaches are available in the same tool and can be used alternatively depending on the needs of the project organization.

3.2.2 Advantages in terms of project organization and visibility

3.2.2.1 Displaying products and activities simultaneously

As noted in the second chapter, different types of WBS exist. The first types are either product- or activity- oriented (Colenso, 2000; Bachy and Hameri, 1997, Lanford and McCann, 1983, Smith and Mills, 1983). In this kind of decomposition, products and activities are not mixed, which means that there is no mention of activities in the product-oriented breakdown, or no mention of products in the activity-oriented breakdown. This looks of rather poor interest as a management tool. In effect, the same activity will be performed differently and require different skills according to the products it involves, and thus cannot be considered as a unique way of describing a project. Similarly, the same product will often go through so many activities it cannot be considered as a way to decompose the work to be done.

Thus, although conceptually interesting and certainly providing a useful description of certain aspects of the project, this kind of unique orientation cannot be used as a unique basis for management. A management tool requires that both products and activities be displayed simultaneously.

3.2.2.2 Clearly separating products from activities

A second way of building a WBS is to mix product and activities on the same level of decomposition (Saynish, 1983; Reilly, 1993; Ruskin; 1995).

To explain the advantage of the WBS matrix over this kind of “mixed” WBS, let us take the example of the SOuthern Astrophysical Research (SOAR) telescope[8]. The SOAR telescope is funded by a US-Brazil partnership and under construction in the Chilean Andes.

The first level of the WBS comprises the following items:

- Mechanical
- Optics
- Electronics
- Software & Computers
- Installation and Commissioning
- Support Equipment and Supplies
- Travel
- Management, Reporting and Documenting.

It can be noted that this WBS displays, on the same level of description, products (like mechanical, optics, electronics, software and computers, support equipment and supplies), and activities (installation and commissioning, travel, management, reporting and documenting). Budgets are defined and cost performance monitored for each of these

[8] The SOAR WBS is available on the following website:

http://www.soartelescope.org/sac/IFU_DesignReview/sect4timesched.pdf items and their sub-components. The issue when managing a project under such a WBS is to answer some critical project control questions such as the following ones.

First, what is the total cost of the mechanical system? This question can arise, for instance, at the end of a project, to evaluate whether this system should have been sub-contracted, whether the person in charge properly managed the work, etc. However, it is impossible to answer this question based on the available WBS decomposition, as the total cost to be calculated will include not only the "mechanical system" budget, but also part of the "installation" costs, "support equipment" costs, "travel" costs and "management, reporting and documenting" costs, that are classified under another category and do not make the distinction between the different systems to produce.

A second question might be: How did the installation and commissioning of Optics perform? Similarly, one cannot answer as the cost of installation and commissioning concerns all equipment elements (including mechanical and electronics), preventing from identifying the item "optics" specifically.

It might also be hard to identify the full "installation and commissioning" cost, as some of it might be included in the product-based categories.

Thus, although budget figures are available, the most careful monitoring will not enable managers to identify items or activities that may be going through problems. It is therefore very difficult to take decisions such as assigning more technical staff or increasing budget for a specific activity to be performed on a specific item. **Thus, it can be concluded that a WBS must not mix products and activities on the same level of a WBS.**

3.2.2.3 Facilitating simultaneous product- and activity-oriented visualization

A third way of constructing a WBS is to start the decomposition adopting one approach (product or activity) for the first few levels, and then switch to the other, so as to finally obtain work package merging both views (Matthews, 1986; Tiner, 1985; Christensen and Thayer, 2001, Warner, 1997).

The issue with this kind of classical tree-like WBS has been pointed at by Albert (1995). The main problem is that when describing a project in a WBS, people think about both activities and products. Tree-like WBSs will force them into restricting the first few levels of detail to activities, waiting for the last levels to mention products, or vice versa to limit the first levels to products and the last ones to activities. For instance, it is mentioned that "program-phases … are inappropriate elements of a work breakdown structure", "rework, retesting, and refurbishing should be treated as work on the appropriate work breakdown structure element affected, not as separate elements of a work breakdown structure". Albert (1997) also mentions "conflicts between types of WBS used". These details indirectly refer to the fact that some individuals might prefer to have an activity-oriented view, while some others might prefer to have a product-oriented view, these different mental images leading to issues at the time of building the WBS. As Christensen and Thayer (2001) precisely wonder: "are the products paramount and the processes the method of implementation, or are the processes central and the product the result of the execution of them?"

The fundamental issue is that a project cannot be viewed from only one point of view. It is intrinsically made of activities, but intrinsically also concentrating on a particular product or system to build. The very fact that two main types of WBS exist (product- and activity-oriented) proves that both views are useful and recognized as such in the project management field of research. The WBS, to be appropriate for the use of all project members and in all contexts, should reflect this binary view without bias.

The best view to represent product and activity decomposition simultaneously naturally appears to be a matrix structure.

3.2.2.4 Not forgetting any activity

One issue of project definition and management is not to forget anything. The WBS should indeed represent the complete project (Richman, 2002). As noticed by Lewis (2001), the Work Breakdown Structure is supposed to provide a visual representation of the total scope of the project, thus helping managers not to forget to plan for any activity. The advantage of the WBS matrix over tree-like WBS is that it gives an even more accurate vision of the work to perform than conventional tree-like WBS. All activities are indeed first crossed with all products. The WBS definition team then systematically goes through each line and column of the matrix and identifies the activities that are not supposed to be performed (if applicable), instead of identifying activities to perform one by one, product per product. Thus, they have less chance to forget items of work.

Thus, the WBS matrix is a simple tool making use of two existing breakdowns: the ABS and the PBS. It provides a clear and complete picture of the work to be done under a project, and avoids the usual problems of the tree-like WBS previously proposed. The following section will present a tool based on the WBS matrix that is intended to assist in controlling and managing projects.

3.3 The WBS management package

The management tool developed in this thesis relies on the WBS matrix as a conceptual framework. Although many authors explain that a WBS can serve as a framework for various purposes (see section 2.2.2), there are very few indications concerning the practical way it can and should be used to perform its functions. The general impression given by these articles is that the WBS, by dividing a large work into pieces, already accomplishes a significant simplification of planners' and managers' work. Having such a decomposition of the work, they can proceed with the usual planning, budgeting, organizational and reporting tools, adapted to the work package level. This thesis proposes to place the Work Package at the center of project and interface management to guarantee that all their aspects are structured in the same way and integrated with one another. To this aim, separate sheets are associated to the WBS matrix in order to practically document work packages and facilitate the integrated management of and reporting on the activities, thus increasing the part the WBS can play in project management and the value it can add to it. These documents are described in Figure 3.2, and elaborated in the succeeding sections. Figure 3.2 shows that the implementation of the WBS matrix management package responds to the questions surrounding interface definition and management and naturally drives people to fully address them.

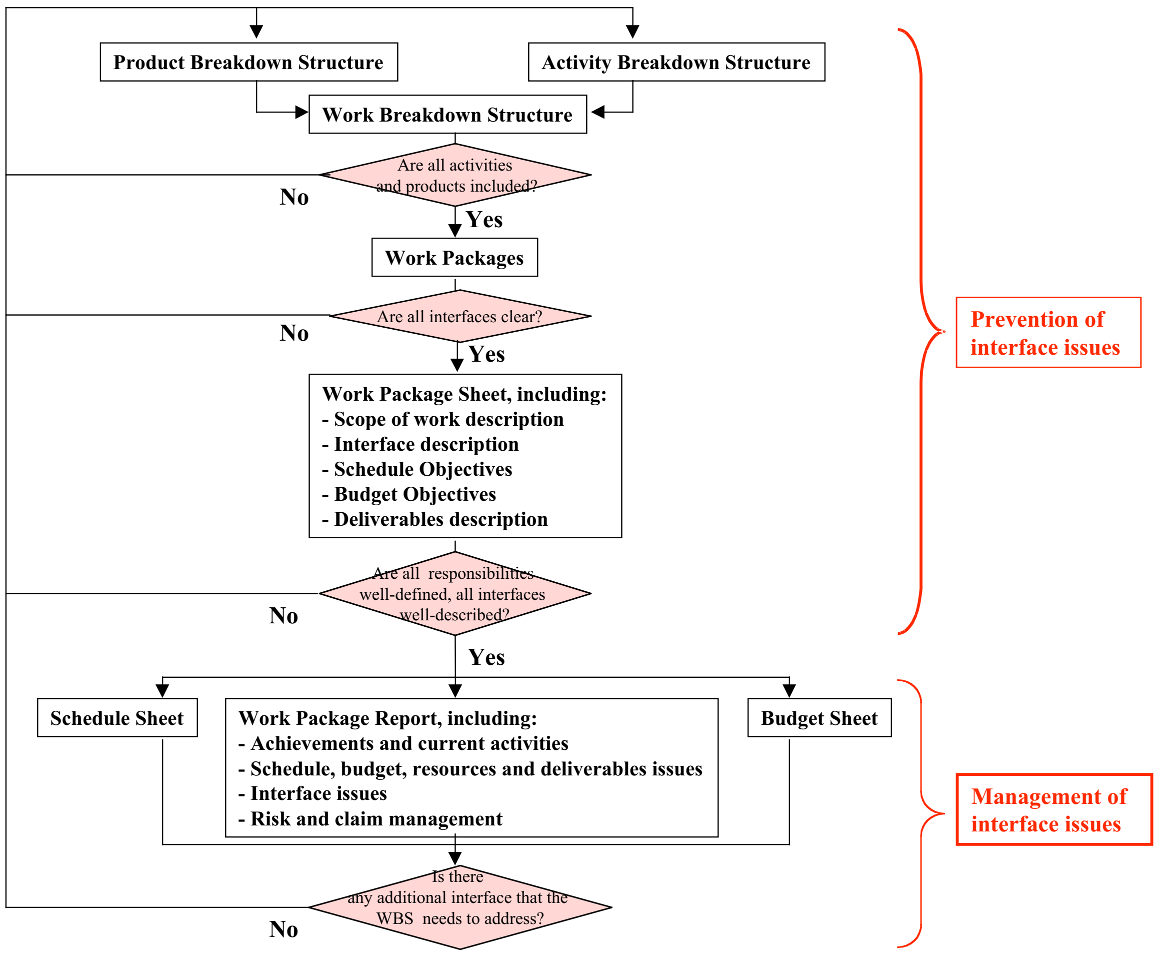

Figure 3.2: Components of a WBS matrix management package

To summarize, the WBS matrix is made of an ABS and a PBS forming work packages as described in section 3.1. These work packages and their interfaces are described using Work Package Sheets. While the WBS matrix and Work Package Sheets are prepared at the beginning of the project to define interfaces, other documents are needed to manage them during implementation. A Work Package Report, Schedule Sheets and Budget Sheets are prepared on a regular basis for this purpose. At all stages, if it is found interfaces are not adequately defined, described or managed, preceding steps can be gone through again, so that the tools continuously improve while the project makes progress. This section will describe the tools complementing the WBS matrix to improve interface management.

3.3.1 The Work Package Sheet

After the WBS matrix is finalized and visually displays work packages, each of the work packages is further defined in a separate sheet, the Work Package Sheet. The Work Package Sheet (WPS) is a simple Excel sheet that concentrates data on the scope of work, the schedule, the budget, the deliverables and the interfaces involved in a work package. It is defined and agreed upon with the corresponding work package manager.

Warner (1997), Tiner (1985), Richman (2002) and consultants of the Center for Project Management[9], indicate that a work package description should contain:

- clear measured achievements and their associated task sequence
- product specifications
- simple predecessor networks
- resources and their task assignments
- realistic task durations
- resource costs and methods of procurement
- a budget, chargeable to a single cost account
- target dates
- authority and responsibility for the completion of the tasks.

[9] See website: http://www.c4pm.com/wbs.htm

The Work Package Sheets used in this thesis also include an interface description, in order to clearly integrate interfaces in overall project management.

3.3.2 The Work Package Report

The Work Package Report (WP report) is another Excel sheet enabling reporting on all work package aspects on a regular basis.

The WP report summarizes, for a work package, the activities that have been carried out or are on-going, as well as qualitative details on all the issues faced by the team, be it in terms of interfaces, schedule, budget, deliverables, and resources. These issues can be related to suppliers performance, internal mistakes, misunderstandings, or any reason that the WP manager can think of. The WP report can also include other data useful for project management, as needed, such as data for claim or risk management.

As schedule and budget can only be partially described qualitatively, a budget sheet and a schedule sheet are added to the WP report and must also be updated with the same regularity. This is useful for the following reasons. First, for large and complex projects, a schedule is usually made of hundreds or even thousands of activities, related to the work of many different teams. At the operational level, so much information is useless and can actually deter managers from using the schedule, considered complicated and to take too much time. Selecting the data relevant to only one work package and collating it on a single sheet will enable managers at the operational level to have a clear vision of their schedule objectives, and the simplicity of the document (displaying only the relevant activities) will enable its use on a more frequent basis. Schedule sheets can also display work in progress, thus enabling easy monitoring of technical project advancement.

Second, a budget sheet with a common format for all work packages enables management to have a clear vision of financial project progress between project reviews. This avoids the situation of having different financial data displayed for different activities, which prevents management from being able to compare and monitor their performance and to detect potential issues. Further, having a common format of financial reporting adapted to the work package structure allows to aggregate data at any level of the WBS to monitor performance of various higher-level activities.

Thus, the WP report is a tool of regular reporting and, completed with a schedule sheet and a budget sheet, provides complete information on project progress. As advised by Warner (1997), it can be used to "periodically total [the] information up the levels of the WBS and compare performance against budgets and estimates", and take appropriate corrective action if necessary.

3.3.3 Timeline for WBS matrix package use

The WBS matrix management package contains several components that have different functions and thus need to be prepared at different times in the project timeframe. The WBS matrix and Work Package Sheets should always be prepared as early as possible in the project, for instance during the tender phase. This enables the project team to have, at all times, the most accurate representation of the project in mind. While project definition evolves, the WBS matrix and Work Package Sheets should be modified accordingly (Bachy and Hameri, 1997; Reilly, 1993; Rosenau, 1992).

However, once the WBS and Work Package Sheets are finalized, normally at the latest at the time of contract signing, they should be agreed upon and modified occasionally only, when project scope changes or is refined. Stoehr (2001) thus advises that the WBS be created iteratively, with a first version being developed in the early stages of the project, and updates made subsequently, but only when project scope is contractually changed or if it is realized that the WBS is flawed or misses items. This allows for partial revision, but also avoids constant changes that would be unmanageable in a central project management and control document.

Budget sheets, Schedule sheets and Work Package reports are more concerned with project control than project definition, and should therefore start being prepared once the project is launched and from then on, on a regular basis in order to enable precise monitoring and planning of activities based on accurate information. Usual lean construction tools such as Last Planner recommend that project control updates and planning be done weekly (Ballard, 1994 and 2000), and this can be applied to Budget sheets, Schedule sheets and Work Package Reports.

3.4 Interface management using the WBS matrix package: a framework and some expected findings

This thesis intends to answer the question of whether the WBS could be used as the basis for an interface management tool. This section will present a framework in which the two concepts are linked. The results of the case study, presented in Chapter 4, will enable the refinement of this framework and propose an empirically derived theory.

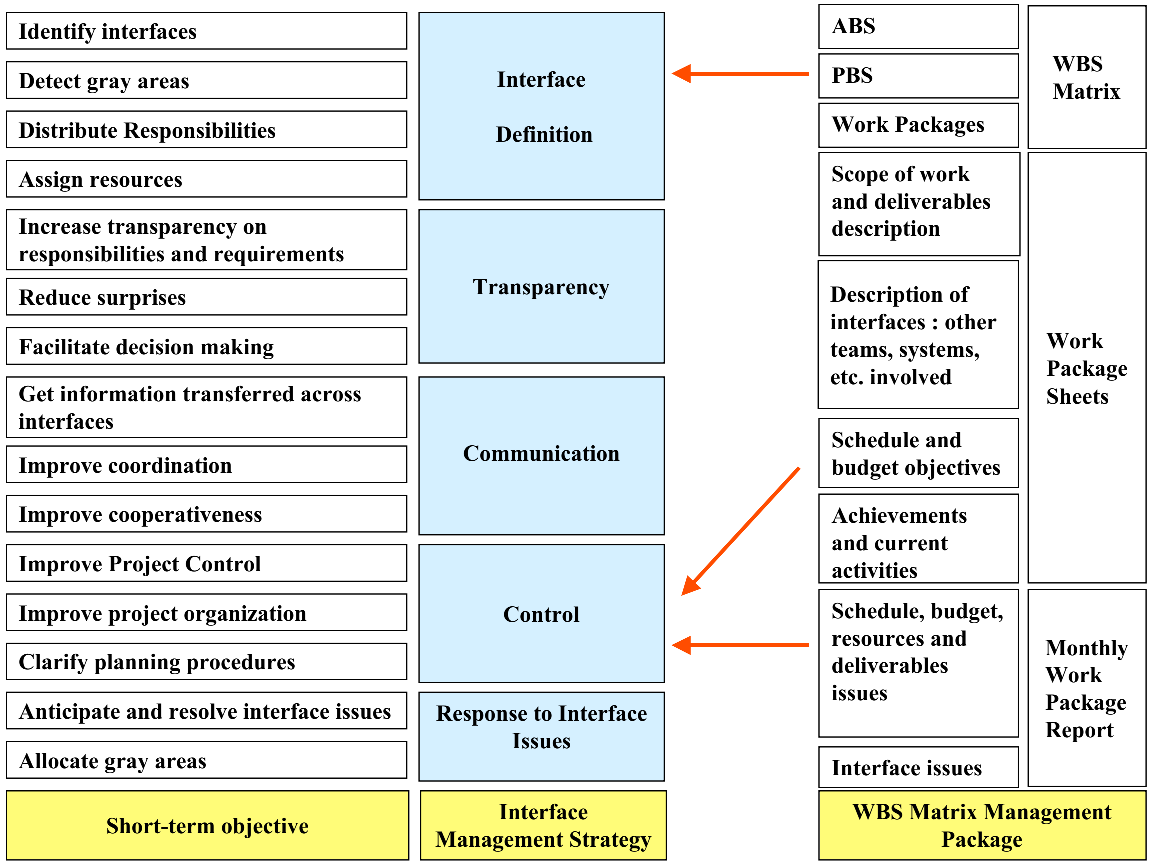

Figure 3.3: Research problem: how to use the WBS matrix management package to improve interface management?

As illustrated in Figure 3.3, it is proposed in this thesis to use the WBS matrix management package described above in as many ways as possible, to improve or help the process of interface management. Figure 3.3 is constructed in the following manner. The left part displays a set of shorter-term objectives that could improve interface management, as described in Figure 3.3. The central part recalls the five strategies that could enable the achievement of these objectives, as described in paragraph 2.1.2.2. To implement these strategies, the WBS matrix management package was set up and its components, as listed in Figure 3.2, are recalled in the right-hand side of the figure.

The objective of the case study will be to link the two halves of the figure by a set of arrows, showing how each of the elements of a WBS matrix management package can be used for a certain purpose related to interface management. The rationale for such a study is that, as described hereafter, some of the links can be built quite intuitively, as shown in Figure 3.3. The case study will allow to confirm and draw more of these links, to provide a complete theoretical framework linking the WBS matrix management package with the principles of interface management.

First, it can be expected to find that the WBS matrix, by displaying a project's end-product as well as all the activities that will lead to it, requires the team in charge of its creation to clearly define the interfaces between subsystems and teams. As Reilly (1993) notes, throughout the WBS definition process, "as systems begin to crystallize, so do the required interfaces between them."

Indeed, subdividing the overall system into smaller sub-systems and sub-components is usually naturally done for the biggest and most obvious components. For instance, for a house construction project, teams will naturally be formed for the different main systems according to the technical skills needed for them, such as a roofer for the roof, a plumber for the plumbing, etc. Similarly, the plumber will have a plumbing designer, a person responsible for the procurement of the necessary equipment and some workers for its installation, and this organization will be repeated for all components of the final house. Thus, activities and products are always grossly divided into different parties. However, there might be no precise definition of how these people will interact and coordinate with each other. Formalizing the ABS and the PBS can be expected to be an opportunity to point to the mere existence of interfaces, and further to think about the organization of work across them. Indeed, a common problem at interface is the "partial match" mentioned by Healy (1997), when the interface is not perfectly defined, leading to what can be called a "gray area", with no determined responsibility. Gray areas are common at interfaces, as this is where work definition is the most difficult. When teams are assigned some work, the bulk part of it is usually better defined than the limits with other teams' work, their interactions, their share of responsibilities, etc. There is some work that needs to be done by several teams simultaneously or with feedback from one another, and there is some work that can be performed by one of the teams alone, but that has not been allocated to any of them. For instance, two teams eligible for carrying out an activity can expect each other to do it, resulting in none of them doing it. It can be expected that the WBS, by precisely allocating responsibilities, will reduce the chance of having to manage gray areas.

Secondly, as a project control tool, the WBS strategy can also be expected to indirectly enhance interface management. Indeed, an important part of interface management relates to scheduling and progress monitoring. Schedules, general project reviews and configuration reviews are essential to predict and monitor the evolution of interfaces (Healy, 1997). Resource balancing and planned access to critical resources ensure that financial matters are well balanced across the boundary of interfaces. This is important as the interests of interfacing parties are often affected by the distribution of financial power (Morris, 1983). Stuckenbruck (1983) promotes the idea of developing integrated project control, with resource allocation and reporting periods coordinated with interface events, thus integrating schedule and budget. Thus, as a project control tool, the WBS will again contribute to interface management.

Thus, a simple analysis of usual utilizations of the WBS leaves some hope regarding potential benefits it can bring to interface management in construction projects. The case study in Chapter 4 will help specify how the two concepts can be more precisely linked to each other to complete Figure 3.3.

CHAPTER 4: Case Study – a WBS for a Mass Rapid Transit Line Project

This chapter presents the case study that was performed during this research to assess the possible uses of the WBS to improve interface management processes. After a description of the project and the interfaces it involves, the chapter will focus on how the WBS matrix management package was developed and used, and how it improved interface management at a strategic level. Research findings will then be summarized and a comparison of the WBS with other interface management tools will be proposed.

4.1 Description of the project

4.1.1 Background

The case studied here is a fully automated 35km-long Mass Rapid Transit (MRT) Line to be built in five stages. Overall project management organization is structured as illustrated in Figure 4.1.

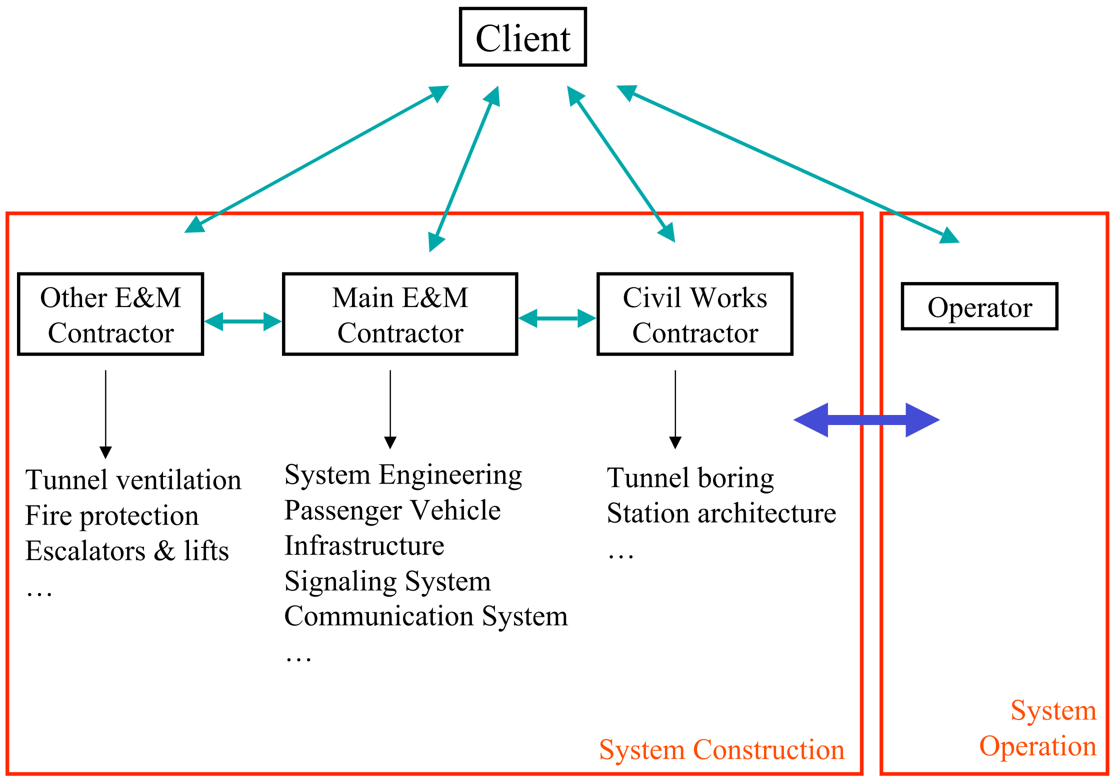

Figure 4.1: Structure of project management organization

The contract for the design, manufacture, supply, installation, testing and commissioning of its electrical and mechanical systems was awarded to a single contractor, who will be called "the main E&M Contractor" in this thesis. In addition, this Contractor is responsible for the integration of the subsystems it provides with other E&M subsystems, specific training of the future operating staff, as well as post-commissioning activities such as warranty, reliability analyzes, etc. As illustrated in Figure 4.2, this transportation project is complex due to:

- the fully automatic feature and its implication in terms of safety;

- the size of the project and its sequence of implementation over several phases;

- the system approach with the integration of several sub-systems involving various engineering fields to be interfaced;

- the design and build context.

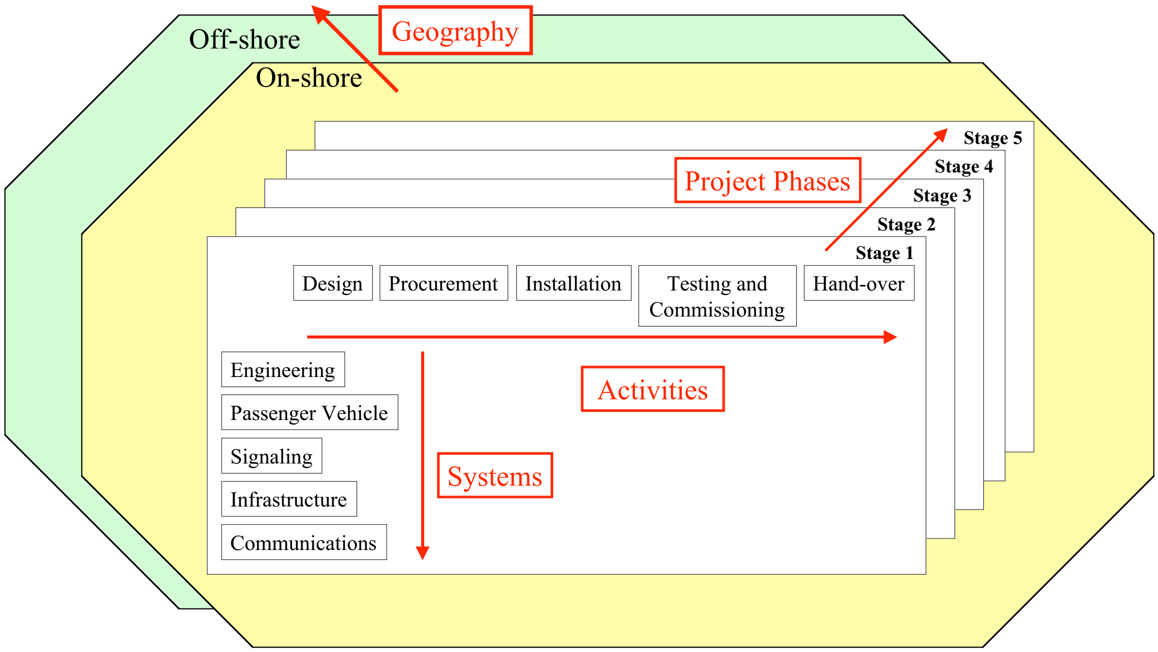

Figure 4.2: Complexity of the transportation project studied

It can be seen on Figure 4.2 that all possible interfaces are present: technical and organizational between the systems and the teams responsible for them, geographical between working site and temporal between successive activities and between the five construction stages of the MRT line.

After a short presentation of the project and its interfaces, this chapter will elaborate on how the WBS was developed and helped improve interface management.

4.1.2 System, subsystems and interfaces

As illustrated in Figure 4.3, the project involves a series of systems and actors that must be properly interfaced. This thesis will concentrate on the work of the team responsible for the system's **infrastructure**. However, as the strategy was deployed at the system level too in order to solve system-level interface issues, WBS implementation and corresponding interface management benefits will also be described.

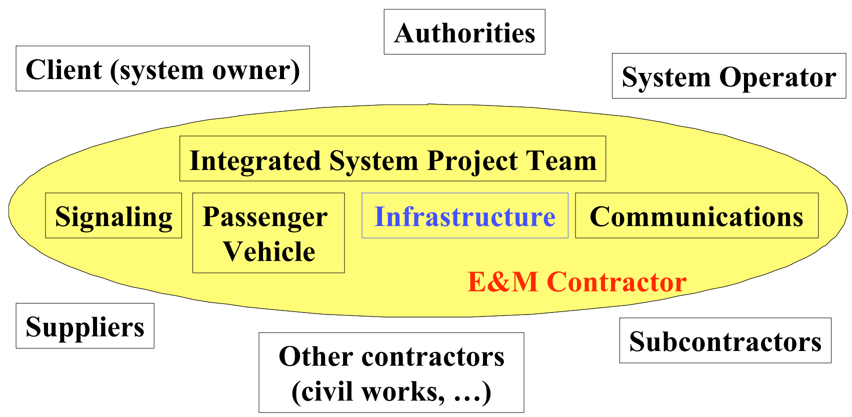

Figure 4.3: External Interfacing agents for the Infrastructure Subsystem

Table 4.1: External and internal interfaces in the MRT project

Type of interfaces	Internal	External
Organizational	**Between Subsystems :** 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 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 ans 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	

As illustrated in Table 4.1, the project involves a great number of interfaces, both internally and externally. They will be described here.

First, the scope of the contract covers several subsystems that must be properly interfaced and integrated with each other. This is called **internal interface** management and obviously has to be done under the contract. As illustrated in Figure 4., the project team is organized in what will be called technical “Subsystems”[10] in this thesis. There are five Subsystems. One of them is responsible for 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. It will be called “the Engineering subsystem” in this thesis. The four others are responsible for the design, construction, installation, testing and commissioning of the remaining equipments (see Table 4.1 for details). All these subsystems are under the overall responsibility of a project management team.

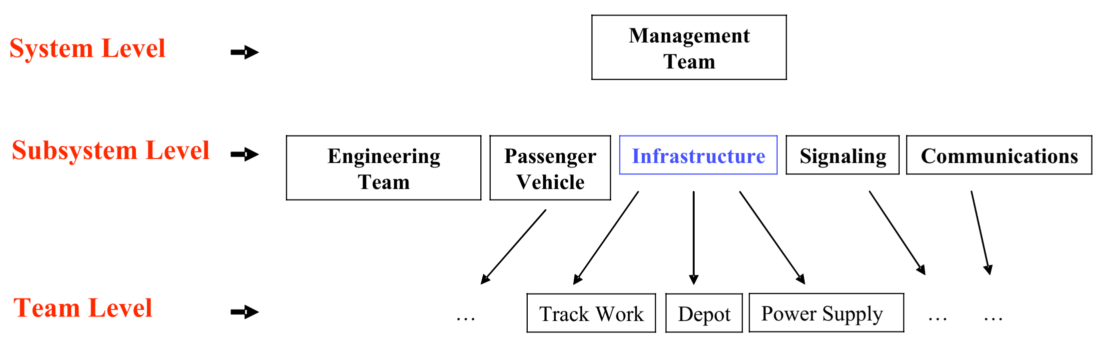

Figure 4.4: System and subsystem level in the MRT Project

At the subsystem level, many internal interfaces also have to be dealt with. Given the size of the project, even at the subsystem level it is still necessary to breakdown the work into several teams. For instance, in the infrastructure team, the track work and the power supply are not allocated to the same team (see Figure 4.). Many teams are thus formed and have to integrate their work and manage their **organizational interfaces** (between team members) and **technical interfaces** (between the components of the subsystem).

The main E&M Contractor is composed of companies of different nationalities, imposing further efforts in communication and work harmonization. Lastly, for the same reason, part of the staff works locally while the rest of it is located in a different country, thus complicating communication among project staff. Performing management tools are required to ensure that the project is properly managed in terms of quality, cost and schedule for a successful realization.

There are **time interfaces** as the contract includes all the phases of a typical construction project, and not only one of them. This includes design, procurement, installation and testing of very complex systems, and thus the smooth transfer of the project from one phase to another is critical for eventual success and on time completion. Furthermore, as the line is to be built in several stages, each of them must be managed simultaneously while they are at different phases of their life cycle.

Geographical interfaces arise from the necessity of having a team abroad, where the main company of the main E&M Contractor is based, and a team on site, where the project is implemented and more and more activities are carried out when the project advances into its schedule.

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[10] In this thesis, “subsystem” means the technical product on which a team called “Subsystem” (with capital S) is working.

In addition to the internal interface management, the main E&M Contractor is responsible for the proper integration of its own E&M system with the various E&M systems it does not supply and with the civil work, through the management of its **external interfaces.** The Electro-Mechanical systems (E&M) included in the project are indeed complemented by systems to be provided by other parties, and that need to be integrated to form a performing MRT system. In particular, civil works contractors will complete the depot, tunnels and underground stations and separate contractors will deal with tunnel ventilation and environmental control, station electrical services, fire protection, escalators and lifts, automated fare collection, signage and graphics, station control room and RATIS.

4.1.3 Interfaces at the system level in the MRT Project

Table 4.2: Description of internal interfaces on transversal activities

Activity	Description	Type of interface involved			
		Organizational	Technical	Geographical	Time
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 site areas and works trains	Installation of intricately related systems	Different installation procedures in different places, zones in Staging Area	Transition with Design and Testing phases, 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		Transition with Design and Hand-over phases, several stages of the line to be tested simultaneously
RMDT Validation	Tests and statistical analyzes 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		Transition with installation and testing phase
Warranty	Maintaining the installed system in good operating order.	Duration of warranty period depends on all systems' acceptance			Transition with installation and testing phases

At the system level, Subsystems are considered as responsible entities and have to work out their sub-components and team interfaces internally (see Figure 4.4). Thus, only Subsystem external interfaces are considered. These can involve the different Subsystems, as well as other contractors working on the project such as civil work contractors, electrical services contractors, etc. When activities involve such interfaces, they are considered as transversal. The following activities were identified as transversal: Design, Configuration Management, Installation, Site Safety, Testing and Commissioning, Reliability and Maintainability Demonstration Test Validation, and Warranty. All these activities involve Subsystem interfaces for the following reasons, summarized in Table 4.2.

Design is a very complex activity when related to such a system as a MRT line. It must in particular ensure that all possible issues related to installation are anticipated. The interfaces involved are mostly human and technical (with the coordination of Subsystems and suppliers to design a coherent product, the need to respect client's requirements, etc.) and geographical, as teams on site and abroad need to coordinate.

Configuration management corresponds to the recording and updating of document and product configuration in a computerized system at the different stages of the project, production of specific documents to record design changes, and configuration meetings held to solve potential issues. These activities involve technical and human interfaces for the management of common computerized systems and document change recording. Time interfaces also exist because of the necessity of this activity throughout the whole project, imposing that teams transmit from one to another the work done up to a transition.

Geographical interfaces arise from the fact that teams in different countries have to perform functions on the same computerized system, and therefore to coordinate.

Installation is one of the most complex activities of the project, corresponding to the installation of highly interconnected and intricate equipments on site. Human interfaces arise from the necessity of coordination for the use of site areas and of works trains by the various Subsystems in a restricted period of time. Works trains are vehicles used during installation to transport equipment all along the track, and have to be shared among Subsystems. This distribution is done through a weekly coordination meeting. Geographical interfaces appear because installation procedures are different in tunnels, in stations, in the depot track and in the depot buildings, requiring coordination of teams in these four places. Moreover, a staging area is set up for all Subsystems to manage their own works and store their equipment during the installation period. This staging area is divided into zones reserved for each Subsystem, and these zones must be properly managed even at interfaces.

Site safety is always delicate on construction projects. The main activities to be performed are related to safety management, with the recruitment of safety officers, safety process definition, safety training of all workers and safety coordination on site. Interfaces involved are, as for the installation phase, related to each Subsystem's responsibility on site. It has to be ensured that responsibilities are perfectly defined and acknowledged to prevent any accident from occurring because of insufficient coordination.

Testing and commissioning is one of the activities involving the most interfaces, as all subsystems must be internally consistent and match perfectly with one another to enable the overall system to function properly. This means that each subsystem has interfaces to be tested among its sub-components as well as with all other subsystems.

Reliability and Maintainability Demonstration Test (RMDT) validation is the activity taking place in the latest stages of the project, when the system is fully installed and it has to be proven, through a series of tests and statistical analyzes, that the objectives of reliability and maintainability defined by the contract are met by the final system handed over to the client. This activity is separated into RMDT procedures preparation, maintainability and reliability demonstration and RMDT corrective actions, corresponding to the investigations done in case of non-performance and necessary modifications to the system.

Interfaces are also quite delicate at this stage of the project, as the cause for a technical failure has to be identified and attributed to the right origin, and remedy necessitates coordination of the Subsystems involved. The identification of a design mistake by the RMDT team can also be referred to the design team for support, thus requiring coordination of several teams of the same Subsystem.

Warranty consists in maintaining the installed system in good operating order for a period defined contractually. The duration of the warranty period depends upon the rapidity of all Subsystems to complete and get acceptance on their system from the client, and this forms additional interfaces to manage.

4.1.4 Existing interface management tools

General interface management is done in accordance with a System Interface Management and Integration Plan covering all internal and external interfaces. This plan includes:

- the methodology to control and integrate cross-discipline interfaces activities;
- the processes and procedures to define the work-sharing and the responsibilities of each interface;
- the processes and procedures to control and manage interfaces, their identification, resolution and implementation, and;
- the procedures to control and manage the interface change process.

A table, in the shape of an organization DSM (see section 2.1.3.2), also lists and describes interfaces between subsystems.

More practically, combined services drawings for structural, electrical and mechanical systems give an integrated representation of all services provided under the project. The main E&M contractor is responsible for providing combined services drawings for the systems installed in the tunnel. This requires careful coordination of all Subsystems and contractors, so that no system hampers the installation or functioning of any other. Coordination of subsystems is ensured by Interface Coordinators.

At the subsystem level, technical interfaces are controlled through Subsystem Interface Control Documents (SICD) giving the exact description of the functional, performances, mechanical, electrical, and software aspects of each of them. These documents are updated regularly to reflect potential improvements of the definition level and achieve excellent coordination of teams at all phases of the project.

There are also very detailed procedures for the testing of subsystems' interfaces, as testing is a phase where interfaces are of utmost importance. These are called Subsystem Interface Test Procedures (SITP), and give details about the timing of the different Subsystems' intervention, the tasks to be performed, etc.

Thus, it can be seen that the company studied already had a detailed and complex system of interface management and control. The next section will show how the WBS matrix management package helped improve the complex process of interface management.

4.2 Building the WBS in the MRT Line Project

The company decided to implement and validate the Work Breakdown Structure (WBS) methodology on the MRT line project. In order to let Subsystems develop a tool that would be useful to them, it was decided that a Project WBS would be developed at the project level, and Subsystem WBSs would be developed at the subsystem level (for Engineering, Passenger Vehicle, Signaling, Infrastructure and Communications Subsystems, as described in section 4.1.2). Each work package of the Project WBS would then be associated to a work package of the relevant Subsystem to ensure that all the work is accounted for, while leaving to the Subsystems the responsibility of their internal organization. In line with this movement, the Infrastructure Subsystem decided to develop a fully integrated project management tool comprising not only the WBS matrix, but all the elements of the WBS matrix management package described in Figure 3.2.

Under the guidelines defined by the company head office methodology and auditing team and using the input provided by the Infrastructure Subsystem teams, the following objectives were defined for the case study:

- Elaborate a PBS and an ABS and cross them to form a WBS
- Derive the Work packages from the WBS
- Build the Work Package Sheets, including relevant quality, cost, and delay objectives
- Reconsolidate with the existing reporting tools (Project Reviews, Master Schedules, Progress Reports)
- Implement the overall process for a systematic integrated reporting, if necessary modifying existing tools
- Provide a critical analysis of the benefits/limits obtained from such a process in terms of organization, reporting enhancement, visibility enhancement for the management and decision making improvement, clarification of scope of work issues, resources planning, rationalization of management documents and possible ameliorations to the process/tool after the validation phase.

4.2.1 Product Breakdown Structure (PBS)

As noted by Stoehr (2001), a WBS is never made up from scratch. “Usually the project scope description already contains a list with project deliverables that have to be handed over to a client. This deliverables list has to be detailed”.

In the case studied, documents were already available to describe the system and the PBS was inspired from them. The entire PBS is displayed in Annex 1, and a less detailed version of it is in Figure 4.5.

	Infrastructure
03	POWER SUPPLY
031	HV POWER SUPPLY SYSTEM
032	DC TRACTION POWER SUPPLY SYSTEM (750 V)
036	AUXILIARY STATION POWER SUPPLY
037	OTHERS MISCELLANEOUS
06	DEPOT
062	MACHINES
07	TRACKWAY
071	BASEMENT EARTHWORK AND CONCRETE
0711	Concrete
0712	Walkway
0713	Cable troughs
0714	Drainage (clayware drain, grating, …)
0715	Embedded pipes
072	SPECIAL ITEMS
073	TRACKS
076	STRAY CURRENT MESH AND JUMPER BOX
077	CONDUCTOR RAIL
078	WILD
079	OTHERS MISCELLANEOUS
09	SITE WORKS LOGISTIC FACILITIES
091	TW HEAVY EQUIPMENT
092	TW LIGHT EQUIPMENT
093	TRIP HEAVY EQUIPMENT
094	STAGING AREA
095	OTHERS MISCELLANEOUS

Figure 4.5: Part of the PBS used on the MRT Line project for the infrastructure subsystem

The first level of the PBS at the system level includes the subsystems described in section 4.1.2. The Infrastructure Subsystem is in charge of three main elements: track work and site logistics facilities, functional engineering of depot facilities, and power supply, which form the second level of its own PBS. These elements can be broken down into components such as: "basement earth work and concrete", "tracks", "stray current mesh and jumper box", "conductor rail" and "wheel impact load detection" (WILD) for Track Work, that form the third level of the PBS. A further decomposition is displayed on the PBS (see Figure 4.5). It is possible to describe the system still a better level of detail, but it was decided that this would not be helpful but rather add useless complexity to the PBS. A more detailed PBS thus exists separately but is not displayed in the final WBS.

The PBS is coded. The second level of the PBS for the Infrastructure System has two numbers, imposed by the standard coding of systems in the company. Thus, Power Supply appears first on the PBS with the code 03, the Depot appears second with the code 06, the Track Work appears third with the code 07, and the Site Works Logistic Facilities appear fourth with the code 09. At the third and fourth levels, additional numbers are added to the code of each element. For instance, under Power Supply (03) it is possible to find High Voltage Power Supply (031) and under this item is located the 66-22kV Intake Transformer (0313).

4.2.2 Activity Breakdown Structure (ABS)

The ABS, contrarily to the PBS, can be applicable to all Subsystems and was defined at the system level with a fairly high level of details. In order to be able to use the WBS as a budget control tool, the first level of ABS follows the budget structure defined at the project level and includes: project management, design, industrialization, procurement, production, off-site testing, transport and delivery, installation, site test and commissioning, logistic support, warranty and defect liability period activities. This first description of project scope can be refined to lower levels of activities if smaller work packages are necessary.

As all Subsystems do not perform all activities, the second level of the WBS does not need to be common to all Subsystems. Thus, the Infrastructure Subsystem selected the activities most relevant to its duties.

Similar to the PBS, the ABS is coded with a letter and three numbers, the letter representing a general activity and the number going to a further level of detail.

The final ABS is as follows.

Project Management	General Project Management	M000
	Interface Management	M700
Design	Design	D000
	As Built	D700
	Safety management	S000
	RAM	R000
	EMC	E000
Industrialisation (Method statements/ T&C plans and procedures)		M500
External Sourcing	Procurement including spare parts and special tools	A000
	Developpement Testing	D600
	Factory Acceptance Tests	A600
Production		P000
Off-site Testing	SP	T330
	IFAT Group 1B	T340
	VTT testing	T350
Transport and delivery		L000
Installation	Site Heath & Safety	Y210
	Mock-up	Y400
	Equipment installation	Y100
	Operation and maintenance of temporary assets	Y500
Site Test and Commissioning	Site Tests	C310
	Integrated Test & Commissioning level 1	C320
	Integrated Test & Commissioning level 2	C330
	Tests Running	C350
	Trial Running	C380
Logistic support	Training	F000
	O&M Manuals/Asset registration	H100
Warranty & Defect liability Period	Warranty, Care of the works & Defect liability Period Activities	W000
	RMDT Validation	R200

Figure 4.6: ABS for the MRT Line project infrastructure system

4.2.3 Work Breakdown Structure (WBS)

Once the PBS and ABS are ready, they are crossed to form a matrix whose body will be used to make up the work packages. The entire WBSmatrix and the corresponding list of WP are given in Annex 2 ; the upper-left corner of the matrix is displayed in Figure 4.7.

The PBS is on the left vertical axis, and the ABS on the upper horizontal axis. Both display the level of detail required in the case studied, but can be extended or reduced according to the user’s needs in other cases.

Product includes Spare parts and Special tools		Project Management		Design					Industrialisation (Method statements/ T&C plans and procedures)
		General Project Management	Interface Management	Design	As Built	Safety management	RAM	EMC	
		M000	M700	D000	D700	S000	R000	E000	M500
	Infrastructure	0							
03	POWER SUPPLY	[illegible].M000	03000.M700	03000.D000	03000.D700	03000.S000	03000.R000	14	03000.M500
031	HV POWER SUPPLY SYSTEM	1	5	03100.D000		03100.S000	03100.R000		03100.M500
0311	22 kV Switch Board			03110.D000		03110.S000	03110.R000		03110.M500
0312	22 kV Cables including Supports and Accessories			03120.D000		03120.S000	03120.R000		03120.M500
0313	66/22kV Intake Transformer			03130.D000		03130.S000	03130.R000		03130.M500
032	DC TRACTION POWER SUPPLY SYSTEM (750 V)	03[illegible]00 2		03200.D000		03200.S000	03200.R000		03200.M500
0321	DC Switchboard			03210.D000		03210.S000	03210.R000		0[illegible] 16
0322	Load Breaking Switch			03220.D000		03220.S000	03220.R000		0[illegible]
0323	Inverter Group			03230.D000		03230.S000	03230.R000		03230.M500
0324	Stray Current Corrosion Control			03240.D000		03240.S000	03240.R000		03240.M500
0325	Transformer Rectifier Group			03250.D000		03250.S000	03250.R000		03250.M500
0326	Touch voltage protection			03260.D000		03260.S000	03260.R000		03260.M500
0327	Traction Safety Shutdown System			03270.D000		03270.S[illegible]	[illegible]0.R000		03270.M500
0328	Stray current and earthing cables			03[illegible]0 7		03280.S[illegible] 12	[illegible]0.R000		03280.M500
0329	DC Cables and accessories			03[illegible]0		03290.S000	03290.R000		03290.M500
032A	Bus Duct			032A0.D000		032A0.S000	032A0.R000		032A0.M500
036	AUXILIARY STATION POWER SUPPLY			03600.D000		03600.S000	03600.R000		03600.M500
0361	Cable trays			03610.D000		03610.S000	03610.R000		03610.M500
0362	Control cubicle			03620.D000		03620.S000	03620.R000		03620.M500
0363	Service transformer			03630.D000		03630.S000	03630.R000		03630.M500

Figure 4.7: Part of the WBS matrix for the MRT Line project infrastructure system

There are cells on the matrix that do not correspond to any activity. For example, there is no integrated factory acceptance test (IFAT) for the running rail, as IFAT concerns the testing of the interfaces between a software (the ISCS) and its interfacing equipment, and the running rail does not interface with the ISCS. All cells of the matrix that do not correspond to an activity are left blank. It is also possible that certain activities are only performed at a certain level. For instance, project management in itself is performed at the team level by a specific project manager for Power Supply, Track Work, etc. Consequently, the corresponding work package is only represented by one colored cell at the team level, and the lower cells are left blank.

All other cells, that represent an activity, are called Elementary Work Packages (EWPs) and are colored. EWPs are then regrouped into work packages, which are visualized by the common color given to all their EWPs, and giving them a common work package number that is displayed on the matrix.

The WBS matrix as presented is the result of a lot of discussions and thinking about the organization of the project. For instance, it can be seen that no Work Package (except n°1, "General Project Management"), pertains to several teams. For each activity, several Work Packages are used to cover the various technical parts of the Infrastructure Subsystem. This is to reflect that, although these are parts of the same Subsystem, they are managed independently, sometimes by different people or with different schedule objectives. Although some of them were grouped when the project started, the elaboration of the WBS lead to their separation in order to clarify the allocation of responsibilities.

4.2.4 Work Packages Sheets (WPS)

Once the decomposition of the work into work packages is done, a precise definition of each of them is needed. This is done on a Work Package Sheet. An example of the WPS format is shown in Figure 4.8.

<table>
<tr><td>PROJECT</td><td colspan="2">MRT Line</td><td>WP Code:</td><td>WP03200.M000</td></tr>
<tr><td>Title</td><td colspan="2">Power Simulation</td><td colspan="2">WP 2</td></tr>
<tr><td>Group</td><td colspan="2">Power Supply</td><td colspan="2" rowspan="3">Includes all below EWP as defined in EWP Matrix
03200 .M000</td></tr>
<tr><td>Issue</td><td colspan="2">A</td></tr>
<tr><td>Issue date</td><td colspan="2">31/01/03</td></tr>
<tr><td>Responsible</td><td colspan="4">XX</td></tr>
<tr><td colspan="5">Scope of work description</td></tr>
<tr><td colspan="5">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.</td></tr>
<tr><td colspan="5">Reference items (document, ...)</td></tr>
<tr><td colspan="2">Interfaces</td><td colspan="3">Description</td></tr>
<tr><td colspan="2">Data book (including Rolling Stock data), speed profile, operation manual</td><td colspan="3">Input from Engineering Subsystem</td></tr>
<tr><td colspan="2">Traction line diagram, LV consumptions</td><td colspan="3">Input from Power Supply Subsystem</td></tr>
<tr><td colspan="2">Delivery Objectives (as for PS design)</td><td>Preliminary</td><td>pre-final</td><td>Final</td></tr>
<tr><td rowspan="5">Duration</td><td>Stage 1</td><td rowspan="3">02/10/01</td><td rowspan="3">30/01/02</td><td rowspan="3">02/07/02</td></tr>
<tr><td>Stage 2</td></tr>
<tr><td>Stage 3</td></tr>
<tr><td>Stage 4</td><td colspan="3" rowspan="2">To be defined</td></tr>
<tr><td>Stage 5</td></tr>
<tr><td colspan="5">Cost Objectives
Budget Cost (man hours):
Budget Cost (KEuro):</td></tr>
<tr><td colspan="2">Deliverables</td><td colspan="3">Description</td></tr>
<tr><td colspan="2">Power Simulations</td><td colspan="3">Traction Power Supply Simulations.
D.C. Traction Short-Circuit Calculations.</td></tr>
<tr><td>Frequency of reporting</td><td>Monthly</td><td colspan="3"></td></tr>
<tr><td>Scope Change Record</td><td>Issue</td><td colspan="3">Modifications</td></tr>
<tr><td></td><td></td><td colspan="3">a</td></tr>
<tr><td colspan="5">Associated means (resource, equipment & materials)
Power simulation software (ELBAS)</td></tr>
<tr><td colspan="5">Comments</td></tr>
<tr><td>Work Package Manager</td><td colspan="2">XX</td><td>Approved by</td><td>ZZ</td></tr>
<tr><td>Signature</td><td colspan="2"></td><td>Signature</td><td>Subsystem Manager</td></tr>
<tr><td>Sub-Subsystem Manager</td><td colspan="2">YY</td><td>Approved by</td><td>TT</td></tr>
<tr><td>Signature</td><td colspan="2"></td><td>Signature</td><td>Asian Area Manager</td></tr>
</table>

Figure 4.8: Typical Work Package Sheet adopted in the company

Administrative, financial and WBS management data are displayed in a similar format for all work packages. In addition, the most important sections for interface management are the following.

First, the scope of work to be performed under the WP and the corresponding list and description of the deliverables to be produced are described, thus clarifying all WP managers' objectives and increasing visibility on project requirements and responsibilities.

A list of the interfaces involved in the work package focuses the attention of the WP manager on interfaces. 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 thus clarifies the flow of documents or information through the different teams.

Lastly, time interfaces are described in terms of delivery objectives for each of the main tasks involved and for each of the project stage. These are in the form of milestones. Forty-six work packages were thus described in the corresponding work package sheets.

4.2.5 The reporting package

As described in section 3.3.2, the project reporting is based on three elements: the Work Package Report, the Budget Sheet and the Schedule Sheet.

- **The Work Package Report**

Work Package reports serve the purpose of regularly informing project members on the status of a work package. As Warner (1997) explains, "reports from the WBS must be easy to produce without requiring complicated computer programs or manual collection of data. Designers of the WBS must ensure that both the WBS and the reports generated from it clearly convey what is required, what work has been done toward it and what is expected by the user of the report”. This is what was done in the case of the company studied here. The following format was adopted (see Figure 4.9).

PROJECT	MRT Line	WP number	0	Responsible	ZZ
Subsystem	Infrastructure	Title	Infastructure Subsystem Project Management	Issue date	31/01/03

Activities terminated since last report

WBS structure and WPS scope, dates, inputs/outputs : validated by WPS leaders
PR3 held on 6th Jan 03
PGR hold on 29th Jan 03
Submission of Stage-4-5 VO proposal
Submission of price for 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

Issue with Interfaces

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 (Please also refer to the time impact analysis done by the planning team)

Schedule item concerned	Description of issue	Action Proposed
Civil Work delay Stage 1	Announcement by Client of potentail 6 mths 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 accept

Issue with resources

Resources concerned	Description of issue	Action Proposed
RAMS	Secure RAMS engineer to adress RAMS issues after FD until RMDT	Investigate for available resource in department

New potential individual risk

New potential mutual risk

Wheel / Rail interface

New potential variations

Third rail gaps at escape shafts

Figure 4.9: Work Package Report format

The first part summarizes administrative information on the work package such as the project and Subsystem codes, the work package number, title and responsible, as well as the issue date.

The second part is used for the reporting on achievements since the preceding report, and on on-going activities.

The third part is used for the reporting on issues encountered in relation with interfaces, schedule, budget, deliverables and resources. In each of these categories, two columns are dedicated to the naming and description of the issue, and the third one to a proposal for remedial action.

The fourth part is related to reporting on new potential individual and mutual risks and variations.

Lastly, two sections are dedicated to communication between the WP manager and the Subsystem or sub-Subsystem manager. Comments can be added by both parties in order to exchange views on the work package report content. These sections were added in order to reduce the risk of having reports done but not read or for which no real solution is found to the problems mentioned. In particular, if WP managers would like their work package or the WBS to be modified, they can propose their changes in these sections. This makes the WBS a living document, updated whenever project implementation makes it necessary.

Thus, the Work Package Report is a very simple format that is used for regular qualitative reporting on all issues encountered, as well as for general comments on the progress of the work package. It is the basis for communication between the WP manager and his/her management.

It was decided to organize monthly meetings to discuss on the Work Package Reports, instead of asking staff to report to their direct superior. This has the advantage of reducing the time necessary for the information to go up the hierarchy, and of facilitating communication and awareness on the team's potential issues. As argued by Bernardes and Formoso (2002), meeting provide a means for participants to be "clearly informed about what has to be done and the sources of problems that should be tackled so that the execution of goals is not compromised", and thus favor the application of lean construction principles. Although weekly meetings would have provided more information and are said to be necessary in the literature (see Ballard, 2000), the company launched the work package reporting procedure on a monthly basis first, to let its staff accustom themselves with it. Existing weekly meetings may be adapted to the WP report structure at a later stage.

- **The Work Package Schedule Sheets**

Work Package schedule sheets were defined for the most important work packages, for which a whole set of dates was defined and had to be managed and monitored. The program used for scheduling allows predefined filters to select only the activities relevant to one work package, and to form a simple document with them. A typical WP schedule sheet is shown in Figure 4.10.

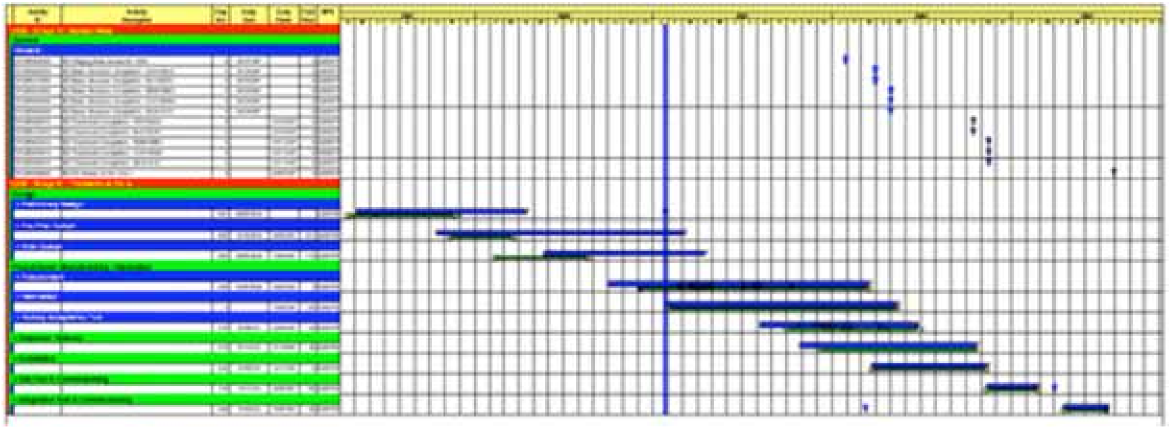

Figure 4.10: Work Package Schedule Sheet used in the case study

The interest of this sheet is that it not only shows the planning and milestones for activities, but also physical progress on each of them. This allows the project team to have an idea of the work package advancement and possible delays.

These sheets must be updated regularly, as is done for the general schedule used at the project level. Thus, WP managers always have an updated version of the documents when they have to complete their WP report, and more generally whenever they need to monitor project progress.

- **The Work Package Budget Sheets**

Work Package Budget Sheets were prepared for all work packages, following the format shown in Figure 4.11.

WP XX	Sit 0	Sit. N-1 (Do not modify monthly)						Sit at Month m							
FORECAST EXPENSES Currency Month m	Budget	Recorded Costs	Qty (man.month or material qty)	Rate (salary or unit price)	Contingencies	Forecast	Situation N-1	Recorded Costs	Qty (man.month or material qty)	Rate (salary or unit price)	Contingencies	Forecast	Situation Month m	Situation variance	Comments (Variance Analysis)
	a	b	c	d	e	f=cxd+e	g=f+b	h	i	j	k	l=ixj+k	m=l+h	n=m-g	
EXPENSES X Y Z															

Figure 4.11: Budget Sheet Format

In order to allow for complete financial monitoring, several groups of columns are defined. The first one, named "situation 0" corresponds to the budget as it was defined during the tender phase. The second one, named "situation N-1", corresponds to the budget as it was defined during the preceding Project Review, which happens every six month. The third one, named "situation Month M", corresponds to the budget as it is at the time of reporting. In each group of column, there are sections related to recorded costs, manpower time amount or quantities of materials forecasted, salaries or unit prices, contingencies and budget forecast. Separate sheets of the same format aggregate the data of work packages at required levels: there is one for the aggregation at the subcomponent level (data for Track Work, Depot or Power Supply, see Figure 4.4), and one for aggregation at the subsystem level (data for the whole infrastructure subsystem).

In relation to this new budget control tool, accounting had to be reorganized to be adapted to the work package structure. The existing cost categories had to be refined so that each work package has its own cost account and can be independently monitored. Thus, as recommended by Lewis (2001), charges against the project and labor costs are recorded following the same structure to enable easy comparison between performance and estimates.

4.3 Using the WBS to improve interface management

As highlighted in Chapter 1, in order to gather data on how the implementation of the WBS methodology helped improve interface management, data was collected using interviews, internal reports and working documents, minutes of meetings, personal observation, and informal conversations. The results related to the case study are presented here, and a summary framework will be provided in 4.4. Results are sought in reference to the interface management strategies presented in section 2.1.2.2. Consequently, it will be presented here how the WBS methodology improved interface definition and visibility, facilitated communication and project control, and helped detecting and responding to interface issues during its implementation on the MRT line project.

4.3.1 Improving interface definition

First of all, the WBS allowed the team to clarify the exact scope of activities, their precise allocation to the various sub-teams and the requirements associated to them, thus improving visibility in the project. This corresponds to the interface definition strategy described in section 2.1.2.2.

When building the **Product Breakdown Structure**, the team had to gather data from several people to be able to make sure the whole system was covered and properly described. Although the scope and breakdown of the system to be constructed had already been defined and structured at the time of contract award, building the WBS provided and opportunity to re-consolidate available information and to create an optimized description of the final output of the project. For instance, some names used during the tender phase were outdated at the time of WBS creation, some parts of the subsystem had been replaced by others, more complete lists of the equipment to be used during construction were available, etc. The process of PBS creation thus allowed the team to obtain enhanced visibility on the final product to be produced and to make sure there were no gaps of scope between subsystems. This is particularly true of installation equipment and site works logistics facilities, for which it was necessary to gather data from different sources and organize them clearly to facilitate management of corresponding activities.

The task of building the **Activity Breakdown Structure** similarly increased the preciseness of the Subsystem scope in the work description. The task of building the Activity Breakdown Structure was simplified by the existence of a list of transportation project activities at the company level, and from which the team simply had to choose the activities that were relevant to the Subsystem and to the particular project. However, even that was an opportunity to add preciseness to the Subsystem scope of work description. For instance, the team in charge realized the importance of support activities such as cost control or interface management, that, although less central than design or installation activities, had to be mapped in the Subsystem's scope of work. Similarly, activities that the team did not readily think of, like the operation and maintenance of temporary assets only used during the installation phase, still required proper definition, budget and responsibility assignment. Thus, the traditional list of project activities (design, procurement, construction, hand-over) was completed and refined through this process of analyzing and censing the current activities of all the staff and identifying the ones to be expected in the future.

Finally, during the definition of **work packages**, the WBS allowed the team to add clarity to the allocation of responsibilities. Indeed, the complexity of the MRT system is such that it is very difficult for the management to clearly distinguish the scope of all activities from the project beginning and to distribute their responsibility to staff accordingly. When the WBS was put in place, various technical teams already existed and an interface management process had been set up to facilitate technical coordination of interfacing subsystems, as highlighted in paragraph 4.1.4. However, dividing the project scope into elementary items, grouping them into work packages and matching them with existing teams allowed, in some specific cases, to detect “gray areas”, areas under no defined responsibility, and to allocate them to the relevant teams.

For instance, two of the main project activities, called A and B here and corresponding to very different stages in the project timeframe, had been very precisely allocated to some teams. However, a third activity, called C here, had not been so. The reason is that it was to be performed at the same time as activity A, but functionally closer to activity B. As a result, the Project Manager thought this activity should be attributed to the person in charge of activity A, who would be mobilized at the right time, while this very person thought it was more natural for it to be attributed to the responsible of activity B, who was more capable of handling it. As a result, activity C was under no precise responsibility. When the corresponding work package sheet was presented to the manager of activity A for acknowledgement, he mentioned the issue, expressed his point of view, and the problem was solved. Had the WBS methodology not been implemented, it could have dragged on for a longer time and hampered project progress.

Similarly, the simple fact of having work packages dedicated to activities scheduled to take place much later in the project timeframe made the team realize that their responsibility had not been clearly allocated, which could have delayed their preparation if the WBS had not been used.

4.3.2 Visibility on systems, activities and responsibilities

The WBS methodology also participated in improving visibility on work requirements, objective definition, and flows of actions and information throughout the project.

First, extensively defining each **work package** to be performed under the project provided an opportunity to clarify everybody's objectives, responsibilities and requirements. The work package sheets (WPSs, see Figure 4.8), through a simple clarification of the scope of work involved, assigned clear objectives to each of the team members. By displaying the origin of necessary inputs in the interface category, and a list of outputs in the deliverable category, they clearly showed the whole project team the sequence of events and the flows of actions and interactions that make the project progress. For instance, operations manuals for equipment bought from suppliers have to be first obtained from them, then partially reformulated and finally resent to the client as a project document. Identifying inputs for all work packages allowed the team to allocate responsibilities carefully, with the "Procurement" work package in charge of obtaining the operating manuals from suppliers and transmitting them to the "Training and Operations Manuals" work package, and this latter improving them and submitting them to the client. Writing the WPSs thus helped clarify responsibilities and the flow of documents and information in the project. This is the central idea of the Lean Construction philosophy and the WBS provided an opportunity to address it directly.

Second, the **monthly work package report** gave the Subsystem team members an opportunity to describe, on a regular basis, which activities were or had been carried out on the work package and what issues the team was facing at the moment. This allowed all project members to be aware of the progress of other teams, and of the issues they had been encountering, thus increasing transparency on activities and the way they should be managed.

The definition of the WBS thus enabled the Infrastructure Subsystem to bring visibility onto the project, be it in terms of product scope, activities, information flows or responsibilities. This is, as explained above, an essential step of interface management. It allows the team to agree on a common framework of project and objective definition, which is the basis of interface management. It delineates technical interfaces by listing the components of the system without forgetting any, time interfaces by defining the phases of the project and corresponding activities, and organizational interfaces by clearly enunciating responsibilities.

4.3.3 Facilitating communication on interface issues at the system level

During its implementation phase, the WBS matrix proved a very supportive tool for communicating on interfaces at the system level, thus anticipating potential issues. The following methodology was developed to manage interfaces for the whole project.

At the system level, an overall WBS was set up and detailed for each of the transversal activities defined above, except Design: Configuration Management, Installation, Site Safety, Testing and Commissioning, Reliability and Maintainability Demonstration Test Validation and Warranty. Figure 4.12 shows the System WBS for the warranty activity as an example. The System WBS for Design was not developed as the activity was almost over when the WBS process was launched. System matrices have a similar structure as the ones used at the subsystems level, showing a PBS on the vertical axis and an ABS on the horizontal axis. However, the cells of the matrices are not regrouped into work packages as in the subsystem case. They simply display the name or number of the Subsystem responsible for the corresponding crossed product-activity job, thus enabling, from a simple look at the matrix, to know under what responsibility is each activity.

		WARRANTY			
		Care of the Works	Warranty	Defect liability period	Extended Warranty
		V100	V200	V300	V400
00	System				
01	Passenger vehicle	PV Subsystem	PV Subsystem	PV Subsystem	PV Subsystem
02	Signalling & Controlling	Signaling Subsystem	Signaling Subsystem	Signaling Subsystem	Signaling Subsystem
03	Power supply	Power Supply Team	Power Supply Team	Power Supply Team	Power Supply Team
	031 HV POWER SUPPLY SYSTEM				
	032 DC TRACTION POWER SUPPLY SYSTEM (750V)				
	033 N/A				
	034 N/A				
	035 N/A				
	036 AUXILIARY STATION POWER SUPPLY				
	037 OTHERS MISCELLANEOUS				
04	Communications	Communications Subsystem	Communications Subsystem	Communications Subsystem	Communications Subsystem
05	Public area & facilities				
06	Logistic support				
07	TRACKWAY	Trackwork Team	Trackwork Team	Trackwork Team	
	071 BASEMENT EARTHWORK AND CONCRETE				
	072 Special structures				
	073 TRACKS				
	074 N/A				
	075 N/A				
	076 STRAY CURRENT MESH AND JUMPER BOX				
	077 CONDUCTOR RAIL				
	078 WILD				
	079 OTHERS MISCELLANEOUS				
08	Civil works				
09	SITE WORKS LOGISTIC FACILITIES				
0A	Miscellaneous				

Figure 4.12: System level WBS for the Warranty Activity

The System matrices' PBS and ABS do not show the same level of detail as in the subsystem case. Subsystems' PBSs usually go to the fourth level in order to specify the precise scope of each work package, as shown in Figure 4.4. The System PBS only goes to the second or third level, as shown in Figure 4.12, for only external Subsystem interfaces are considered to matter at this level of decision and management.

On the other hand, the System ABS is more detailed. Indeed, the matrix' overall objective is to clarify scope of work issues on transversal activities, where coordination is essential, and to make sure all activities are covered. For each cell of the System WBS where it is identified, each Subsystem has to acknowledge its responsibility. Having too few cells in the matrix would mean that is it difficult for a Subsystem to acknowledge some responsibilities but not all of them. On the contrary, Subsystems need to enhance their visibility of the project scope and this can only be attained through the production of complete but compact single documents, easy to use on a day-to-day basis for management tasks. As a result, Subsystem WBS have a less detailed ABS, maintain a single matrix, and report all necessary details in the work package sheets.

To clarify responsibilities on the project, the following procedure was put in place. Once a transversal activity System WBS matrix is prepared, it is sent to Subsystems who are asked to acknowledge their responsibility for the activities they have been attributed in the project WBS. To each cell of the System WBS Matrix containing a Subsystem number is associated a comment explaining the exact responsibility of the Subsystem. On a separate sheet, these comments are displayed on a single column and Subsystems are supposed to acknowledge or refuse their responsibility simply by writing their answer in front of the task. Following the previous example, the acknowledgement sheet for the warranty activity is displayed in Figure 4.13. Columns are reserved to display the product and subsystem concerned by the activity, and their codes in the PBS and ABS. The central column describes the expectations of high-level project management regarding the activity. The two remaining columns are left for the Subsystem to acknowledge its responsibility or to reject it by answering YES or NO, and to specify in which work package it will be included in the case of a positive answer.

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		

Figure 4.13: Acknowledgement Sheet for Subsystems' duties used in the case study for the Warranty phase.

If the Subsystems do recognize their responsibility, they simply indicate the number of their own work package that includes or is to include the activities identified. For example, one activity of the testing phase is: "PLC delivery on IFAT", meaning that the Programmable Logic Controller (a piece of the Power Supply System) has to be delivered on a specific site for Integrated Factory Acceptance Testing. As the Infrastructure Subsystem, who is responsible for the Power Supply System, acknowledges this responsibility and has included it in its own work package "IFAT for Power Supply system", number 23, the information "Yes" and "23" are simply recorded in the corresponding cells. Another example, related to the warranty activity, is displayed in Figure 4.1313.

This system of correspondence between the System and Subsystems matrices enables the high management of the project to make sure that all Subsystems are aware of their duties, and that all activities are covered. Obviously, it is also a tool for detecting when it is not the case, which means that an interface between two Subsystems is in the case of partial mismatch, as explained earlier on (Healy, 1997). Indeed, although it does not represent the majority of cases, Subsystems sometimes did not readily accept to perform all the activities higher level management expected them to acknowledge, for different reasons. For instance, there are activities whose importance or necessity was recognized by everybody, but that all Subsystems expected to be performed by others. As a result, the teams had not planned the corresponding budget, staff and resources to perform them. When this happens, these activities without responsible party form what is called a "gray area" showing that insufficient definition of Subsystem interfaces has caused an activity to be in danger of not being carried out, and that the issue has to be addressed. For each transversal activity, the System WBS enabled the detection of gray areas that will be described hereafter. The WBS methodology, through this process, improved communication on interface issues and facilitated their resolution.

Regarding the **installation phase**, the coordination of technical teams on site was the most delicate issue detected. Installation of equipment requires special trains called TRIP (Track Related Installation Program) trains. It was found that the technical responsibility for TRIP trains at a certain phase of the installation and in a certain area could be defined more precisely. One of the Subsystems was responsible for the coordination of the use of TRIP trains but did not plan to perform that task in a certain area of the project, as it did not expect TRIP trains to be used there. Similarly, it had to be clarified that TRIP trains safety should be distinguished from general site safety and the responsibility for corresponding activities allocated accordingly. Lastly, the WBS methodology allowed the project team to point out to the fact that the transition between civil works and E&M

system installation should be carefully managed. Thus, the simple exercise of defining major tasks for the main phases of the installation and attributing responsible parties to them helped detect that some gray areas existed and encouraged discussion on possible solutions.

Regarding **RMDT validation and configuration management**, discussions arose about the organization and ownership of some databases to be set up. The WBS methodology allowed the project manager to realize that they were not clearly defined.

Regarding the **testing and commissioning** phase, the most important issue involved all the Subsystems. For each interface between any two technical subsystems, a series of tests has to be done to ensure that they are compatible. These tests therefore require the participation of both Subsystems involved in each interface, as illustrated in Figure 4.14.

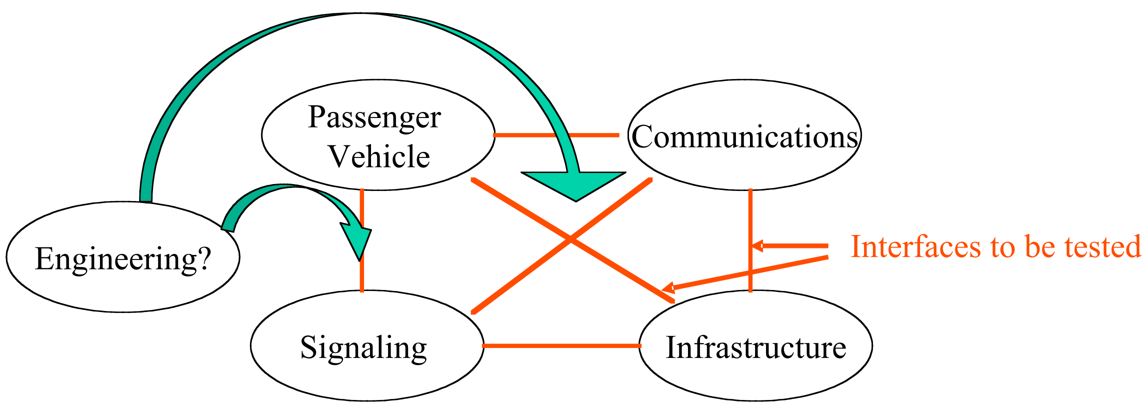

Figure 4.14: Testing interfaces between subsystems: who should do what?

The procedures for these tests involve several technical subsystems. Therefore, their elaboration requires close coordination between the Engineering Subsystem and the technical Subsystems, who have different skills and responsibilities: the Engineering Subsystem is responsible for the management of all technical interfaces for the system and therefore has a key role to play in the elaboration of interface test procedures; the other

Subsystems have the technical skills needed to specify details of the procedures and are responsible for the tests on site. The interface between the various Subsystems thus is very complicated. The WBS exercise allowed all Subsystems to realize it could be more clearly defined; this was done immediately and avoided the adverse repercussions on the overall test schedule that could have been experienced otherwise.

As can be seen from the above examples, gray areas are activities that are known to be necessary, but that all managers think are going to be performed by another party. The exercise of attributing responsibilities to activities, although obvious most of the time, regularly points out to interface where responsibilities are not clear. Thus, the teams conduct their meetings and discussions using the rigorous WBS framework to detect interface issues. It favors communication and provides a common technical basis for negotiation and the search for acceptable solutions. Indeed, having detected these gray areas, all parties must reach agreement on the one that will finally take the responsibility for it.

The importance of the WBS in this process comes from the fact that it identifies delicate issues early and is a means to confirm to all Subsystems what is expected from them. Without the effort made, through the use of the WBS, to identify and solve these gray areas, all these interface issues would have been discovered much later, possibly too late. The WBS is also a means to confirm to all Subsystems what is expected from them through a detailed list of the activities that they have to carry out. It thus forms an essential communication tool for the project team.

4.3.4 Enabling integrated project and interface control

The WBS was also used to integrate project control with interface control, thus easing interface management.

The first support for this component of the WBS strategy is the coordinated use of the Work Package Sheet as a tool for daily management and of the Work Package report as a tool for regular reporting (see Figure 3.2). Concentrating technical, schedule and budget objectives in single documents for monitoring and reporting on progress enables managers at all levels to have a clearer idea of what they have to achieve and how fast they should progress. By gathering the reporting on schedule, budget and interfaces, the WP report allows issues related to these subjects to be considered, mentioned to management and resolved simultaneously. The Work Package becomes the single level at which all kinds of reporting are made. For instance, one of the first work package reports to be issued related the design submission slippage for a subsystem to the organizational interface issues that were leading to this situation, thus allowing full understanding of that work package situation. Interface issues become part of daily project management and are addressed simultaneously with other problems. This provides a sound basis for interface management.

Secondly, by ensuring that all aspects of all work packages are regularly reported on, the WBS matrix package avoids situations where only the most critical activities are monitored and the others not paid sufficient attention, where budget is only monitored for the costliest activities, etc. This ensures resources are adequately distributed across interfaces. Integrated project control is indeed a way to resolve conflicting needs for resources, personnel, and facilities, and thus participates in reducing organizational interface issues (Stuckenbruck, 1983). For instance, when budget sheets were prepared, many activities only had an overall budget with no detail and no specific monitoring. Launching cost control with the WBS started to focus attention on their management, thus putting an end to the disequilibrium between activities. Another benefit of controlling cost and time issues is the reduction of external organizational interface issues, for instance with a client (Healy, 1997), as the information circulated is more reliable.

Third, the schedule sheet mentioned in Figure 3.2 clearly displays milestones related to interfaces, thus facilitating interface management and project monitoring and control at the operational level. At the same time, it also provides the work package manager with the schedule and milestones related to his/her work package only, and allows him/her not to refer to a much more complex project-wide schedule. Thus, improving interface management processes gives an opportunity to optimize project management efficiency through the simplification of existing tools.

The use of the WBS matrix package is not only related to useful in relation with interface control, but also with more general project management practice which, as argued by Stuckenbruck (1983), is an obvious condition of the integration process. The improved time and cost control for instance, even when not addressing interfaces directly, do contribute to a well-organized, planned and monitored project where interfaces are easier to manage. For instance, the use of common data formats and protocols has great integrative effect, as it reduces errors due to the re-interpretation of data (Fisher et al., 1998). The WBS methodology thus improved project management by encouraging standardized project reporting across the team. Before its implementation, there were many different formats available for financial reporting, prepared on a case by case basis when needed. As a result, the information available on different activities was not the same, comparing files was difficult and reading through them always required a re-adaptation effort. When budget sheets were prepared, they enabled the standardization of the format of budget reporting, thus facilitating reading, comparison and aggregation of figures. Similarly, the WP report was a means to standardize reporting on qualitative issues encountered by all teams of the Subsystem. As reported by Bernardes and Formoso (2002), the standardization of managerial processes supports lean construction principles by reducing variability of activities and by establishing parameters to improve continuously. The WBS methodology thus participates yet another way in the application of the lean construction theory. All in all, by encouraging good management practice, it reduces imbalances between activities and facilitates the management of organizational interfaces.

Thus, the WBS matrix management package provided a framework for integrated and standardized interface and project control, improving project visibility and paving the way for better interface management. The improvement of interface management processes led to an optimization of project control tools and vice versa.

4.3.5 Facilitating response to interface issues

Finally, the WP reports provided a means to detect and respond to interface issues during the project, by allowing WP managers to mention their interface problems and propose action to solve them, and then to discuss them with higher management. The following interface issues were detected in the WP reports.

The first type of interfaces most readily mentioned was **technical**. Although existing documents such as the Subsystem Interface Control Documents (SICD) do serve the purpose of monitoring the state of interfaces, they could be adequately complemented by the WP reports, which provided a monthly update on their current state and possible actions required, so that they could be regularly updated if necessary.

Organizational interfaces also aroused some issues. Some were related to the client. For instance, the comments on design documents submitted for approval can affect the design schedule, and one of the WP reports recommended that video-conferences be organized regularly to improve understanding between the Infrastructure Subsystem and the client. Another organizational interface that arose some issues was the one related to suppliers; one work package report thus suggested that monthly call conferences be organized so that suppliers' progress could be more carefully monitored. Other interfaces are more delicate to manage, for instance when the company acts as an intermediary between its suppliers and its clients to have suppliers be accepted by the client. This involves two interfaces to manage at the same time. Still other organizational issues detected in the case study thanks to the WBS are related to other contractors whose input is missing, thus delaying internal activities. This happened for the design of installation drawings, for which Civil Works contractors input was necessary. Lastly, there are interfaces issues with other Subsystems inside the project team. For instance, all systems' installation drawings have to be checked by a coordination team to ensure that the final system will be properly interfaced and that one system is not disturbing the activity of another. This coordination activity is an important internal organizational interface and can sometimes affect Subsystem internal activities and schedule targets.

Time interfaces are also very important to monitor, as they represent contractual obligations for the company. WP reports enabled the detection of activities where available float was becoming critical, thus indicating that action had to be taken. Others mentioned how to manage the transition from design to manufacturing, recommending that some elements of a system component be manufactured even while others' design was being accepted by the client, thus ensuring that time was not optimally used.

Geographical interfaces were also sometimes mentioned as problematic. For instance, when a working site is affected by a disease, thus preventing visits from overseas, other working sites must adapt to this new situation and solutions for the best communication possible have to be found.

Thus, the implementation of WP reporting provided information on a whole set of interfaces and focus the attention of managers on their resolution.

4.3.6 Implementation issues when introducing a WBS

4.3.6.1 Timing

The main problem encountered during the implementation of the WBS on the MRT Line project was related to the timing of its introduction.

Many authors insist on the necessity to prepare the WBS at the earliest stages of the project (e.g Albert, 1995 and Colenso, 2000). Unfortunately, although a PBS was done early in the project life, the full WBS was only implemented for the case study when all the teams were already at the Design phase of the first stage. This implies that all staff already had their working habits in terms of reporting, budget and schedule management. What were then the problems encountered?

First, the budget structure was already set up, but not exactly according to the work breakdown structure developed later. It had comparatively few categories of expenses, and detailed monitoring of the project was difficult. The number of categories of expenses jumped from 12 to 46, thus greatly improving the controlling capacity of managers and giving them more visibility on the project finances and the way they could be improved. However, the change was opposed with arguments such as the difficulty to manage such a complicated decomposition of the budget, the problem of contract already signed that it was complicated to assign to new categories, etc. These issues could have been avoided had the WBS been set up earlier than the budget structure.

Second, as in most organizations, there was some resistance to change regarding this new tool for monitoring and reporting. The WBS could improve control standards and visibility on budgets and schedules, but this was not obvious to all and using the new tool was sometimes considered too burdensome in comparison with potential benefits. This could have been avoided if the WBS had been implemented at the very beginning of the project.

Thus, the timing of WBS implementation is of much importance, both in terms of its technical feasibility and human acceptance. Developing a WBS should be done even before the project starts, so that a sound basis can be found to integrate schedule, budget and technical data without having to redesign any of the systems already put in place. It could be opposed that developing the WBS when the project was more advanced made it more specific, with more knowledge of the delicate interactions between all the activities, etc. However, it must be kept in mind that the WBS is and must be a flexible tool. Implementing the WBS before the project starts does not mean that nothing can be changed thereafter. A WBS keeps evolving all along the project to reflect its possible changes of scope and the increase of knowledge about technical and human interfaces between work packages.

4.3.6.2 Involvement of different parties

As any important change in the way to manage teams and projects, the development and implementation of a WBS in a company that is not used to it require all stakeholders to be involved in the project and motivated by it. As highlighted by Devaux (1999), "the WBS is far too important to trust to the efforts of one individual". In the case study, participation from lower-level managers could have been more successful. The process was launched from the top, by high-level managers who were convinced of the good the WBS could bring to project management, but communication about its benefits could have drawn more motivation and commitment from lower-level staff. As Warner (1997) notices, "standard WBS definitions only generally explain the WBS. Although these definitions encourage project teams to use a WBS, many team members lack specifics of how a WBS helps achieve project goals." This certainly was the main issue when trying to get people to use the WBS. However, the problem was progressively solved and people eventually increased their participation.

What can be done to solve this problem in future projects? Richman (2002) and Verzuh (1999) recommend that the entire project team be involved in the development of the WBS. This should start with a launch meeting where the purpose of the WBS is explained, the program of implementation presented and discussed, and staff are assigned a specific role in WBS development. Such a process would avoid situations of the WBS development team having to explain to each work package manager what the WBS is about and what his/her role is expected to be. Secondly, at each step of WBS definition, at least the team managers should be involved earlier. The PBS and ABS require their participation to avoid wasting time. 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 work package definition, work package managers need to be involved earlier too, so that they understand what is at stake and how the WBS can benefit them. There should also be a meeting at the time of Work Package Reporting launch, so that all work package managers start working on their reports simultaneously.

This being said, it should be added that little literature is available about the practical way the WBS must be used for day-to-day management. Adequate strategy and tools had to be developed all along the project, thus making it difficult to raise interest about the WBS at its earliest stages of development. The WBS could now be expected to be easier to launch, as the appropriate tools are now ready to use and can be presented to people to raise their interest even before the WBS matrix is done. Moreover, having high-level management at the core of the WBS implementation permitted to have a clear, strategic view of the subsystem decomposition and functioning, and was therefore a positive element of the case study. Finally, the commitment of a company to the implementation of a new tool at all its levels is a risk and it was expected that the process would take time.

4.4 Summary on Research Findings

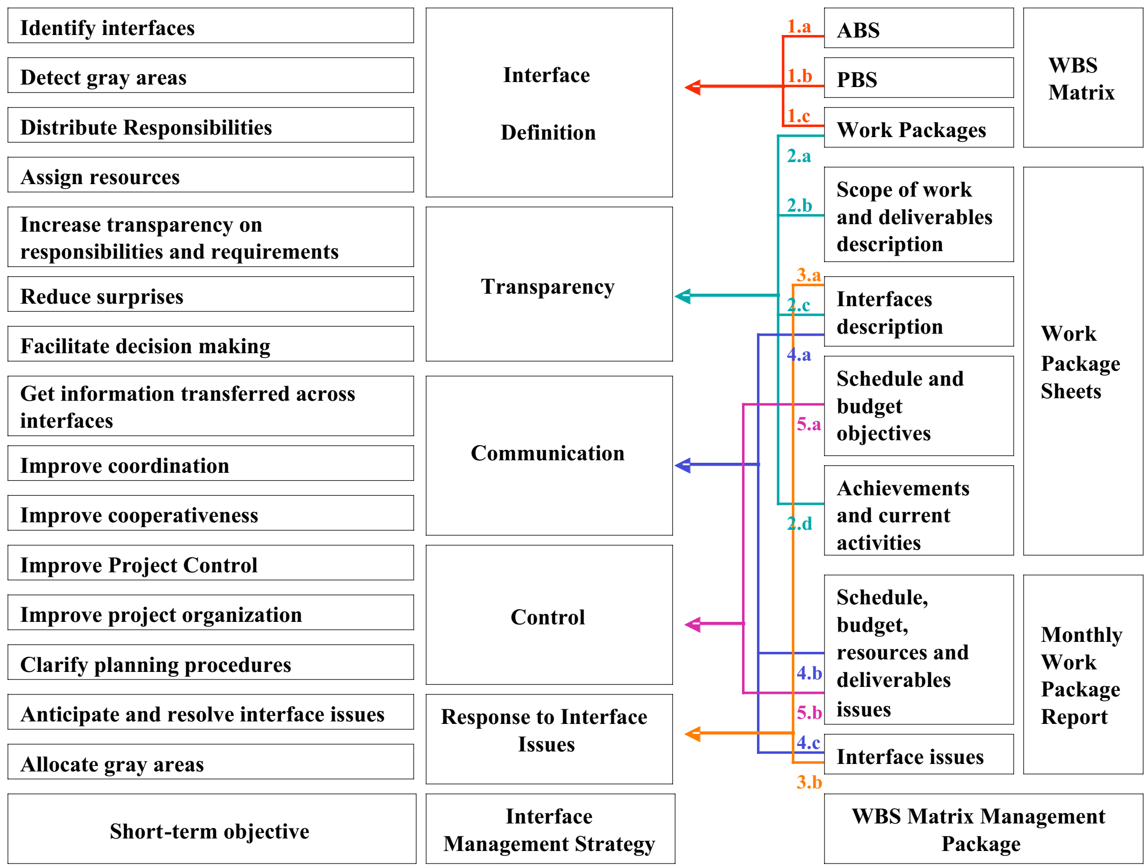

Figure 4.15: Different possible uses of a WBS matrix management package for interface management

This chapter will summarize the findings of the case study and the facts proving that, as illustrated in Figure 4.15, the WBS matrix management package can be used in a variety of ways to improve or help the process of interface management. Figure 4.1515 is constructed in the following manner. The three main columns are the same as in Figure 3.3, but the two halves of the figure are now linked by a more complete set of arrows, showing how each of the elements of a WBS matrix management package can be used for a certain purpose related to interface management. The corresponding activity will be described in the following paragraphs, based on the experience acquired in the case study.

As highlighted in section 3.4, two phases can actually be distinguished in the use of a WBS matrix management package. The definition phase corresponds to the definition of the WBS matrix in itself and of the corresponding work packages, which gives opportunities to define interfaces and bring visibility to the whole project organization. The implementation phase is the use of the entire WBS management package, once it is finalized, as a management tool. The uses of the WBS matrix management package during these two phases will be described in the next sections.

4.4.1 Definition Phase

4.4.1.1 Determining interfaces and allocating responsibilities

The making of a WBS matrix provides an opportunity to clearly identify interfaces both on product and activity points of view.

On the product point of view, subdividing the overall system into smaller sub-systems and sub-components is usually naturally done for the biggest and most obvious components. However, what usually remains unclear is the boundaries of such systems and their interfaces with others. Formalizing the product breakdown is an opportunity to point to the mere existence of interfaces, and further to think about the organization of work across them. This corresponds to link #1.b in Figure 4.15.

On the activity point of view, the interest of a WBS definition is similar. There always are teams responsible for the main phases of a project. However, there might be no precise definition of how these people will interact and coordinate with each other. It is formally recognized by the lean construction theory, for instance, that designers and contractors do not sufficiently exchange information and knowledge, resulting in reworks and delays in construction. The WBS, by defining the areas of responsibility of all parties, makes the first step towards the determination of necessary interactions between them. This corresponds to link #1.a in Figure 4.15.

Thus, on both activity and product points of view, the WBS helps define interfaces between parties that have to collaborate. Furthermore, by formalizing the precise scope and functioning of each work package both on the activity and product points of view, it strives to identify how work package teams will interact with each other in terms of general communication, information and document exchange, collaboration on common tasks, etc. As argued by Bernardes and Formoso (2002), "a task whose specification has been poorly detailed may result in activities that are inadequate to the client's requirements, causing rework and further interference in the subsequent tasks". More than the simple drawing of boundaries between parties, the WBS achieves the definition of the whole process of interface management at these boundaries and contributes to reducing the probability of interface issues. This corresponds to link #1.c in Figure 4.15. Finally, as Reilly (1993) noted in relation to traditional WBSs, "with a preliminary WBS completed, we have made constructive strides, based on a knowledge of the user needs statement, toward understanding what the complete system consists of, what its boundaries are, and how its elements will basically interact". Using the WBS matrix management package has an even greater impact, with product and activities clearly separated and their interfaces more specifically identified.

It is important to note that this is true at all levels of the decomposition. The simplicity of the matrix allows working at any level simply by extracting the necessary data. For instance, if the objective is to study external interfaces at the project level, the whole matrix is considered. If, on the other hand, the objective is to work on the interfaces of a sub-system or activity, the corresponding rows of the PBS or columns of the ABS respectively are extracted to form a sub-matrix that can be regarded as a project in itself. If, finally, the objective is to analyze some of the internal interfaces of the project, the corresponding work packages can be extracted and analyzed.

4.4.1.2 Identifying gray areas

Allocating responsibilities is the first step for a second important use of the WBS, the identification of gray areas at interfaces.

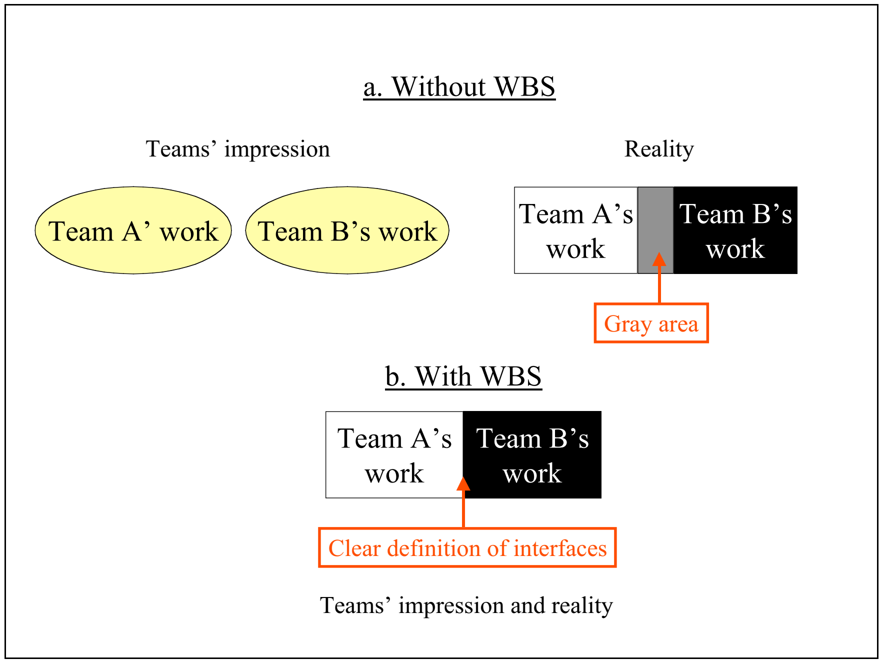

Figure 4.16: Interface definition with and without WBS; from assuming to managing.

Figure 4.16 summarizes this aspect of WBS interface management. As shown in Figure 4.16.a, when the WBS is not used, teams do not readily think about interfaces. Rechtin (1991) mentions this about external interfaces, saying that, when subsystems are contracted out, subcontractors usually have less knowledge about and less control over the periphery of their assigned subsystems than over their core. The process is certainly similar when team members are allocated activities. They concentrate on the bulk of their work and no issue is identified (upper-left side of the picture). Actually, what happens is that teams' work allocation does not perfectly cover all the work to be performed, thus forming a gray area at the interface (upper-right side of the picture): there are tasks or activities that are supposed to be covered by the overall scope of the project, but are under no clear responsibility within the project team. This situation is not sustainable and, if discovered too late, will be solved in relatively poor conditions. In particular, delays and cost overruns may occur (PMI, 2001, p.7; Devaux, 1999). On the contrary, when the WBS is used, gray areas are identified and solved before they become critical (Figure 4.16.b). As discussed above, by formalizing each team's and team's member work, the WBS assists in defining organizational work interfaces. It also serves as the basis for discussion among teams and team members for the identification and resolution of gray areas. Work is clearly allocated to both of the interfaced teams in adequate proportions and gray areas disappear. More importantly, teams' attention is drawn to the very fact that interfaces have to be managed. There is no difference between what they think and the reality, as in the previous case. Work definition at interfaces is formalized, leaving no chance for activities to be forgotten or inadequately planned.

The WBS, in addition to clearly identifying interfaces, thus intervenes to serve as a tool to foster discussion among teams and remove potential gray areas.

4.4.2 Management phase

4.4.2.1 Visibility on responsibilities

Visibility is of paramount importance in construction projects. Leiringer (2000) looked at how a housing project in Sweden could have been improved, and identified several critical phases where transparency on work definition was not sufficient, although the client, suppliers and contractors had agreed to share information openly.

The first one was at project launch, when clients' requirements have to be interpreted in a structured and methodical manner in terms of cost, time, quality and definition of objectives. It was found that some of the performance failures could be traced back to an insufficient recognition and sharing of project needs and priorities by all members of the project. Leiringer highlighted that "some actors had not recognized the full extent of the work that lay ahead of them." This led to decreases in the other teams' performance. Thus, he argued that "throwing light on the actions required of each team member enables the project team to concentrate upon doing the job to the best of its ability", and "awareness of what each team member does is of paramount importance if communications and actions are to be effective".

The second instance of the project when transparency was important was during construction, when modifications have to be made to the schedule or the design. According to Leiringer, these "can only be considered properly if there exists an understanding of the underlying processes and the flows of information and actions needed".

As a consequence, Leiringer recommends the use of a project plan, and more precisely of a process model, to allow all parties to know "what to expect and what to do" and "identify the connections between the information, resources and components that are needed". He proposed a model based on the IDEF0 information processing standard for function modeling, which results in more than 80 A4 pages of hierarchical diagrams.

The case study done in this thesis showed that the WBS can achieve the same objective of continually increasing, during the whole project, visibility on work requirements, objective definition, and flows of actions and information, by extensively defining each work package to be performed under the project. As explained before, the WBS presented in this thesis consists of a WBS matrix and of Work Package Sheets defining each of the work packages. These WPSs, through a simple clarification of the scope of work involved, first assign clear objectives to each of the team members (link 2.a in Figure 4.15). Secondly, by displaying, in the interface category, what the input required are (link 2.c in Figure 4.15), and in the deliverable category, what the outputs to be produced are (link 2.b in Figure 4.15), the WPSs clearly show to the whole project team the sequence of events and the flows of actions and interactions that make the project progress. This allows to reduce surprises related to activities' prerequisites. The precedence relationships between teams, sometimes hidden in a scheduling bar chart as internal data, are indeed clearly revealed in accessible WPSs, and allow them to request missing items from other parties in advance. This supports the view of Alarcon and Mardones (1998), who proposed that task lists be used by designers to specify all information needed from external agents or other designers, in order to improve the coordination process between actors.

Lastly, the monthly work package report gives an opportunity to describe, on a regular basis, which activities are or have been carried out on the work package and what issues the team is facing at the moment. This allows all project members to be aware of the progress of other teams, and of the issues they have been encountering, thus increasing transparency on activities and the way they should be managed (links 2.d, 2.e and 2.f in Figure 4.15).

4.4.2.2 Information management and communication

The WBS can be used as a tool for information and constraints management. As defined by Chua et al. (2001), "a constraint is anything that limits a system from achieving higher performance versus its goal." The theory of constraints, developed by Goldratt in

1990 (Goldratt, 1990), argues that removing constraints from bottleneck(s) is the most effective means of improving the overall system performance. The Critical Path Method usually used in existing project planning tools handles constraints related to the process, but not to resource supply and information acquisition, which results in workflow uncertainties. Other methods have recently been devised to address this issue and model resource constraints (materials, manpower, equipment, space, etc.) and information constraints (drawings, design approvals, etc.). Chua et al. (2001) thus developed an Integrated Production Scheduler (IPS) to handle resource and information constraints, in addition to process constraints, thus improving the reliability of look-ahead plans and optimizing resource utilization.

The WBS can participate in this process of further defining resource and information constraints as follows. As described above, each work package is described by a complete work package sheet, which the work package manager is supposed to use as a daily management and control tool. This document includes a list of the inputs needed by the team to perform the work described. These inputs can be any kind of documents, such as drawings, procedures, company-level or project-level implementation plans, technical data, local safety standards, specifications, schedules, operation manuals, etc. By defining in advance information prerequisites needed by a team to perform its work, the WBS attracts its manager's attention to the necessity of getting it early enough in the process, so as not to be blocked by missing information. Bernardes and Formoso (2002) indeed argue that unfinished precedent work packages or unfinished design drawings are examples of possible constraint sources that should be identified early to be removed. Simply having the team acknowledge its needs and communicate on them in advance (link 3.a on Figure 4.15) is a way to reduce the frequency of constraints blocking the process at bottlenecks.

The WBS management package can also participate in communication improvement in other ways. By making all work package managers spell out, in the work package report, all the issues they are facing, the WBS gives them an opportunity to discuss these issues with upper management or with other managers. This will improve cooperation for the resolution of current issues, and foster cooperativeness for possible interface issues arising later between the parties (link 3.b and 3.c of Figure 4.15).

4.4.2.3 Facilitating project control

As explained by Stuckenbruck (1983), project control is the necessary basis for sound interface management. Time control is a necessary tool of monitoring time interfaces such as important project milestones and transitions from a phase to another. Cost control is a way of making sure that organizational interfaces, and in particular budget balance across interfaces, are adequately monitored. Finally, interface control, in itself, can be added to these features to complete the monitoring of all interfaces.

The WBS is, as shown in the case study, a unique tool of integration for cost and time control, thus enabling a complete interface control. The basis for control is the work package sheet, where all the data on schedule and budget for each work package are gathered, thus enabling, on a single look, to have a complete overview of the work to be performed (link 4.a in Figure 4.15). The WBS becomes the basis for an integrated project control, with a single sheet for qualitative reporting (the WP report) on all issues encountered at the work package level and two additional sheets for more quantitative budget and schedule control: schedule and budget sheets (link 4.b in Figure 4.15). Knowing the status of their project at the level of all work packages, management has a general vision on the evolution of time, organizational and technical interfaces. The precise recording, in the WP reports, of problems interfering in the execution of activities is also, as argued by Bernardes and Formoso (2002), central to the application of lean construction principles. It indeed facilitates the identification of the cause for not completing work packages and the effects of the decisions taken to correct deviations from the plans, which are key elements of the Last Planner Method of Production Control devised to implement the lean construction theory.

4.4.2.4 Facilitating anticipation and resolution of interface issues

The WBS allows management to focus on the most delicate interfaces.

First, when the reporting structure follows the WBS, integrated reports can be produced on all the elements of a work package, as described in the corresponding Work Package Sheet. A work package report will thus concentrate cost, schedule and deliverable data on the same document. As interfaces are part of the WPS description, they too will be part of the regular WP report to be produced. Thus, interfaces become part of the daily monitoring activities of managers at all levels. Knowing that interfaces are part of their work package description and that they will report on them regularly, managers focus their attention on interfaces more naturally (link 5.a and 5.b in Figure 4.15). It can be expected that this will increase anticipation of interface issues and solve the problem of managers delaying the consideration of work interfaces until it is too late.

Secondly, as there is regular reporting on interface issues, the most delicate interfaces can be focused on by higher-level management, if necessary. When looking at all the WP report he/she receives, the project manager will quickly identify those with interface issues. Thus, while knowing that all interfaces can potentially become an issue, he/she will be able to concentrate his/her time and resources to resolve the most delicate or urgent ones.

Thus, by adapting project control to the WBS, it is possible to include interface management as a daily task for managers at all levels.

4.4.3 The WBS: a tool for strategic decisions

The case study clearly demonstrates that the WBS was useful at the system and subsystem levels to overview strategic interfaces and facilitate high-level planning. It can be asked how the WBS could be used at a lower level of decision and action for interface management. Two remarks can be made in this regard.

First, having interfaces more clearly defined and better managed at the highest levels obviously facilitates interface management at lower levels too, by reducing the occurrence of issues that go beyond the power of lower-level operational managers.

Second, although the WBS was used in the case study to gain strategic insight on overall project management, the same methodology could be adapted and used to manage interfaces at a lower level. This would certainly require extracting some parts of the WBS matrix, as it would make no sense to visualize the smallest details of all activities and all products at the same time. The WBS, detailed at an intermediate level, can then be used as a framework for the implementation of smaller-scale management tools such as the Last Planner (see section 0).

4.5 Comparison of WBS with other interface management and lean construction control tools

It has been shown how the WBS can contribute in many ways to the improvement of interface management processes. The following section will elaborate on the differences and possible complementarities of WBS and other existing interface management tools: IDEF0 and DSM.

4.5.1 IDEF0

The main advantages of the WBS over the IDEF0 interface modeling method are its simplicity and easiness of visualization. The WBS matrix is a simple colored matrix crossing activities and products. As such, it appears operational, close to the manager, and is easy to understand. Using simple Excel sheets that most staff at all levels are used to utilizing regularly, it clearly shows to each team member his or her own responsibilities, and allows him/her to view those of others, thus increasing visibility on project requirements and team members' share of work.

On the other hand, IDEF0, by showing boxes linked with arrows (see Figure 2.2), often gets difficult to read when the project complexity increases. Indeed, hierarchical charts using the IDEF0 model involve an important number of boxes linked together by an intricate network of arrows representing the input, output, controls and mechanisms of activities. Although very accurate on the theoretical point of view, these charts require appropriate training to enable understanding by all project team members (Malstrom et al., 1999).

However, the WBS and IDEF0 can be used simultaneously as they are complementary in their modeling of information flows through project activities. While the WBS mentions inputs and outputs of all work packages in WPSs to facilitate their management, the more formal and complete information provided by IDEF0 can be used in computer support systems to improve the overall efficiency of management (Malstrom et al., 1999). Of course, the data provided in the WBS can also be used to partly complete IDEF0 models and vice versa. Thus, although they are not used for the same purpose, both models are useful and complement each other.

4.5.2 Design Structure Matrix

The Work Breakdown Structure has similar benefits as the Design Structure Matrix in terms of communication improvement. Browning (2001) argues that a DSM, by trying to reconcile the information gathered about people's inputs and outputs, provides an opportunity to discuss and reach agreement on interfaces and deliverables. This is actually also applicable to the WBS development process. When work package sheets, and in particular their inputs and outputs, have to be defined, the responsible persons have to agree on a share of work so that work is well defined at interfaces.

However, the Work Breakdown Structure has other advantages over the DSM. First, it gathers information about all types of interfaces in one single document. Unlike the DSM, which requires four different matrices to model interfaces between components, team members, activities and parameters (see section 2.1.3.2), the WBS concentrates all this data on the same document, the work package sheet. This makes it more practical to use at the operational level. Furthermore, a great advantage of managing interfaces with the WBS is that interface management is integrated with project control, and does not imply an additional document to update or consult regularly. Interface management just becomes part of daily project control and is not considered as an additional project aspect to manage, which can facilitate its acceptance by management teams.

The WBS is thus more practical to use as a management tool. However, DSM, by concentrating interface data, is more practical for the reordering of activities and the other functional project improvements that can be derived from it (see Browning, 2001). As a result, the WBS and the DSM also appear complementary, the former being used in daily management and the latter for more strategic changes in project functioning.

4.5.3 Last Planner

The Lean Construction theory has resulted in new control tools being devised to improve project performance. The Last Planner System (LPS), designed by Ballard and Howell[11], thus aims at controlling productive unit and work flows, as well as achieving quality assignments. LPS lookahead programming and weekly work plans were successfully used as a project planning and control tool, for instance in Ecuador (Fiallo and Revelo, 2002).

The corresponding procedure is as follows (Ballard, 2000):

[11] See the Lean Construction Institute Website: http://www.leanconstruction.org/main.htm

- make a list of the assignments that can be completed within the next few weeks, ask the foremen to choose from it what can be done within the first week and examine the remaining weeks to identify and remove the assignments that cannot be done on schedule, taking into account the availability of materials and components;
- divide the lookahead program into assignments;
- compare the number of man-hours needed in the lookahead program and the project's requirements;
- generate a list of activities that must be completed prior to the execution of each assignment.

The WBS and LPS are certainly pursuing the same objective of improving the smooth transfer of the project through activities. The WBS does it by providing practical tools to monitor and report on the Work Packages progress, and the LPS by organizing the work in advance, taking into account the availability of materials and prerequisites. The tools are thus complementary and could be used simultaneously by including a lookahead activity in all work packages. The WP report, in addition to enabling reporting of progress, could be a tool to practically plan activities coming ahead. In return, as the Work Package Sheets already include a list of prerequisites for each activity, the functioning of lookahead would be simplified by the use of the WBS management package. Furthermore, by formalizing the detection of issues and actions to be taken to solve them, the use of work package reports could facilitate the project learning that LPS also pursues.

It must be specified here that, although the WBS matrix presented in the case study stays at a fairly low level of detail to accommodate the need for a global vision for a complex project, it could be detailed further and allow planning and control to be done at a higher level of detail to be more easily used in conjunction with look-ahead planning tools such as the Last Planner. The WBS indeed has this property of being adaptable to the needs of its users in terms of preciseness and visibility enhancement. However, to avoid having a very detailed matrix with a lot of white cells as can be expected if all activities are broken down to the detail level of Last Planner, it could be more advisable to keep the WBS at an intermediate level of detail so that it still provides the strategic view required for the management of large projects, and to use the Last Planner to improve performance on the daily management of work packages at the operational level.

CHAPTER 5: Proposal to use a software of WBS creation to further improve interface management

Based on findings of the preceding sections, this chapter proposes to use a software of WBS creation to further improve interface management. Existing software and an overview of the problems that should be solved in the new software will be presented. The implementation of this component can make the subject of further research.

5.1 Need for more participation in the process of WBS implementation

The main problem encountered during the implementation of the WBS in the case studied earlier clearly was one of communication. Communication could have been improved both at the time of preparing the WBS and at the time of using it for project management and regular control. This may be attributed to several phenomena.

The first one is certainly that staff was not sufficiently aware of the potential benefits of the use of the WBS. An activity-launching meeting, with explanations on the advantages expected from the use of the WBS and on the main steps of its setting up, would have been beneficiary in this respect.

The second one is the complexity of the communication process, with documents sent by email to different persons and modifications made centrally on a common document regularly updated. This process adds to the often upsetting volume of email daily received by managers. Furthermore, the WBS is contained in one Excel file, but all the work package sheets are not of interest to all the people involved in the project. Thus, a great deal of information is useless to them, and makes the process of updating or correcting the WBS data heavier and more time-consuming.

Authors have repeatedly mentioned that “IT is regarded as one of the most prevalent facilitators of process change” (Sripraset and Dawood, 2002). In particular, internet-based strategies are considered an efficient approach to accomplish innovative communication and information management. Hoedemaker et al. (1999) specifically recommended the use of information technology to improve interface management and decrease communication burden. It is proposed here to use internet-based software to facilitate communication on the WBS, and thus accelerate and smoothen its implementation process. As Warner (1997) puts it, “with the correct project-management software, a team can quickly integrate project data, generate performance reports, conduct risk analyses and simulate multiple scenarios to estimate the aspects of any proposed changes.” Stoehr (2001) also recommends to “use project management software or other planning tools to support the semi-automatic generation and presentation of a WBS”. After a brief description of available software, the characteristics of the WBS implementation software that would be required will be developed and described here, so that future research has clear recommendations and guidance to develop it and can benefit from earlier experience in the field.

5.2 Existing software

Existing software related to the creation of a WBS are numerous. Software such as WBS Chart Pro™, Project Pix, B-liner[12] enable their users to easily create and modify a tree-like WBS displaying the budget and duration of work packages (see Figure 5.1). However, existing software description never mention features such as separate Budget Sheets and Schedule Sheets, although a work package can hardly be defined by an overall budget and two dates, at least for the most complex projects. Similarly, existing software are silent about the management and communication system surrounding the WBS software, although it is essential, as illustrated in this thesis, that a WBS not be managed and updated by a single person but by the whole project team. These gaps in available software need to be filled if the strategy proposed in this thesis is to be used successfully.

[12] For more information, please see WBS Chart Pro website: http://www.criticaltools.com/wbsmain.htm ProjectPix website: http://www.visimation.com/projectpix.asp, and B-liner website: http://www.varatek.com/projectmanagement.html

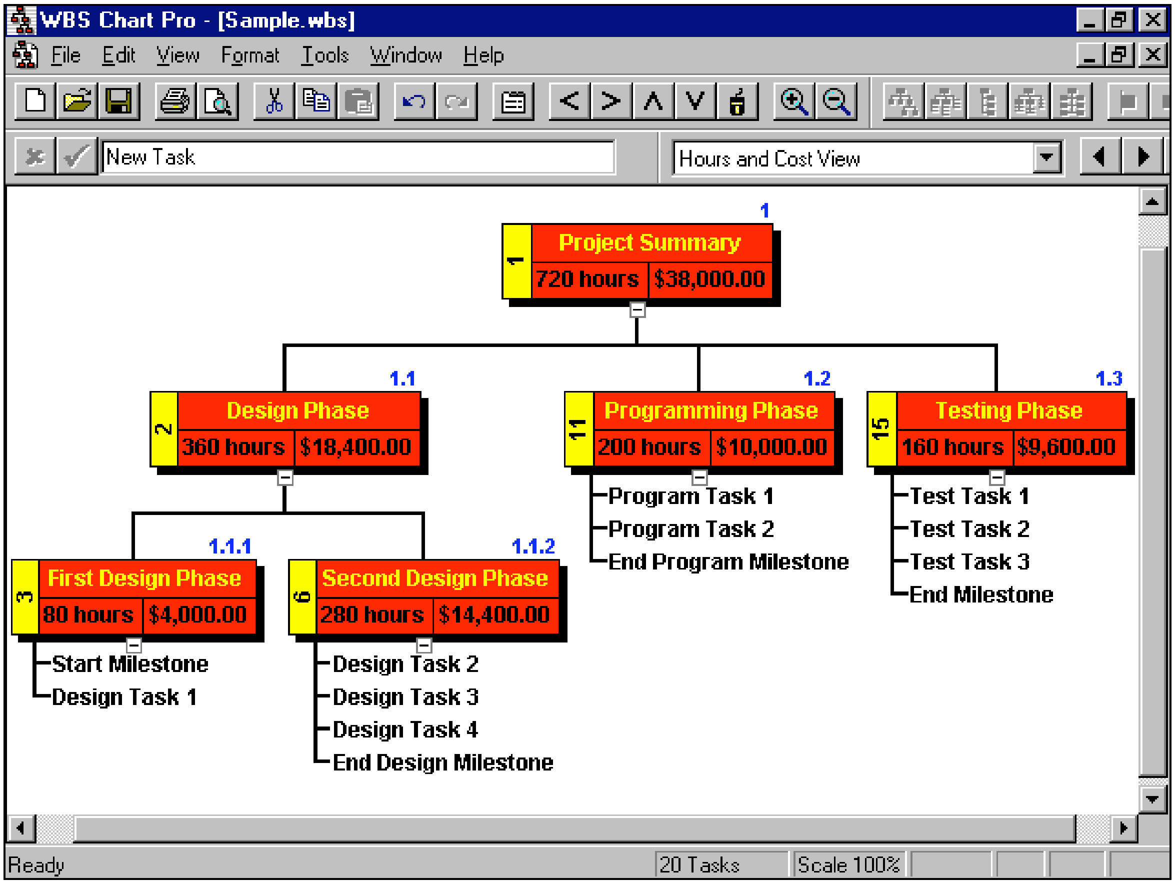

Figure 5.1: A sample WBS using the WBS Chart Pro Software

5.3 Characteristics of the software to be developed

To solve the problems encountered when implementing the WBS using Excel sheets, the software to be created should simplify the creation, management and communication over the WBS components. The following section mentions the problem encountered during the case study when using the WBS. While not formally describing the information system that would be needed, it provides an overview of the problems that should be solved to ease WBS management.

5.3.1 Easiness of WBS creation

The software should facilitate all steps of the WBS management package creation.

- **Creation of WBS Matrix**

The ABS, PBS, and WBS Matrix creation, although not the most difficult task in the Excel-based system, can certainly be facilitated thanks to visual application such as the ones commercially available (see preceding paragraph).

- **Creation of Work Package Sheets and Budget Sheets**

There are simple features of the current WBS matrix that become very tedious to manage using excel sheets. The software to be created should have the following features.

- A new work package should be created simply by selecting, with a click, the corresponding matrix elements. The code of these elements will be automatically displayed in the WBS matrix and in the corresponding work package sheet. If one work package has to be split into two, the original data should be duplicated so that the data does not have to be re-entered. If two work packages are merged into one, the data of both should appear in the final work package sheet, so as to facilitate further modifications.
- When the code for an activity or a product changes in the WBS matrix, it should also change in all work package sheets.

- When a work package is created, moved or deleted, all work packages should be renumbered automatically and the corresponding changes made in all documents (work package sheets, budget sheets, list of work packages, etc.).

Another difficult feature of creating work package sheets using Excel sheets, is that, even if they are part of the same file, they cannot be made on a similar format as they all contain different amounts of information. For instance, in the case studied, the Testing and Commissioning work packages were described in a lot of details, for the activity concerned is complex, made up of a lot of different sub-activities, and as such requires a precise description. On the contrary, a simpler activity such as the factory testing of a specific component, also making up a single work package, did not need such a detailed description. Thus, work package sheets necessarily all have different sizes. When there is a need to change features of the sheets format, they must be implemented separately on each sheet. Similarly, budget sheets were made on different Excel files, thus making generic changes a long and tedious task.

The software should get rid of this feature and allow a format to be defined and redefined at anytime subsequently without having to make identical changes on each and every work package sheet. Similarly, the budget sheet format should be easily modifiable. More precisely, in the work package sheet, it should be made easy to:

- add fields in all sheets;
- change the location, color or formatting of fields in the sheet.

Similarly, in the budget sheet it should be made easy to:

- add a column;

- modify formulas or data displayed in a cell of all sheets by making the modification only once;
- modify formulas in cells common to all sheets.

5.3.2 Easiness of WBS management

The WBS is managed and the project progress monitored through the use of the WP report, schedule sheet and budget sheet. The three documents, in their actual state, should be available on their manager's personal WBS account, besides the Work Package Sheets. Their content should be modifiable, but not their structure. The structure should be modifiable only by pre-defined people such as the project manager. All earlier versions should also be available to the manager, and to other pre-defined people if necessary.

For the purpose of aggregating cost data, all calculations should be automated. While this is difficult to do when different people have to manage several Excel sheets at the same time, it remains an important feature of WBS management.

When a Work Package manager decides to make his/her WP reports, budget sheets or schedule sheets available to other people, it should be possible to do so simply allowing access to them or using emails.

5.3.3 Communication process

The software should be internet-based so as to allow people in different offices or countries to work on a common WBS.

It should be accessible by all project members, but modifiable by only pre-defined people and with the approval of pre-defined people. The WBS is a working document and the information it contains must be as accurate as possible at all times. As Warner (1997) argues, there should be clear policies and required signatures for changes, additions, and deletions to the WBS document, so that the WBS is under control and can be maintained as a valid communication tool. This means that when somebody wants to make a change in the WBS, the modification may have to be approved by the person's immediate superior before it is displayed on the document available to all project members on the Internet.

Thus, for everybody involved in WBS management, there should be a personal account where all pending-approval documents are stored, and the history of all changes proposed, approved, rejected or made by the person is available. As soon as a change is proposed, an email is automatically sent to the person whose approval is required. Using this WBS-updating and communication process, there is no need to have a WBS team once the WBS is set up. The changes are made and approved by the right people directly, minimizing the need for coordination. In addition, certain cells of work packages sheets should be modifiable only by qualified people. For example, it should be possible to limit the modification of schedule cells to the project controller.

There are available software designed to manage data across geographical and organizational barriers based on tree-like WBS and using the Internet, such as TuoviWDM[13]. The software to be created can either use or be inspired from them.

[13] For more information, see website: http://tuovi.cern.ch/tuovi/overview.pdf

CHAPTER 6: Conclusions

To conclude this thesis, the present chapter offers a summary of the research carried out and its findings, and describes possible further research in relation with the topics addressed here.

6.1 Summary

This thesis has first presented the concepts of interface management and of Work Breakdown Structure as they are usually used. Then the concept of WBS matrix was proposed to facilitate representation and interface management of complex projects. The case study of a company using the WBS for the management of a mass rapid transit project showed how the WBS was able to improve all the features of interface management. It is therefore argued that the WBS matrix, completed with the relevant work package sheets and reporting tools, can assist in better managing interfaces through:

- the identification of interfaces,
- the improvement of visibility over responsibilities and project requirements,
- the facilitation of communication across interfaces,
- the integration of project control, and
- the anticipation and management of interfaces issues.

More specifically, when the PBS, ABS and work packages are defined and refined, the project team identifies and describes interfaces, finely allocates responsibilities and detects potential gray areas. When used for general project and interface management, the WBS matrix management package improves visibility on project requirements and communication on issues encountered. It also facilitates project and interface control by providing the tools for regular monitoring and reporting. Finally, the WP report and WPSs provide opportunities to make interfaces a natural component of project management. Interface issues are more easily anticipated and, when they do appear, can be detected and solved earlier.

Thus, while the WBS matrix and Work Package Sheets are found to provide assistance to the project team in the field of interface definition, the reporting tools help them prevent, monitor and solve interface issues all along the project implementation. This contributes to a project environment where the products flow from one activity to another without constraints, a situation the lean construction theory has argued produces faster and less costly projects.

The WBS developed in the case study stayed at a relatively strategic level, describing activities that can last for several months. It did not intend to go into more detail, nor to manage the corresponding small-scale interfaces that make up the daily issues to deal with in such a project as in many others. It provided for a first layer of interface management, preventing the greatest mistakes or omissions from having too great consequences at all levels of management. However, this process could certainly be successfully completed by tools of lower-level management such as the IPS (see section 4.4.2.2) or the Last Planner.

6.2 Research limitations and further research

6.2.1 Using the WBS as an external interface management tool

Many authors argue that the WBS can be an efficient tool not only to manage a project and all its interfaces internally, but also to communicate better with the project's external actors, such as the client, the suppliers, the subcontractors, etc. For instance, talking about the WBS development step, Verzuh (1999) argued that "the deliverables list initially prepared by a client must be expanded and detailed by a contractor in order to achieve a common understanding with a client on what has to be delivered." Thus, the WBS can become a tool of better communication with the client.

This research is based on a case study where many internal interfaces had to be managed. It was therefore the most logical approach to insist on improving internal interface management first. Some progress was done in identifying external interface issues, when WP report mentioned issues related to suppliers and the client, but most of the work was focused on internal interfaces.

Further research could therefore be done to study how the WBS matrix management package could be used to better manage external interfaces. In particular, further research could concentrate on the use of a common WBS management package by the client and the contractor for them to agree on the description of activities, the flow of documents and information, the management of external interfaces, etc. A larger WBS, or "general WBS", could include the client responsibilities as well as the contractor's to make sure external interfaces are properly managed and avoid misunderstandings between them. This research could start with the study of common or classical client/contractor misunderstandings, so that the "general WBS" can address them adequately.

Further research could also be conducted on the use of a common WBS by all contractors working on the same project, be they sub-contractors of the main one or separate contractors working on different parts of the project. It could be studied how the various project management methods of the different firms influence the setting up and use of a common WBS, how communication can be improved by the use of a common project management and control tool in such an environment, how client satisfaction is improved when contractors can agree with each other on the management of their interfaces, etc.

Communication between the various partners sharing a common WBS would certainly be facilitated by the development of an internet-based WBS matrix management software. This could also be developed in further research.

6.2.2 Link with the product model

The Product Model was developed by Song and Chua (2002 and 2003). It incorporates construction progress information into the product component system, as shown in Figure 6.1, in order to meet the following objectives:

- Make project management more construction-driven to improve information exchange among the project participants specialized in different trades and activities and integrate them into a project team with common goals.

- Integrate the product model with the process model to make construction sequence conflicts and temporary construction relationships more transparent and thus avoid reworks.
- Capture, store and reuse construction sequence knowledge from previously used component state networks.

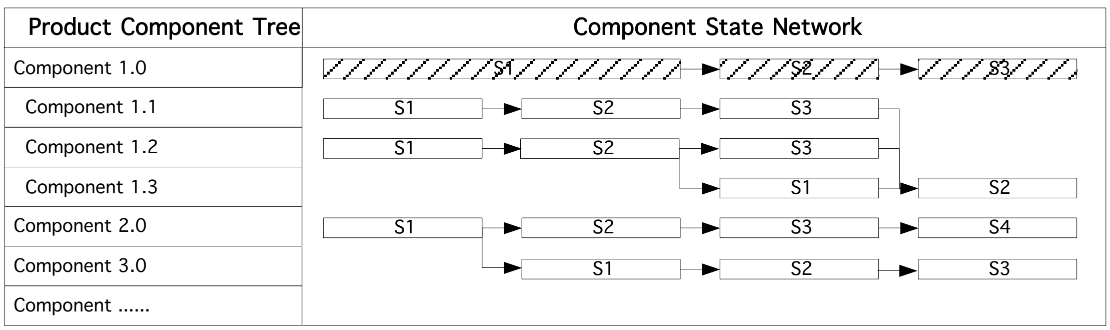

Figure 6.1: Basic structure of the Product Oriented Scheduling Technique model (taken from Song and Chua, 2003).

The Product Model includes two main parts: a product component tree on the left and a component state network on the right (see Figure 6.1). Component states describe the dynamic development progress of a product during construction.

An interesting feature of the Product Model in view of the present thesis is that, if developed to a sufficient level of detail, the WBS matrix could be used as the basis for the component state network of the POST model. It indeed represents project activities and product components simultaneously, as required by the POST model. This makes an additional possible utilization of the WBS matrix. The advantage of such a development of the WBS matrix would be to keep the same basic management tool to integrate all possible project management activities, including construction scheduling. However, the construction step of the WBS matrix would have to be developed to a very detailed level to accommodate the precision needs of the POST model. Further research is therefore needed before integration of the two models can be done.

6.2.3 Boundaries and validity of research findings

As argued by Handfield and Melnyk (1998), any theory should be falsifiable, meaning that it should be “coherent enough to be refuted”, and “specify a relationship among concepts *within a set of boundary assumptions and constraints*.” While it is clear that the WBS was useful in the case studied, it remains to be proven whether variables such as the type of project, its complexity or its geography can affect the efficiency of the use of a WBS management package to improve interface management, and to what extent the package can be adapted to different kinds of situations. As argued by Dunbing et al. (2000), technically complex engineering products offer a great management challenge that involves the management of interactions between the different engineering disciplines. But what about less complex systems? Could they also benefit from the new interface management approach proposed in this thesis? This requires new case studies to be performed in various environment until true empirical generalization can be achieved.

Another process that could be further studied is the one of return on experience. As the project studied in this thesis was only starting, it was not possible to assess the benefits of the WBS in terms of corporate learning, the avoidance of earlier errors, the better management of interfaces, etc. This research could be done later on the same case, or on other projects.

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ANNEX 1: PBS of the Infrastructure Subsystem in the MRT line Project

	Infrastructure
03	**POWER SUPPLY (including Depot)**
031	HV POWER SUPPLY SYSTEM
0311	22 kV Switch Board
0312	22 kV Cables including Supports and Accessories
0313	66/22kV Intake Transformer
032	DC TRACTION POWER SUPPLY SYSTEM (750 V)
0321	DC Switchboard
0322	Load Breaking Switch
0323	Inverter Group
0324	Stray Current Corrosion Control
0325	Transformer Rectifier Group
0326	Touch voltage protection
0327	Traction Safety Shutdown System
0328	Stray current and earthing cables
0329	DC Cables and accessories
032A	Bus Duct
036	AUXILIARY STATION POWER SUPPLY
0361	Cable trays
0362	Control cubicle
0363	Service transformer
0364	400 VAC and 110 VDC Distribution Board
0365	Battery Charger
0366	Station Cabling
0367	Pilot and control cable
0368	Safety equipment
037	OTHERS MISCELLANEOUS
06	**DEPOT**
062	MACHINES
0621	Machines
0622	Train Cleaning System
0623	Testing Equipment
0624	Handling and Lifting facilities
07	**TRACKWAY (including Depot)**
071	BASEMENT EARTHWORK AND CONCRETE
0711	Concrete
0712	Walkway
0713	Cable troughs
0714	Drainage (clayware drain, grating, ...)
0715	Embedded pipes
072	SPECIAL ITEMS
0721	CD blast door components
073	TRACKS
0731	Running Rail
0732	Fastener
0733	Turnout
0734	Insulated Rail Joint
0735	Sleepers
0736	Signs and Markers
0737	Buffers
0738	Fixed and Mobile Structure Gauge
076	STRAY CURRENT MESH AND JUMPER BOX
077	CONDUCTOR RAIL
078	WILD
079	OTHERS MISCELLANEOUS
09	**SITE WORKS LOGISTIC FACILITIES**
091	TW HEAVY EQUIPMENT
0911	TW Locomotives
0912	TW Wagons
0913	Track laying Gantries
0914	Concreting equipment (Secatol)
0915	Road/Rail cranes
0916	Flash Butt Welding Machines
092	TW LIGHT EQUIPMENT
0921	Tools
0922	Concreting devices (concrete pipes, trolley, cleaning set...)
0923	Ventilation, Compressor & Generators
0924	Communication
093	TRIP HEAVY EQUIPMENT
0931	TRIP Locomotives
0932	TRIP Wagons
094	STAGING AREA
0941	Basic ground work and fencing
0942	Storage Areas and Roads Preparation
0943	Office and maintenance facilities
0944	Connection to main utilities supply points
0945	TSA equipment
0946	TSA Heavy plant/Maintenance
0947	Safety/Security/Regulations
0948	Shaft Access
0949	Lighting/lightning/earthing
095	OTHERS MISCELLANEOUS

Annex 2: Work Breakdown Structure of the Infrastructure Subsystem in the MRT line

Annex 3: Work Package List of the Infrastructure Subsystem in the MRT line Project

WP title	WP number
Project management Infrastructure	0
Project Management PS	1
Power Simul	2
Project Management TW	3
Project Management Logistics	4
Interface Management PS	5
Interface Management TW	6
Design PS	7
Design DEPOT	8
Design TW	9
Design Logistics	10
Design Staging Area	11
RAMS PS	12
RAMS TW	13
EMC PS	14
EMC TW	15
Method and T&C Procedures PS	16
Method and T&C Procedures TW	17
Method and T&C Procedures TSA	18
Procurement PS	19
Procurement TW	20
Procurement Logistics	21

WP title	WP number
Procurement Staging Area	22
IFAT PS	23
IFAT TW	24
Transport and delivery PS	25
Transport and delivery TW	26
Transport and delivery Logistics	27
Transport and delivery TSA	28
Site Health and Safety PS	29
Site Health and Safety TW	30
Installation PS	31
Installation TW	32
Operation Trains	33
Operation Logistics	34
Installation and operation TSA	35
Commisioning PS	36
Commissioning TW	37
Training and O&M PS	38
Training and O&M TW	39
Warranty PS	40
Warranty TW	41
RMDT PS	42
RMDT TW	43